



Απορία και Πορεία

Η κατασκευή ενός οδικού χάρτη για την
Αστροσωματιδιακή Φυσική και τη Κοσμολογία

Ημερίδα για τον Φωκίωνα Χατζηιωαννου
22 Δεκεμβρίου 2017

Σ. Κατσανεβας
Καθηγητης Πανεπιστημιου Paris Diderot
Διευθυντης Εργαστηριου APC (Αστροσωματιδιακης Φυσικης και Κοσμολογιας)

Απορία: ορισμός

- **απορία** < αρχαία ελληνική άπορία < άπορος < ά- στερητικό + πόρος (πέρασμα)
 - η κατάσταση κατά την οποία κάποιος δεν μπορεί να δώσει απάντηση σε κάποιο ερώτημα που τον απασχολεί (φιλοσοφία) η κατάσταση κατά την οποία ο φιλόσοφος δεν μπορεί να δώσει απάντηση σε κάποιο φιλοσοφικό ερώτημα, επειδή έχει φτάσει σε αντίφαση ή επειδή δύο αντίθετες προτάσεις φαίνονται εξίσου πειστικές
 - η έλλειψη οικονομικών πόρων, φτώχεια πιστοποιητικό απορίας

Η επιστημονική απορία, ο « Σωκρατικός » Φωκίων

- ✓ Θανάση Λαχανάς: « Οι Έλληνες Φυσικοί, μένουν στην Ελλάδα ή φεύγουν στο εξωτερικό, μερικοί τα καταφέρνουν πολύ καλά, ίσως θα παρουν και το Νομπελ, αλλά όλοι συμφωνούν ενα σκοπο: να καταλάβουν τι στο καλό εννοούσε ο Φωκίων. »
- ✓ Γιατί; Γιατί είχαμε την αίσθηση ότι βλέπαμε τη σκέψη τη στιγμή της αναδυσης της (όπως ο χωροχρονός ...) . Και μπορείς να διδάξεις καλά μόνο τα πράγματα για τα οποία βρίσκεσαι σε απορία
- ✓ Συχνά αυτό που είναι έρευνα, πρόβλημα, απορία, ερώτημα στον δασκάλο γίνεται, μάθημα, πίστις, δόγμα, στον μαθητή. Αυτό που ήταν στο δασκάλο η ζωή της σκέψης, τα εργαλεία που χρειάστηκε να κατασκευάσει για να αντιμετωπίσει το πρόβλημα, γίνονται στον μαθητή στοιχεία ενός συστήματος.... (Francis Wolf : Penser avec les anciens)
- ✓ Η διδασκαλία σαν « αστυνομική πλοκή » η ;
- ✓ Ένας αριστοτελικός ορισμός της τραγωδίας που ταιριάζει στην επιστημονική έρευνα
- ✓ Να απορείς, να προχωρείς στον έλεγχο των σκέψεων, αλλά και να ζεις συντροφικά (να κάνεις δηλ περιπατούς), ήταν οι τρεις αρχές του Σωκράτη

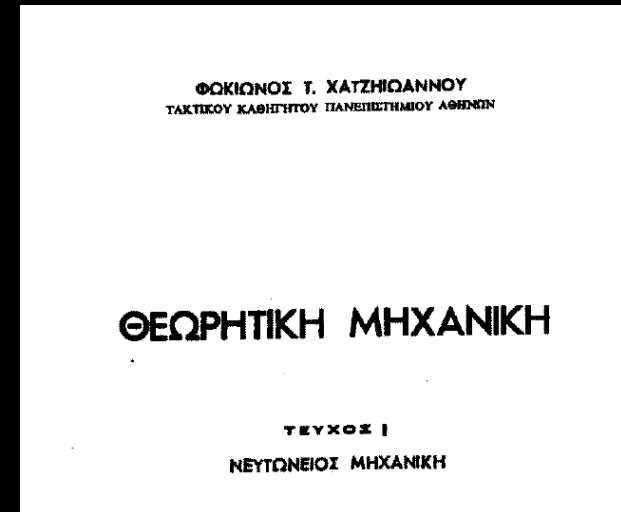
Πορεία η μάλλον πεζοπορεία, ο « Περιπατητικός » Φωκίων

- Αναμνησεις απο πανεπιστημιακες εκδρομες που οργανωνε ημι-παρανομα στη δικτατορια. Τραγουδησαμε χορωδιακα Θοδωρακη στο Κεντρι απεναντι απο το Γαλαξειδι...
- Λιγοι ισως θυμουνται οτι η πρωτη μαζικη πορεία κατα της δικτατοριας ξεκινησε αφου τελειωσαμε να παρακολουθουμε προσεκτικα ενα μαθημα κβαντομηχανικης του Φωκιωνα στη Πανεπιστημιουπολη.
- Foucault για την αντισταση του Cavailles στη κατοχη' « Οι φυσικοι και οι μαθηματικοι εξεγειρονται πιο εντονα και με μεγαλυτερη συνεπεια κατα των δικτατοριων απο τους των ανθρωπιστικων σπουδων , κυριως γιατι οι πρωτοι δεν υποφερουν το ανορθολογικο στοιχειο που αυτα τα καθεστωτα περιεχουν »
- Μετα ως βοηθος του Πεντελη, Σιφνος, ...



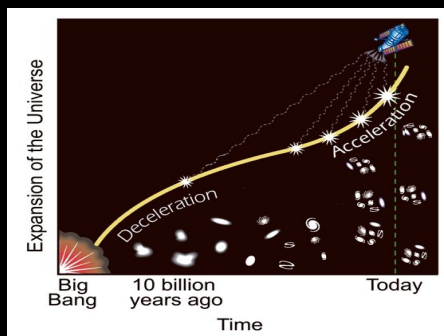
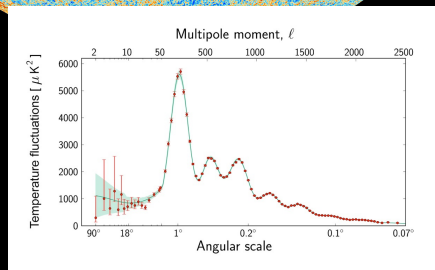
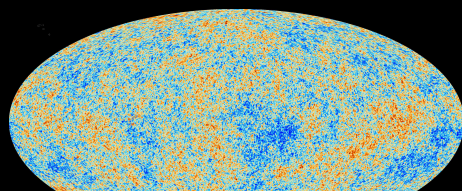
Η δική μου (πειραματική) απορία: τι είναι μάζα; η το αινιγμα της εμφάνισης μιας ή περισσότερων χαρακτηριστικών κλιμακών σε ένα συνεχές

- Mechanism of mass of quarks and charged leptons: the search for the Higgs boson (LEP)
- From quarks to baryons: structure functions and quark-gluon plasma (Fermilab and SPS)
- Dark matter particles and supersymmetry at LEP and LHC (Susygen)
- What mechanism gives mass to neutrinos? (PS180, Neutrino beam CERN to Gran Sasso and Nestor, OPERA)
- Astroparticle Physics with Nestor
- Gravitational masses in collision, black holes primordial, stellar or galactic, neutron star collisions, ... (EGO/VIRGO)



