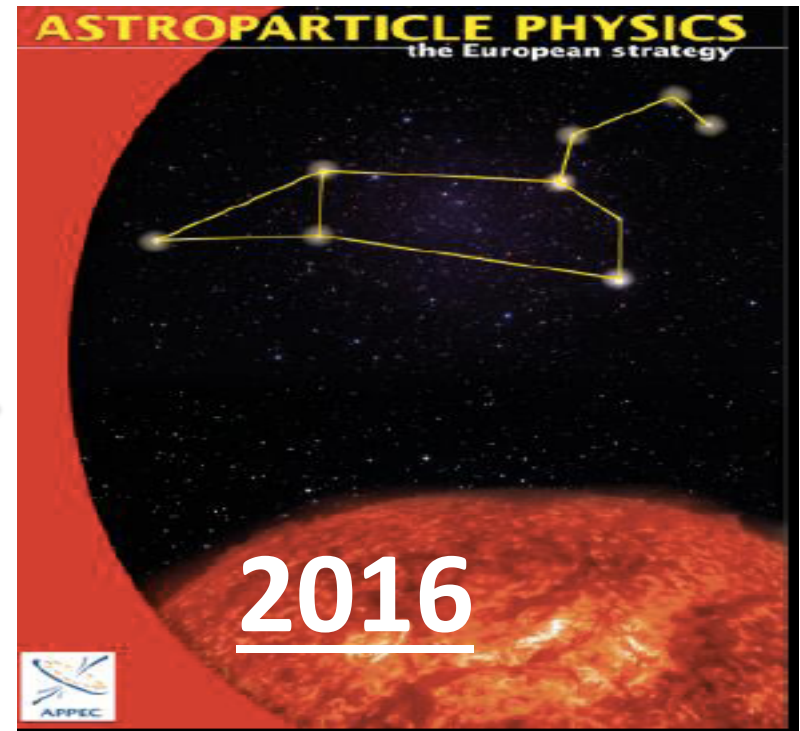
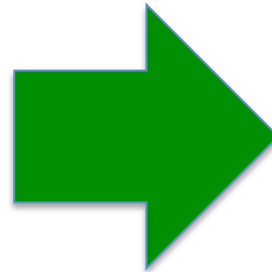
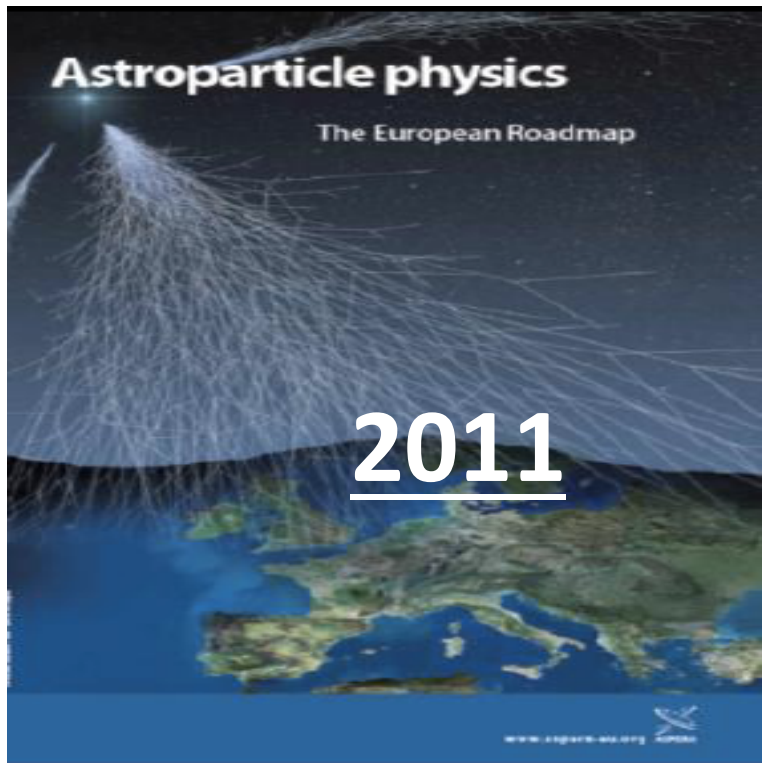


APPEC Town Meeting, Paris, April 6-7, 2016

A. Masiero

chair of the APPEC Scientific Advisory Committee\*



\***SAC**: F. AHARONIAN, G. ANTON, I. ANTONIADIS, L. BAUDIS, P. BINETRUY, J. van den BRAND, A. GIULIANI, F. HALZEN, A. HAUNGS, A. MASIERO, M. MEZZETTO, R. MIQUEL, J. MONROE, M. OSTROWSKI, H. SOBEL, P. SUTTON, P. TINIAKOV, Y. WANG, M. ZITO