Καντ “ο ορισμος ερχεται στο τελος”

Πειραματικη γεννεση της συγκλισης σωματιδιακης φυσικης και αστροφυσικης στο τελος του 20^{ου}

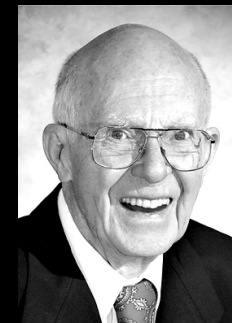


- **αιωνα**
Ανιχνευση Supernova 1987A με νετρίνα

- Διακυμανσεις κοσμολογικου υποβαθρου

Επιταχυνομενη διαστολη του συμπαντος (σκοτεινη ενεργεια)

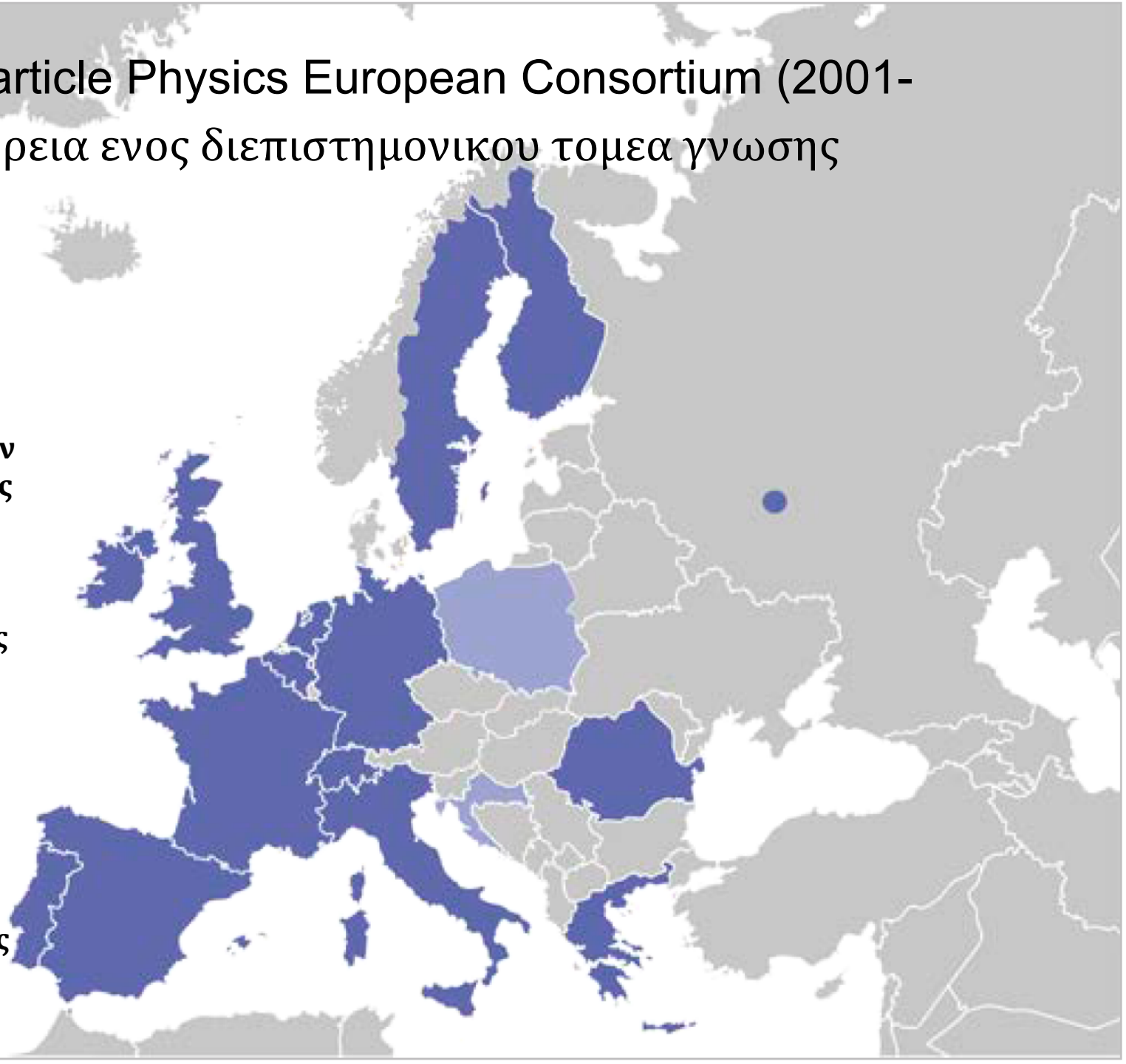
- Ταλαντωση και μαζα νετρινων
- +++



Astroparticle Physics European Consortium (2001- Η πορεία ενός διεπιστημονικού τομέα γνώσης



Χρειαζόνταν για την
Ευρώπη ένας οδικός
χάρτης για να
συνωδεύσει την
πορεία της
αστροσωματιδακής
φυσικής στον 21ο
αιώνα, και την
προστατεύσει από
την απορία (την
φτώχεια του
αστεγού) που
συνωδεύει πάντα
τις διεπιστημονικές
ερευνες στην αρχή
τους



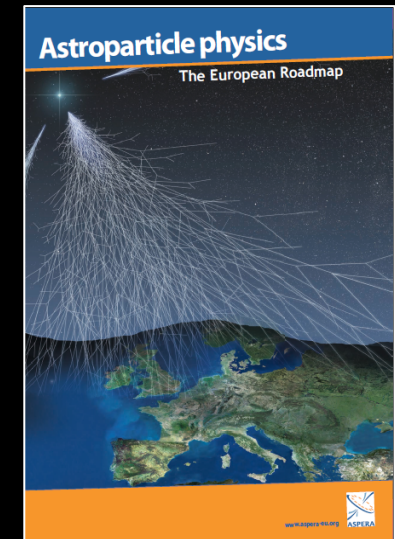
European Astroparticle Physics Roadmaps

The last 10 years

- **2007-2008 ApP scientific vision the “Seven Magnificent”**
 - An attempt to define the field , no priorities
 - A “hidden” message
- **2011 The first APPEC priority roadmap (3 categories):**
 - I. Complete the upgrades:
 - ✓ Adv. Gravitational Wave antennas (Virgo),
 - ✓ Underground science (Ton scale DM and ν less2 β)
 - II. Prepare construction of large CR infrastructures
 - ✓ CTA, KM3Net/IceCube, AUGER upgrade
 - III. Global coordination for very large projects:
 - ✓ Large neutrino detectors, Dark Energy and CMB



From the
Nature article



APPEC: *roadmapping*

2008

2011

‘Magnificent 7’

ASTROPARTICLE PHYSICS the European strategy

Astroparticle physics

The European Roadmap

HE gammas

HE neutrinos

HE cosmic rays

Gravitational waves

Dark Matter

ν -mass

ν -mixing & p -decay

In 2008: still lots of speculation ...