- By the end of the 20<sup>th</sup> century ...  
**we have a comprehensive,  
fundamental theory of all  
observed forces of nature which  
has been tested and might be  
valid from the Planck length  
scale [ $10^{-33}$  cm.] to the edge of  
the universe [ $10^{+28}$  cm.]**

**D. Gross 2007**

# 2013 – 2016 : the triumph of the STANDARD MODEL

- PARTICLE STANDARD MODEL**

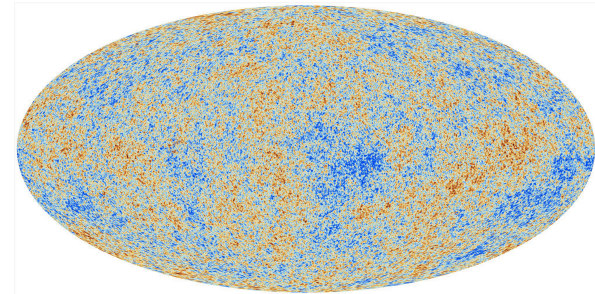
## MODEL

Three Generations of Matter (Fermions) spin  $\frac{1}{2}$

	I	II	III	
mass →	2.4 MeV	1.27 GeV	173.2 GeV	0
charge →	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0
name →	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon
	Left Right	Left Right	Left Right	0
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon
Quarks	Left Right	Left Right	Left Right	0
	$\nu_e$ electron neutrino	$\nu_\mu$ muon neutrino	$\nu_\tau$ tau neutrino	91.2 GeV <b>Z</b> weak force
	0	0	0	126 GeV <b>H</b> Higgs boson
	0.511 MeV	105.7 MeV	1.777 GeV	spin 0
	-1	-1	-1	80.4 GeV <b>W<sup>±</sup></b> weak force
Leptons	Left Right	Left Right	Left Right	spin 1
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	

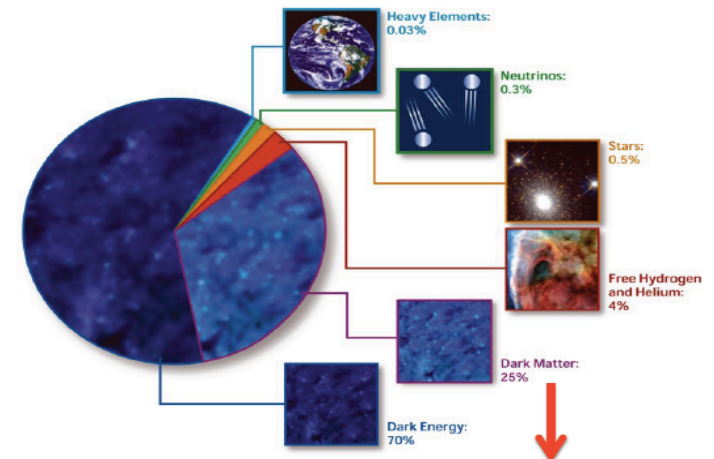
- COSMOLOGY STANDARD MODEL**

## MODEL



$\Lambda$ CDM + "SIMPLE" INFLATION

COMPOSITION OF THE COSMOS

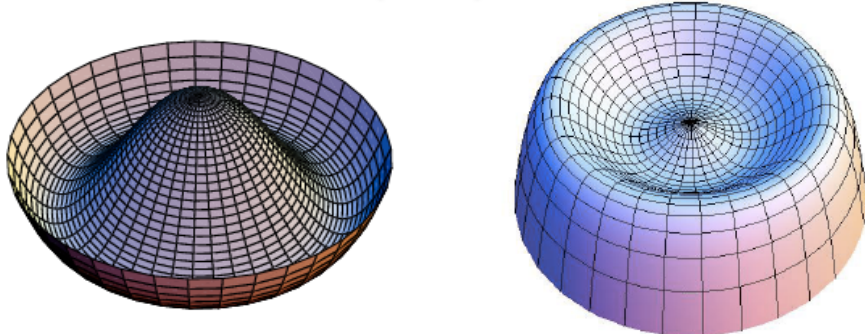


- **PARTICLE STANDARD MODEL**

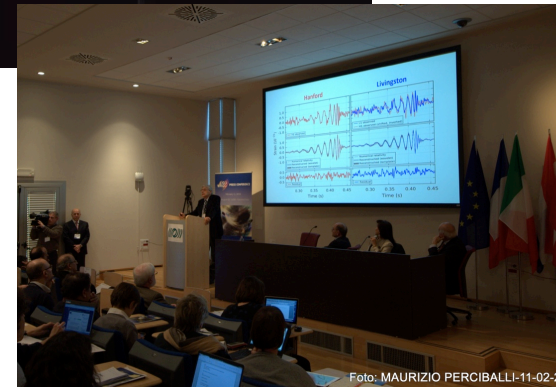
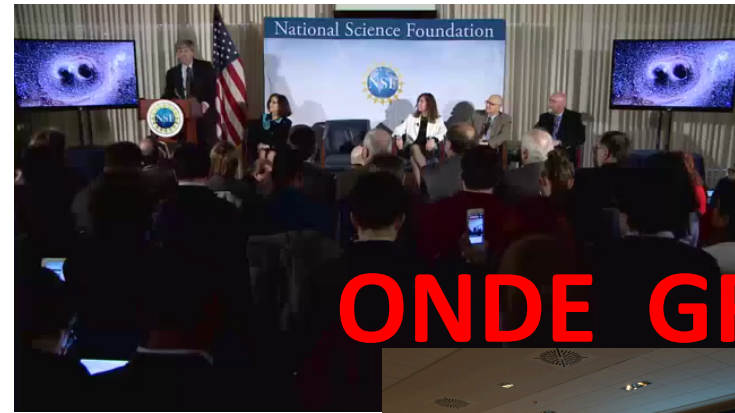
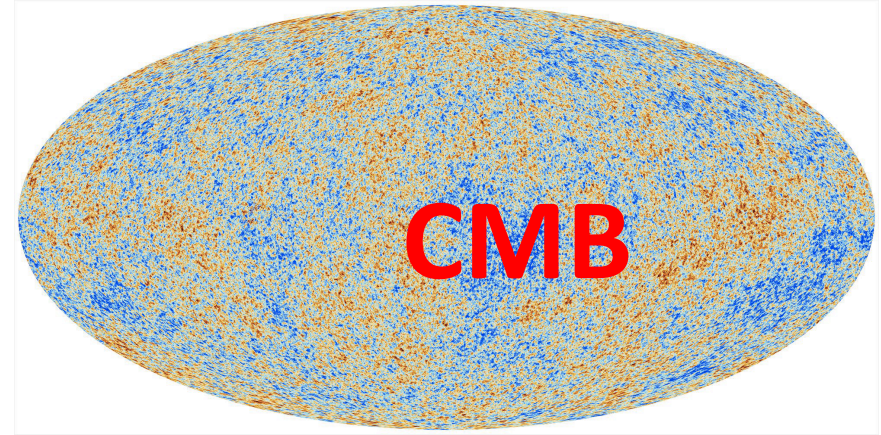


The Higgs boson and the destiny of the Universe

STABILITY ↔ INSTABILITY



- **COSMOLOGY STANDARD MODEL**



Big Bang

Quark-Gluon Plasma

Protoni e neutroni

Protoni e Nuclei leggeri

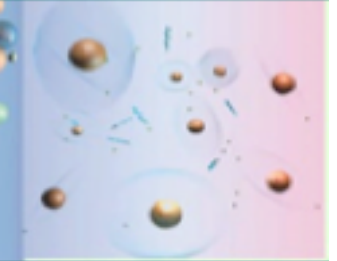
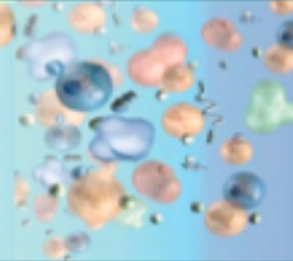
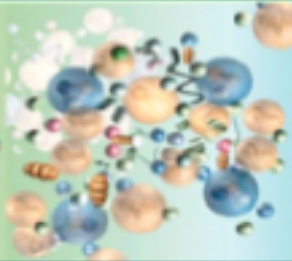
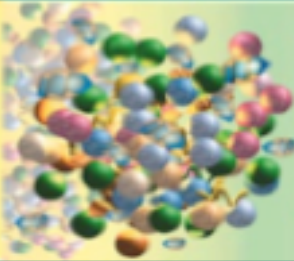
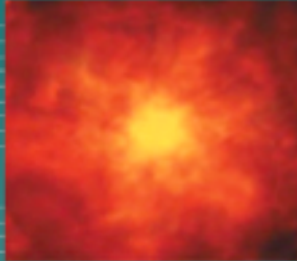
Atomi → Galassie