APPEC: *roadmapping*

2008

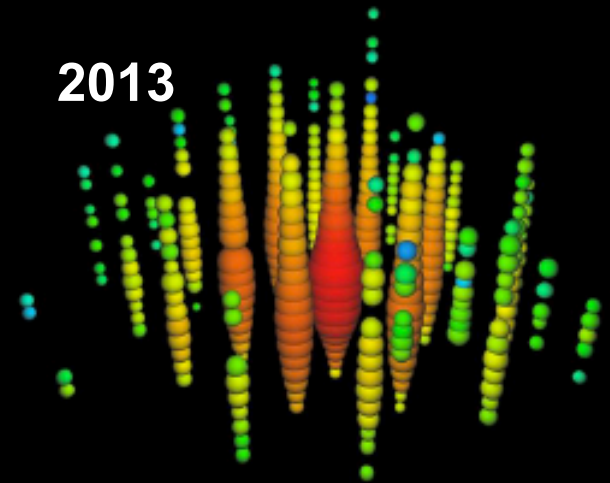
ASTROPARTICLE PHYSICS
the European strategy

2011

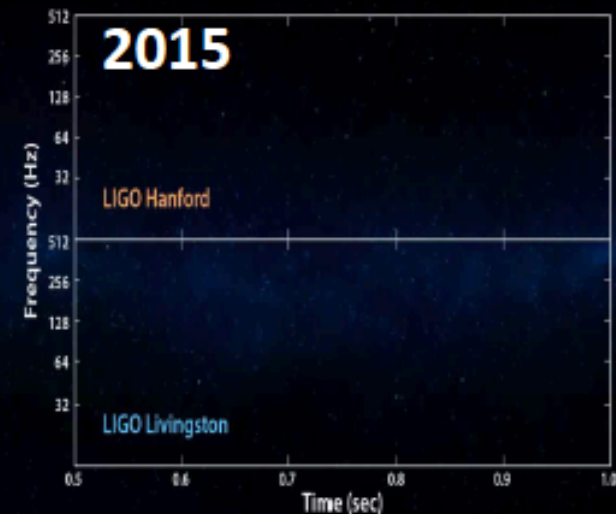
Astroparticle physics

The European Roadmap

2013



2015



From lots of speculation ...

to 1st detections!

APPEC: *roadmapping*

2008

ASTROPARTICLE PHYSICS the European strategy



2011

Astroparticle physics The European Roadmap



2017

European Astroparticle Physics Strategy APPEC 2017-2026



Will be presented on the 9th of January in Brussels

The two challenges of the present era for Astroparticle Physics and Cosmology



Planck-Scale

Grand Unification

Leptogenesis

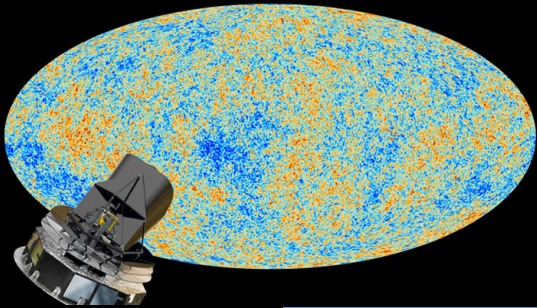
Dark Matter

Fermi-Scale

eV-Scale

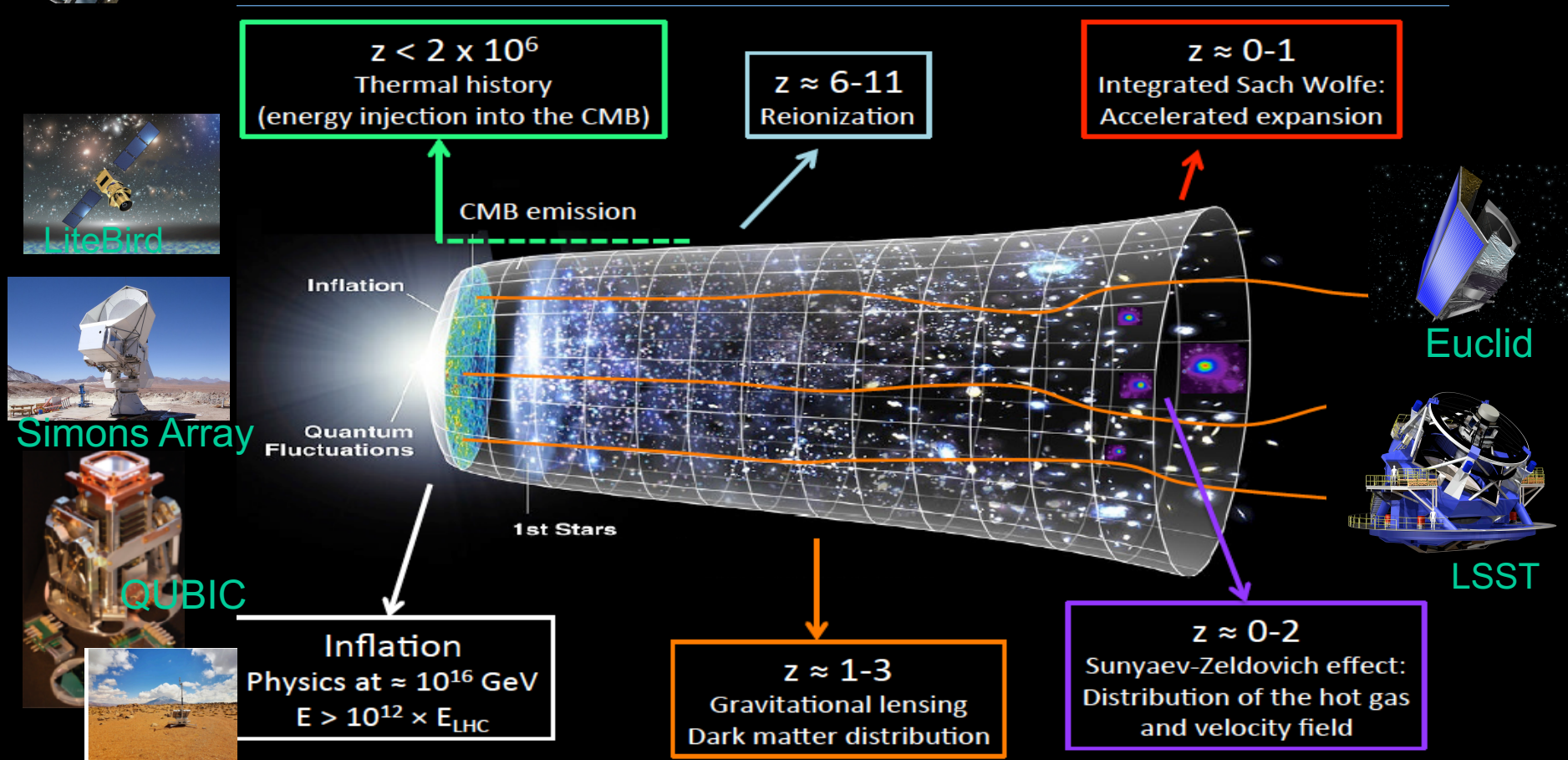
- I. *The Cosmic structures from the CMB to the present provide comparable constraints to the standard models of cosmology (inflation, dark energy) and particle physics (neutrino, dark matter).*
- I. *Multi-messenger astronomy involving photons of all frequencies, gravitational waves, neutrinos and high-energy charged particles provides a deeper understanding of violent phenomena regulating structure formation in the Universe as well as eventually hints for new laws of physics.*