Gravità

Nucleare forte

Nucleare debole

→ Molecole → DNA



$10^{-43}$  sec  
 $10^{-35}$  m  
 $10^{19}$  GeV

$10^{-32}$  sec  
 $10^{-32}$  m  
 $10^{16}$  GeV

$10^{-10}$  sec  
 $10^{-18}$  m  
 $10^2$  GeV

$10^{-4}$  sec  
 $10^{-16}$  m  
1 GeV

100 sec  
 $10^{-15}$  m  
1 MeV

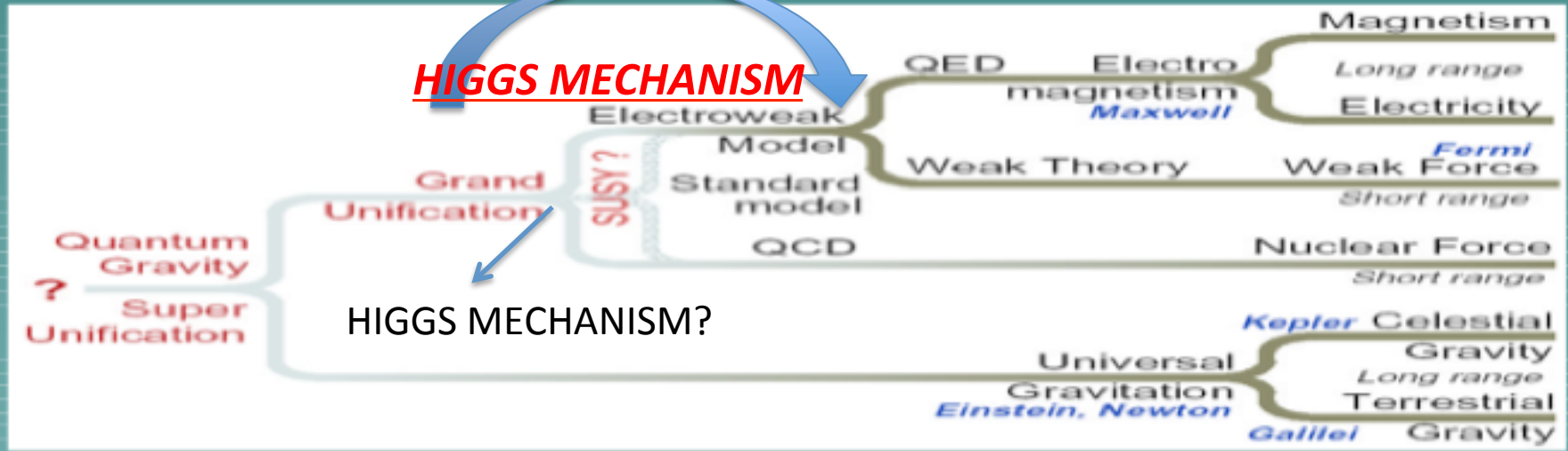
300KY → 15GY  
 $10^{-10}$  m  
10 eV

???

LHC

LEP

As tronomia →



Theories:

STRINGS?      RELATIVISTIC/QUANTUM      CLASSICAL

# Are the SMs really STANDARD?

## G-W-S SM

- All the experimental results of both high-energy particle physics and high-intensity flavor physics are surprisingly (and embarrassingly ) in very good agreement with the predictions of the GSW SM
- Only (possible) exceptions:
  - the anomalous magnetic moment of the muon ( $3.6 \sigma$  discrepancy w.r.t. the SM prediction);
  - diphoton peak at 750 GeV

## $\Lambda$ CDM SM

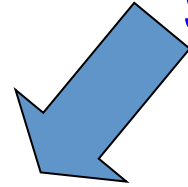
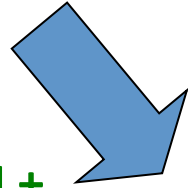
- All the cosmic observations are in agreement with the  $\sim 25\%$  CDM,  $\sim 70\%$  cosmological constant  $\Lambda$ ,  $\sim 5\%$  ordinary matter of the  $\Lambda$ CDM SM
- (Possible) exception: troubles with pure Cold DM from absence proto-galaxies, non-existence of spikes in DM density at the centre of the galaxies
- ...

# MICRO

# MACRO

GWS STANDARD MODEL

HOT BIG BANG  
STANDARD MODEL



UNIVERSE EXPANSION +  
WEAK INTERACTIONS **NUCLEOSYNTHESIS**

NUMBER OF BARYONS and OF  
NEUTRINO SPECIES →

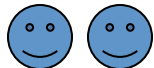
1 sec. after BB

CONFIRMED FROM CMB 350000  
YEARS AFTER BB

BUT ALSO



Independent  
confirmation from  
the study of the **CMB**



-COSMIC MATTER-ANTIMATTER ASYMMETRY

-INFLATION ???