Jacobs' Cosmic Ladder
Homer's Aurea Catena,...
Fokion SU(5), Οι μαθητες του



Cosmology

« Near » and « Far » Complementarities



- A well defined roadmap for dark energy surveys
- Uncertainties in the European roadmap for CMB on ground and space (CMB-E4,CORE+)

Ενοποίηση ο κόσμος, από τα 400.000 χρόνια μετά το Big-Bang ως σήμερα κοινός χώρος μελέτης

CMB measurements probe cosmology and fundamental physics

Inflation

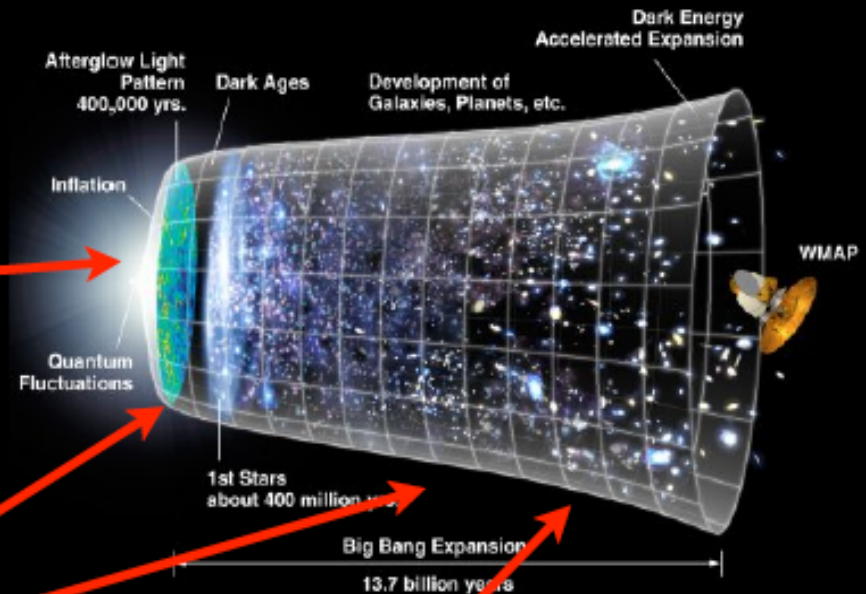
- Spectral index of fluctuations, n_s
- non-Gaussianity?
- Inflationary gravitational waves?

Neutrinos

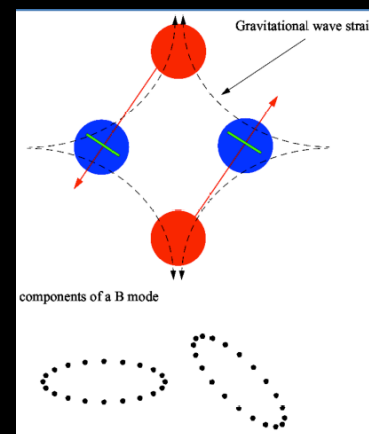
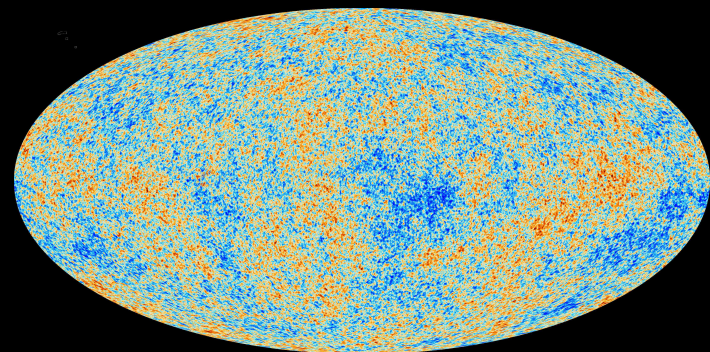
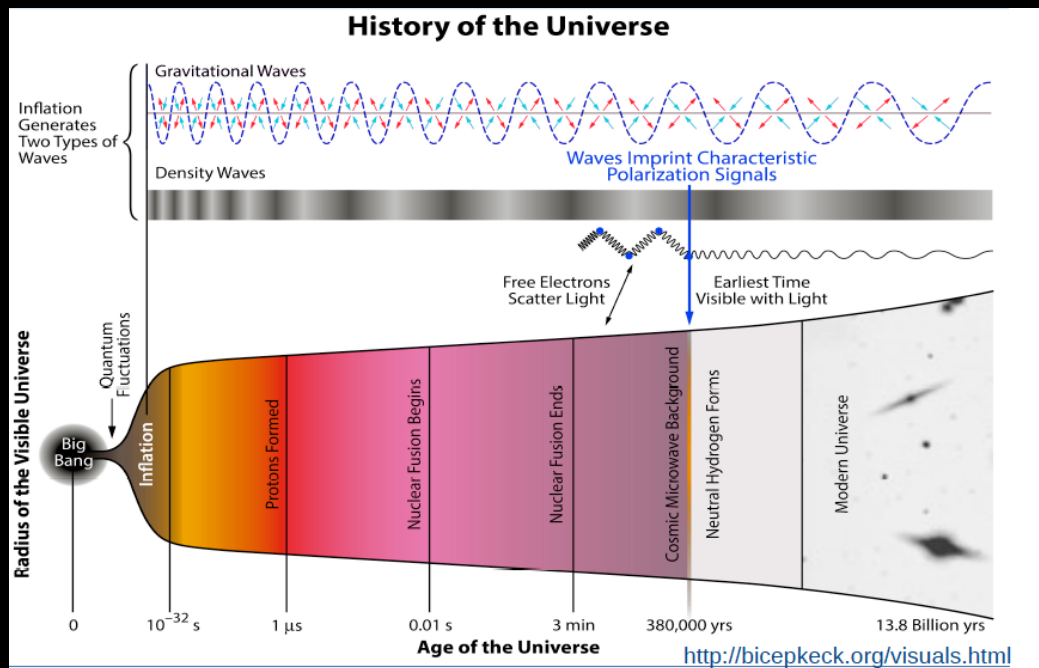
- Number of relativistic species (N_{eff} or “dark radiation”)
- Sum of the neutrino masses, ($\sum m_\nu$) through impact on growth of structure

Dark Energy

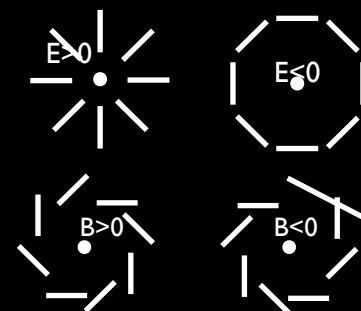
- Probe growth with SZ clusters, CMB lensing, correlation with galaxy surveys
- Is GR correct on large scales?



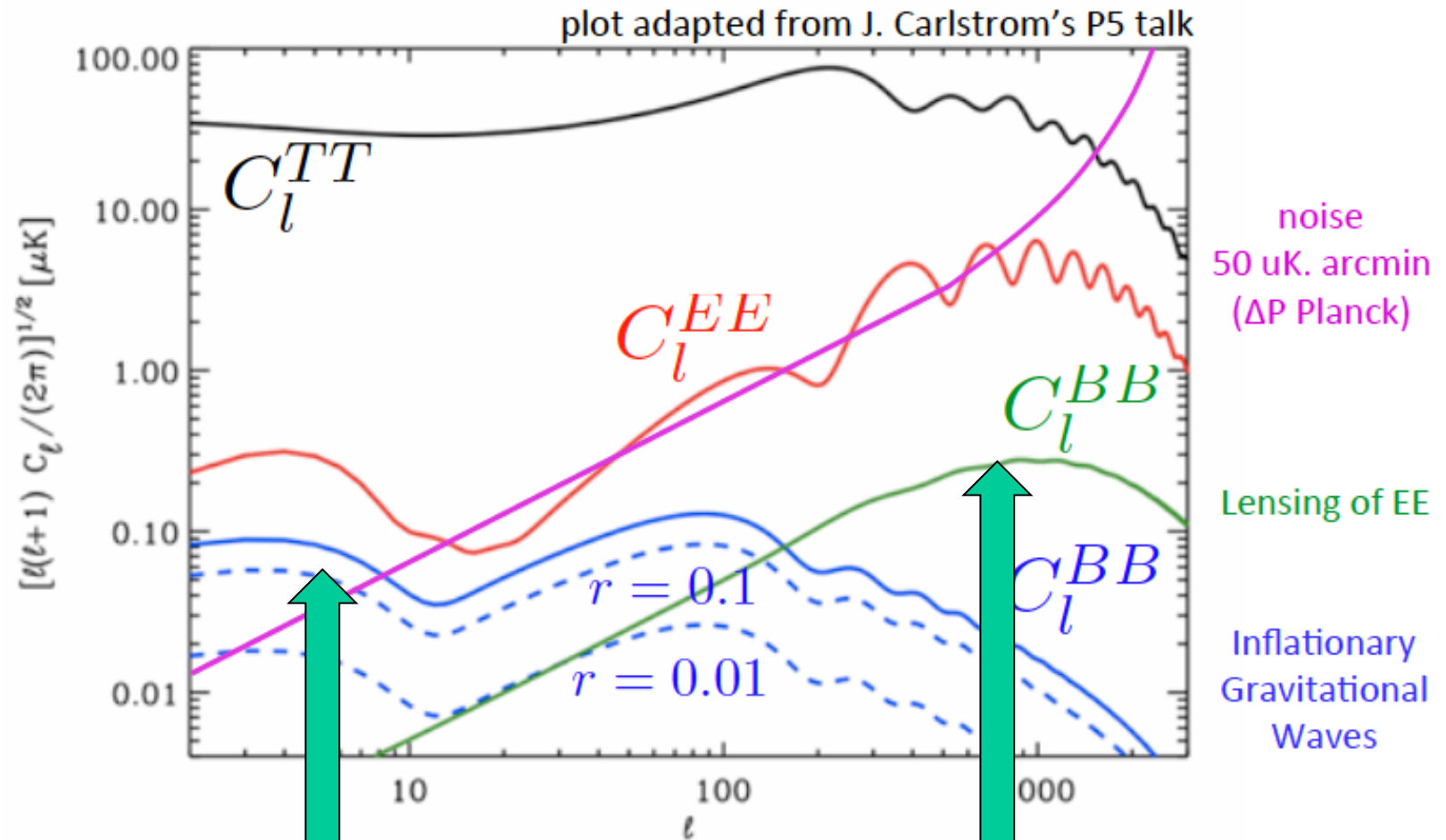
Βαρυντικο αποτύπωμα του πληθωρισμού στο CMB



- Τα βαρυτικά κύματα που έχουν τετραπολικη μορφη δινουν ενα τετραπολικο αποτύπωμα στις κβαντικες διακυμάνσεις
- Τα φωτόνια κοσμολογικου υποβαθρου σκέδαζομενα από αυτές τις διακυμάνσεις απόκτουν τετραπολικη πόλωση B
- Ανίχνευση της πόλωσης B $\rightarrow$ ανίχνευση του πληθωρισμού



Τα επομενα πειραματα · μετρηση της πολωσης B (CMB-S4, CORE+?)