- DARK MATTER + DARK ENERGY

**OBSERVATIONAL EVIDENCE OF NEW PHYSICS**

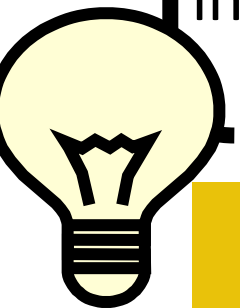
**BEYOND THE STANDARD**

# The Energy Scale from the “Observational” New Physics

neutrino masses  
dark matter  
baryogenesis  
inflation



NO NEED FOR THE  
NP SCALE TO BE  
CLOSE TO THE  
ELW. SCALE



# The Energy Scale from the “Theoretical” New Physics

★ ★ ★ Stabilization of the electroweak symmetry breaking  
at  $M_W$  calls for an **ULTRAVIOLET COMPLETION** of the SM  
**already at the TeV scale** +

★ **CORRECT GRAND UNIFICATION “CALLS” FOR NEW PARTICLES  
AT THE ELW. SCALE**



A) **Multimessenger astronomy,**

B) **neutrino properties,**

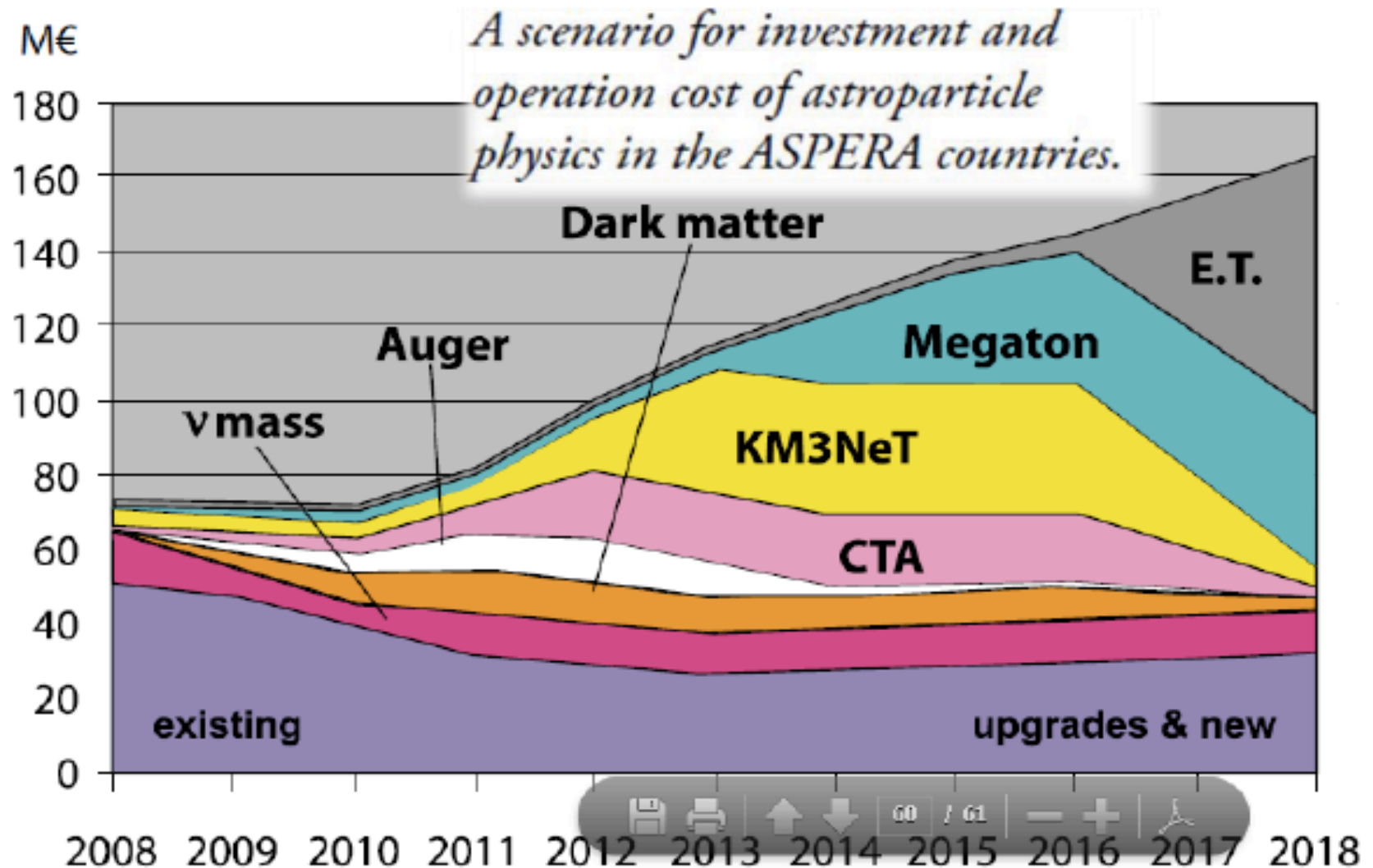
C) **dark side of the Universe and CMB**