31 Aug. 2015

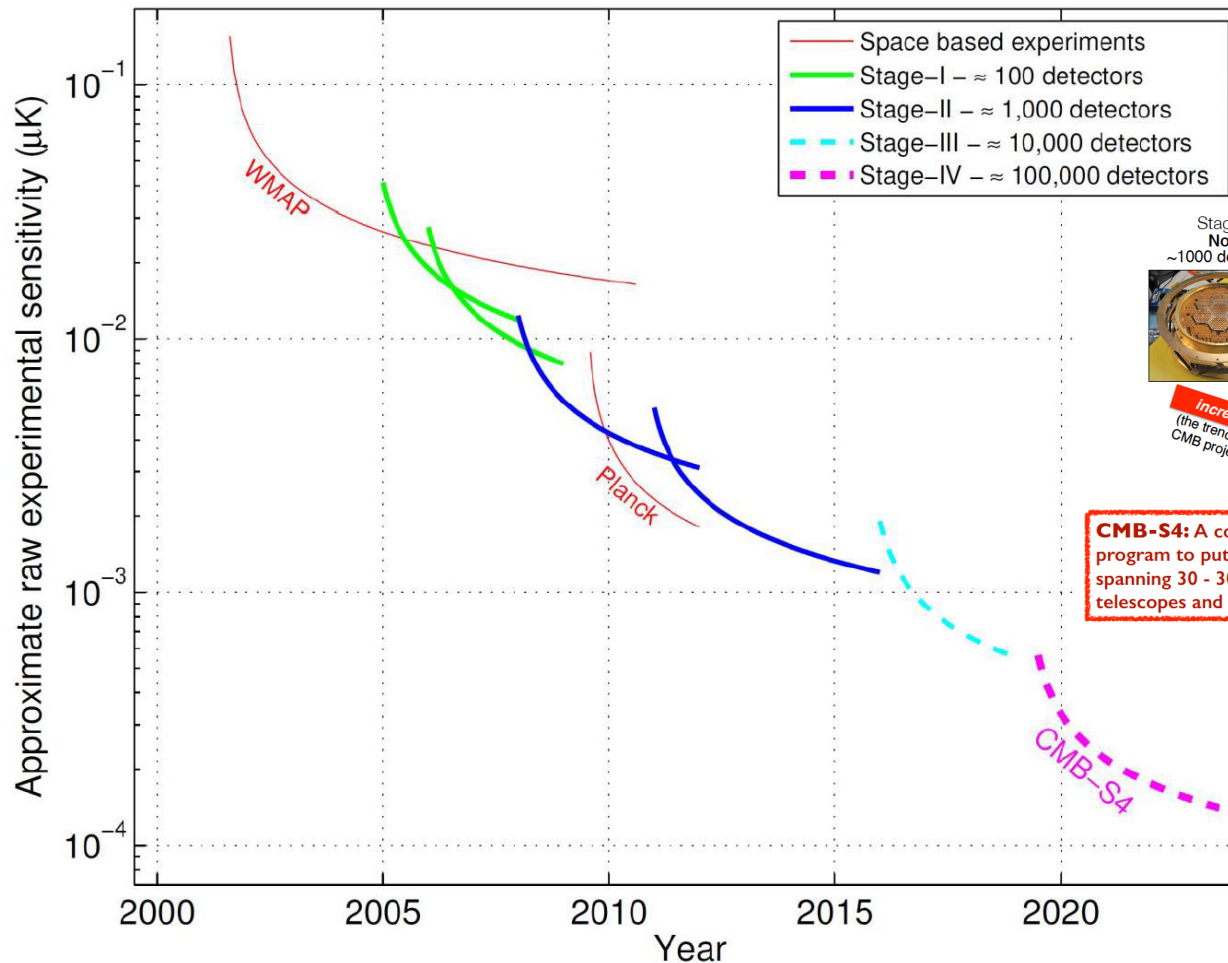
J. Delabrouille - Space Missions

3

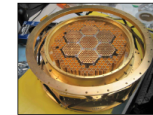
Αποτυπωμα πληθωρισμου

Εστιαση μεσω υλης,
μετρηση του ρολου των ν

Prospective CMB on ground , CMB-S4

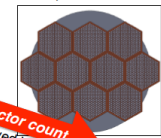


Stage II
Now
 ~ 1000 detectors

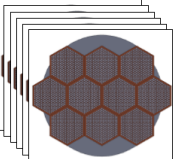


Increasing detector count
(the trend being followed by all
CMB projects, not just SPT)

Stage III
ramping up
 $\sim 10,000$ detectors



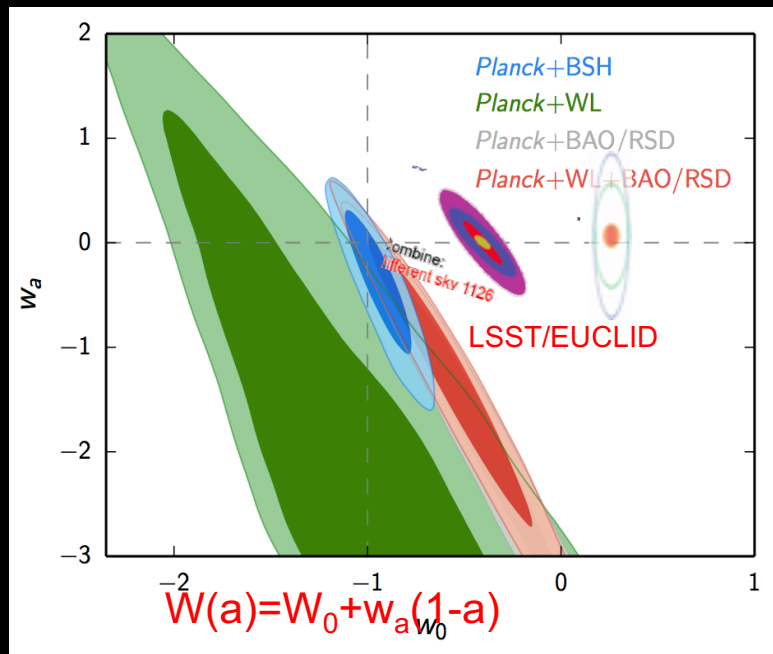
Stage IV
 ~ 2020 - CMB-S4
 $\sim 500,000$ detectors



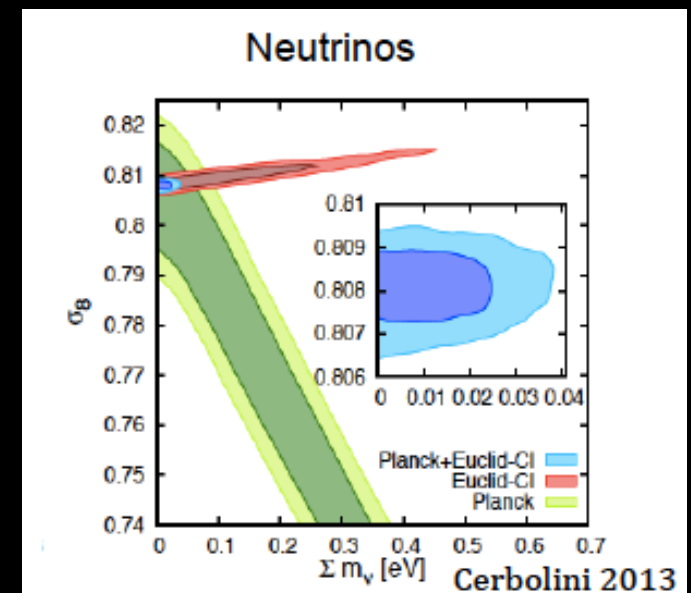
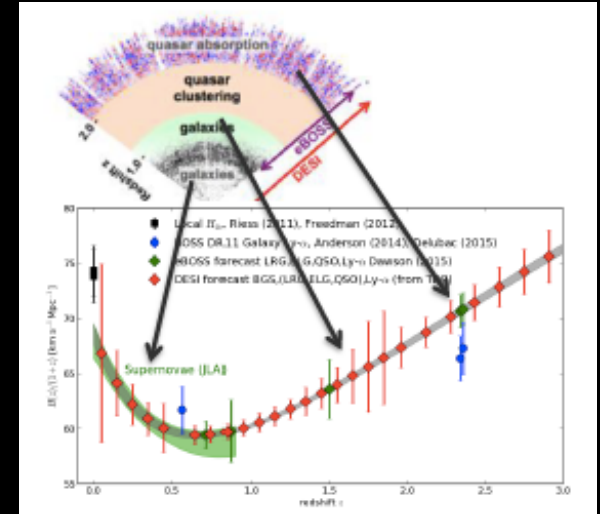
CMB-S4: A coordinated community wide program to put order 500,000 detectors spanning 30 - 300 GHz using multiple telescopes and sites to map $\geq 70\%$ of sky.

Large Dark Energy surveys

- DESI 2018 (BAO and Galaxy clustering)
- EUCLID 2021 ESA M2 mission
- LSST 2021 First light 2021



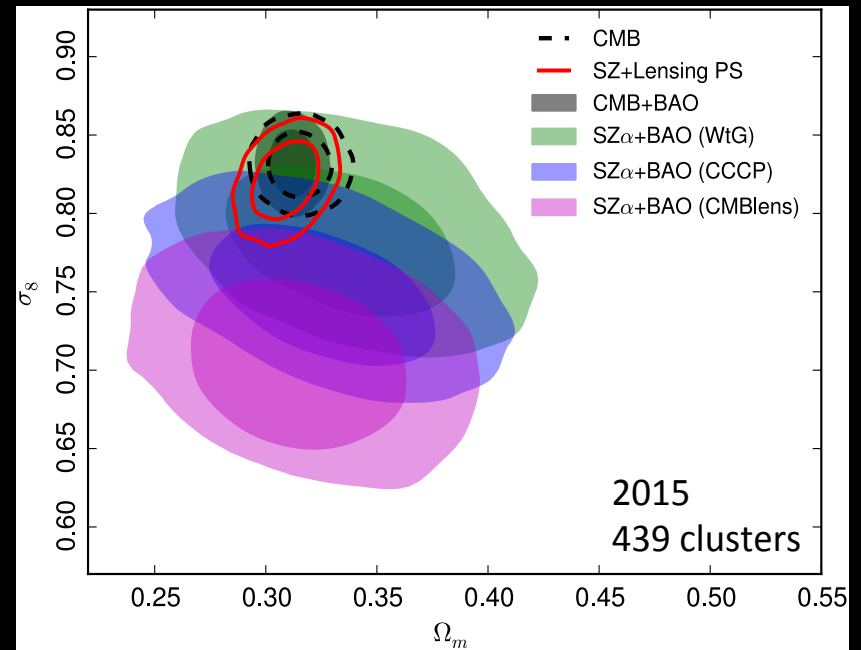
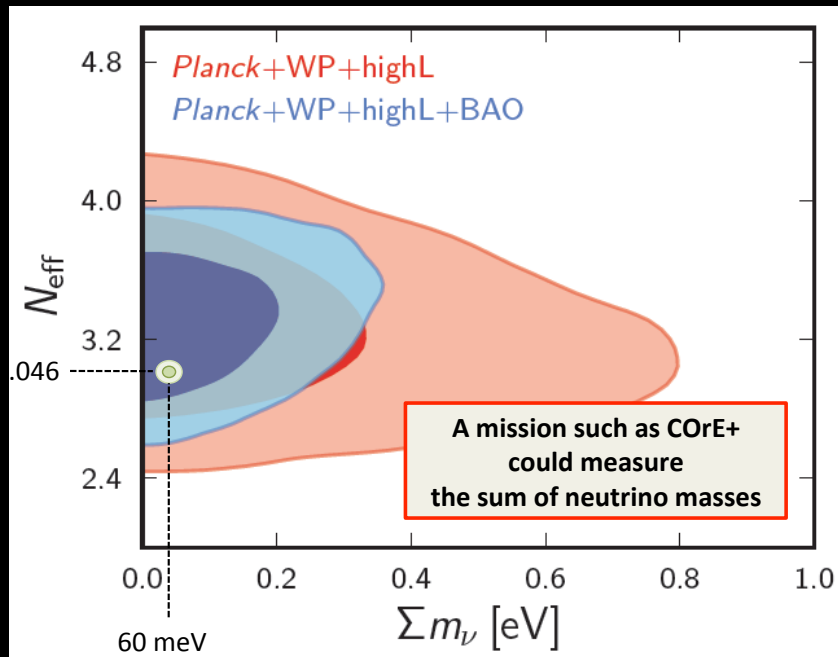
- Equation of state of dark energy
- Deceleration and acceleration of the Universe
- Sum of the masses and the number of ν



Σm_ν and N_{eff} from CMB/Large Surveys

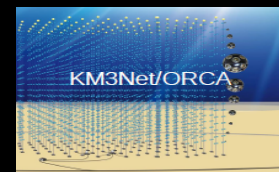
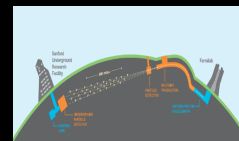
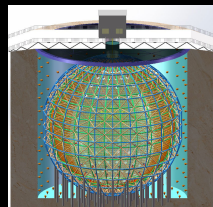
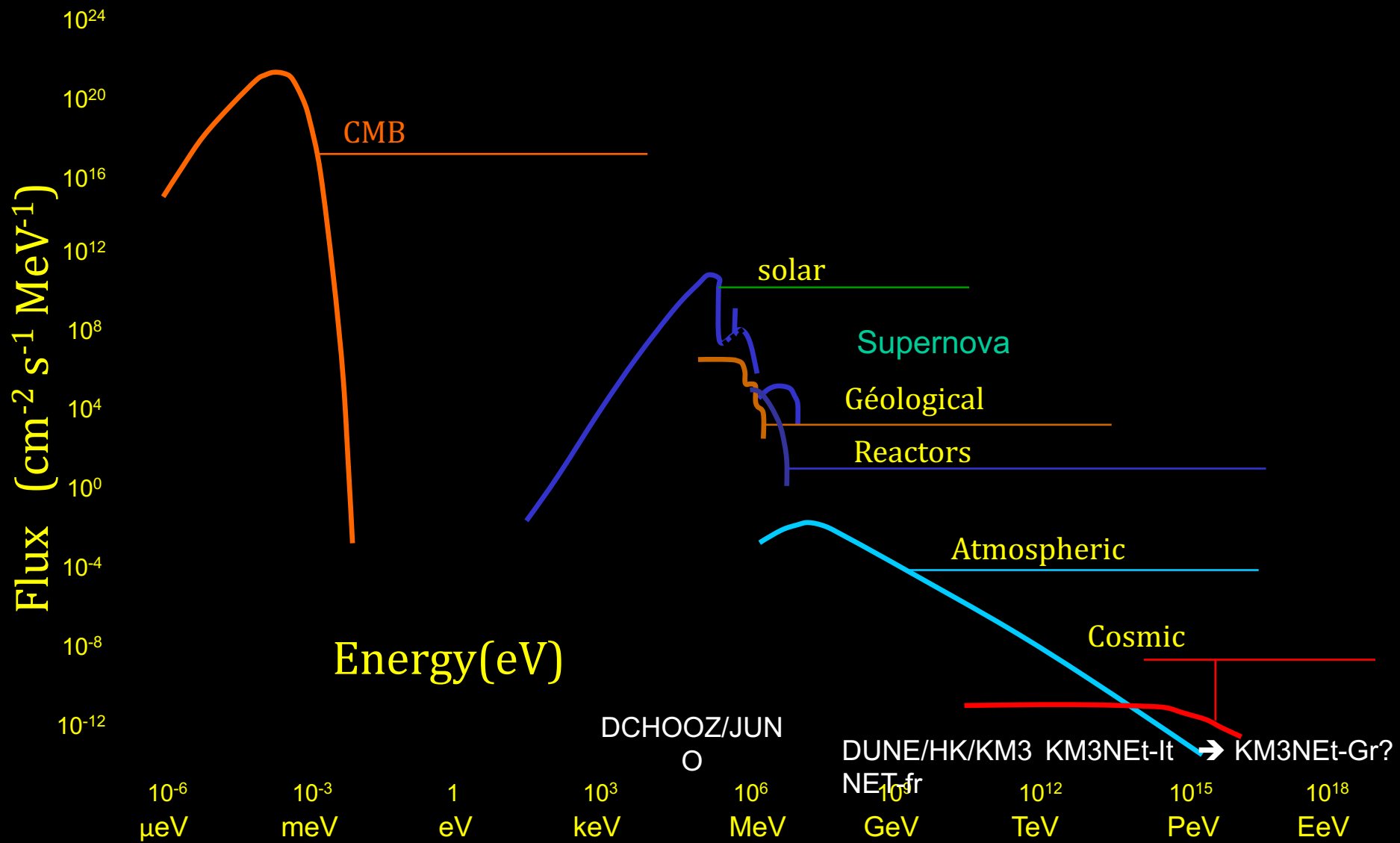
$$\Sigma m_\nu < 0.21 \quad N_{\text{eff}} = 3.15 \pm 0.23 \quad \text{Planck TT} \quad +\text{lowP+BAO}$$

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



Tension with Large Scale Structure (Planck SZ, X-ray) , in the σ_8 - Ω_m plane. In general « recent » variables (H_0 , σ_8) below values measured at recombination. Cluster measurement uncertainties or new physics (sterile neutrinos ?)