- A) **Photon, cosmic ray, neutrino, gravitational** astronomies (some in their maturity, some in their youth, some just baby or even at the embryonic level)
- B) **Neutrino mass** and its relation to the global symmetry of the SM, **Lepton number** (Dirac vs. Majorana nature of the neutrinos); measuring the full **neutrino mass parameters** (neutrino mass hierarchy, CP violation)
- C) **Dark Matter; Dark Energy and their role in the evolution of the Universe; CMB** (primordial inflation, elw. Phase transition, quark-hadron phase transition, nucleosynthesis, matter-antimatter cosmic asymmetry) -

# A memorable past decade for astroparticle physics...

- **Multimessenger astronomy**: 2 new entries, i.e. **2 new cosmic messengers are DISCOVERED, HE cosmic neutrinos and gravitational waves**. Important progress in gamma- and charged cosmic ray – astronomy
- Impressive progress in our knowledge of **neutrino properties** through a combined action of **astroparticle physics and cosmology**
- **CMB**: extraordinary achievements by the Planck satellite on our knowledge of CMB temperature fluctuations as well as the CMB polarization modes
- The **dark side of the Universe**: amazing progress in our bounds especially on **WIMP DM**, but **the DM mystery** still remains. In spite of our better knowledge of some **DE** properties, still **its nature remains completely obscure**.

# from the 2008 roadmap of the **ASTROPARTICLE MAGNIFICENT 7**



to the **2016** RESOURCE-AWARE\*

# APPEC astroparticle physics roadmap

## 0. Introduction

### 1. Formation of cosmic structures: CMB

### 2. Acceleration of the expansion of the Universe: Dark Energy

### 3. Direct detection of Dark Matter

### 4. Probing the ultimate nature of the Neutrino

### 5. Probing the Universe with Gravitational Waves

### 6. High Energy Universe: photons, neutrinos and cosmic rays

## 7. Transverse issues

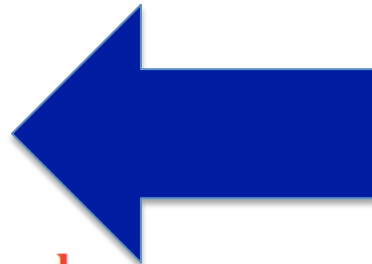
### 7.1 Theory

### 7.2 Computing

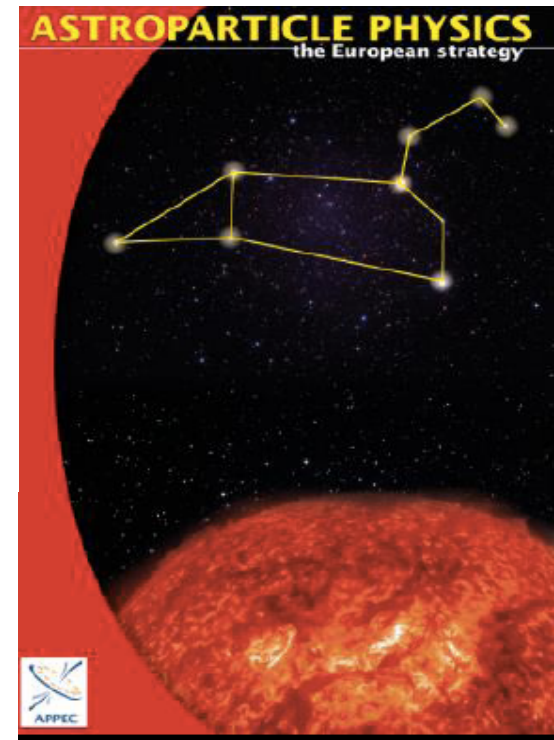
### 7.3 R&D and Industry

### 7.4 Education and Outreach

## 8. The global view



\*gauge the financial impact of the beginnings of operation of the large global scale observatories put forward in the previous roadmap and to examine the possibilities of international coordination of future global initiatives

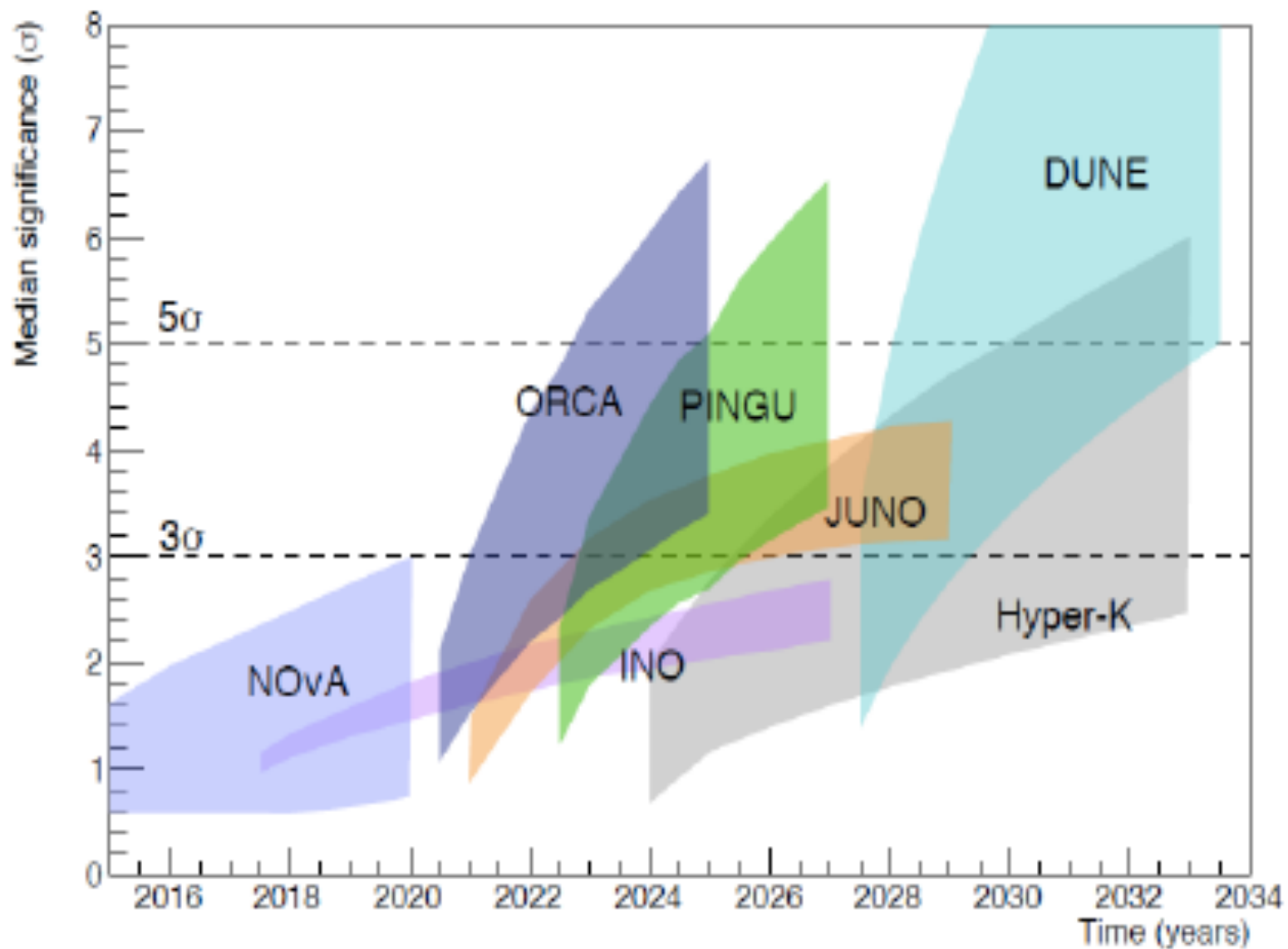


# much depends on the next 5 years ...

- **LHC14** (high energy: ATLAS, CMS; flavor: LHCb; quark-hadron phase transition: ALICE)
- **Flavor**: NA62; upgraded MEG, Mu-e; BELLEII; EDMs; g-2
- **DM** 1-ton exps.  $\rightarrow 10^{-10} - 10^{-11}$  pb
- **Neutrinoless double  $\beta$**   $\rightarrow$   $\nu$  mass degenerate region; enter IH region
- **SBN**  $\rightarrow$  sterile  $\nu$  ?
- **Gravitational waves**  $\rightarrow$  discovery to pave the way to gravitational wave astronomy
- **DE**: BOSS  $\rightarrow$  DESI; DES  $\rightarrow$  LSST
- **CMB**: final PLANCK; B-modes of the polariz.+ black-body spectrum : EU exps. QUBIC, LSPE, QIJOTE + many others on ground and balloons in US, Japan

# ... and a thrilling decade in front of us

- **Multi-Messenger Astronomy** (advent of the cosmic HE neutrino and gravitational waves astronomies, the CTA tremendous leap in gamma astronomy, the new horizon in charged cosmic ray astronomy with the upgrade of AUGER);
- Impressive progress in unveiling (some of) the **neutrino mysteries**: **Dirac vs. Majorana** (1-ton  $(\beta\beta)_{0\nu\nu}$  exps.);  **$\nu$  mass hierarchy** (the race: see fig.);  $\nu$  CP violation (new long baseline  $\nu$  exps.);  **$\nu$  masses** (direct exps., amazing input from cosmology)

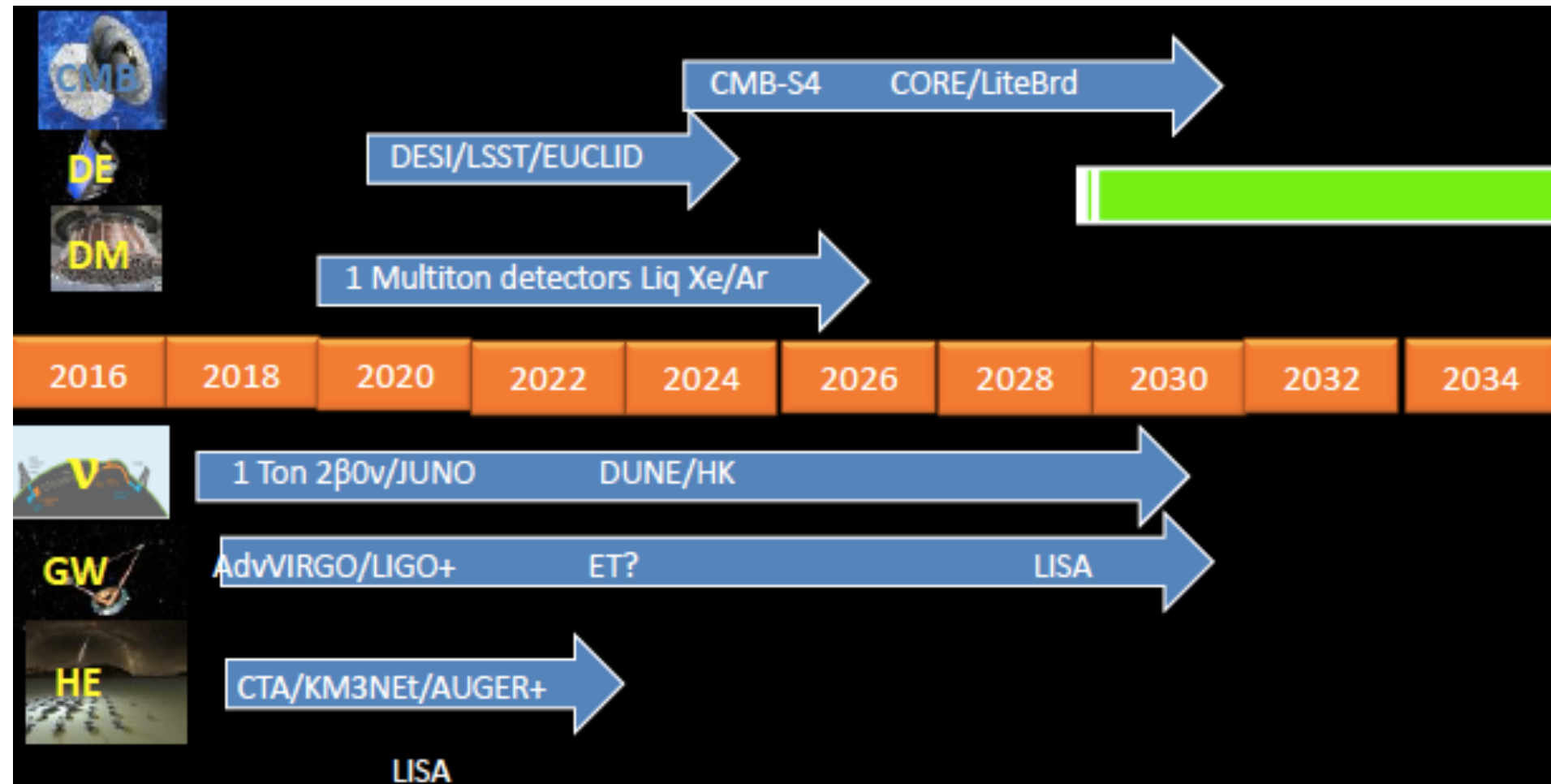


## ... and a thrilling decade in front of us

- **CMB** in the post-Planck (satellite) era → tremendous progress in ground, balloon and space exps.
- Shedding (an impressive amount of) light on the **dark side of the Universe**: **DM** → multi-ton exps. towards the ultimate  $v$  background (attempting to even overcome it); **DE**: remarkable leap in our knowledge of the history of the expansion rate of the Universe and the rate of growth of the cosmic structures through new ground and space exps



# The magnificent 9 of astroparticle physics and cosmology in the next 20 years



LISA

the **two Standard Models** are an extraordinary step forward in our knowledge of the Universe:

but, beware, Nature is rich of “**unknown unknown**”

→ after all Physics had already produced a “comprehensive, fundamental theory of all observed forces of nature” at the end of the XIX century...

Maybe the **DM** and the **DE** mysteries could represent the XXI century black-body and photoelectric problems

2016

known UNKNOWN :

DM DE ~~L~~ ~~B~~ CP

INFLATION ...

unknown UNKNOWN:

beyond QM – GR, ?