Neutrinos : Reactor, accelerator and cosmic



The point of view of the neutrino

Atmosph/Accelerator

$$0.4 < \sin^2 \theta_{23} < 0.6$$

Reactor/Accelerator

$$\sin^2 \theta_{13} = 0.023 \pm 0.02$$

Solar/Reactor

$$\sin^2 \theta_{12} = 0.30 \pm 0.01$$

$$\Delta m^2 / \text{meV}^2$$

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

$C_{12} = \cos \theta_{12}$ etc., + 2 **Μαφωρανα** phases

Solar
 75 ± 3

Atmospheric
 2400 ± 100

Normal

3 e μ τ

Atmosphere

2 e μ τ

1 e μ τ

Inverted

2 e μ τ

Sun

1 e μ τ

Atmosphere

3 e μ τ

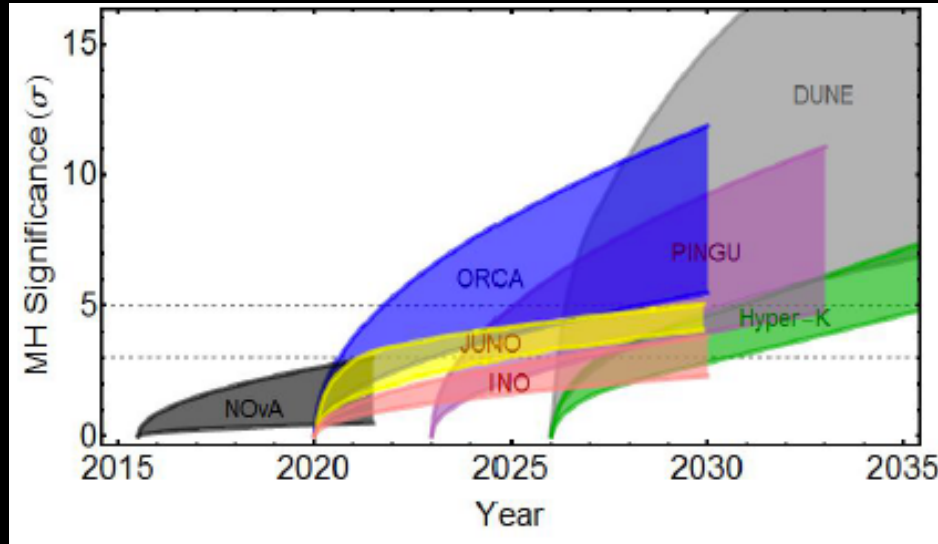
Tasks

- Precision for θ_{12} and θ_{23}
- Mass ordering?
- CP-violating phase δ ?
- Dirac or Majorana?
- Absolute masses?
- Steriles ?

Open Questions

- Relation to formation and evolution of cosmic structures
- Relation to dark matter?
- Relation to dark energy?

Measuring the neutrino mass hierarchy and/or directly the mass and nature

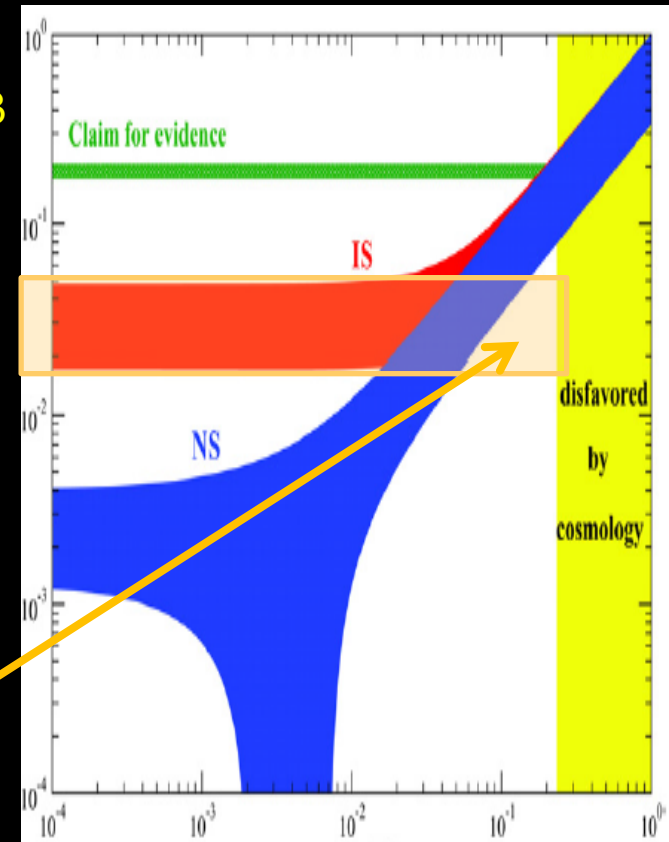


Mass hierarchy by 2025?

Lower limit of IH
by 2025-2030?

$m_{\beta\beta}$

20 mEV
0.5-5
evts/y/ton

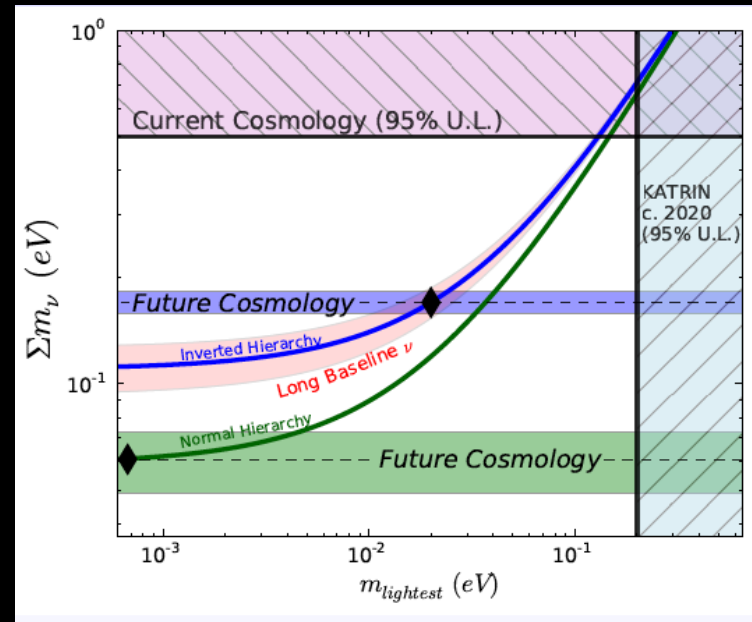


Σm_ν

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

Future Σm_ν measurements (2025-2030)

Forecast sensitivities				
		$\delta(\Sigma m_\nu)$ meV	$\delta(N_{\text{eff}})$	
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?**

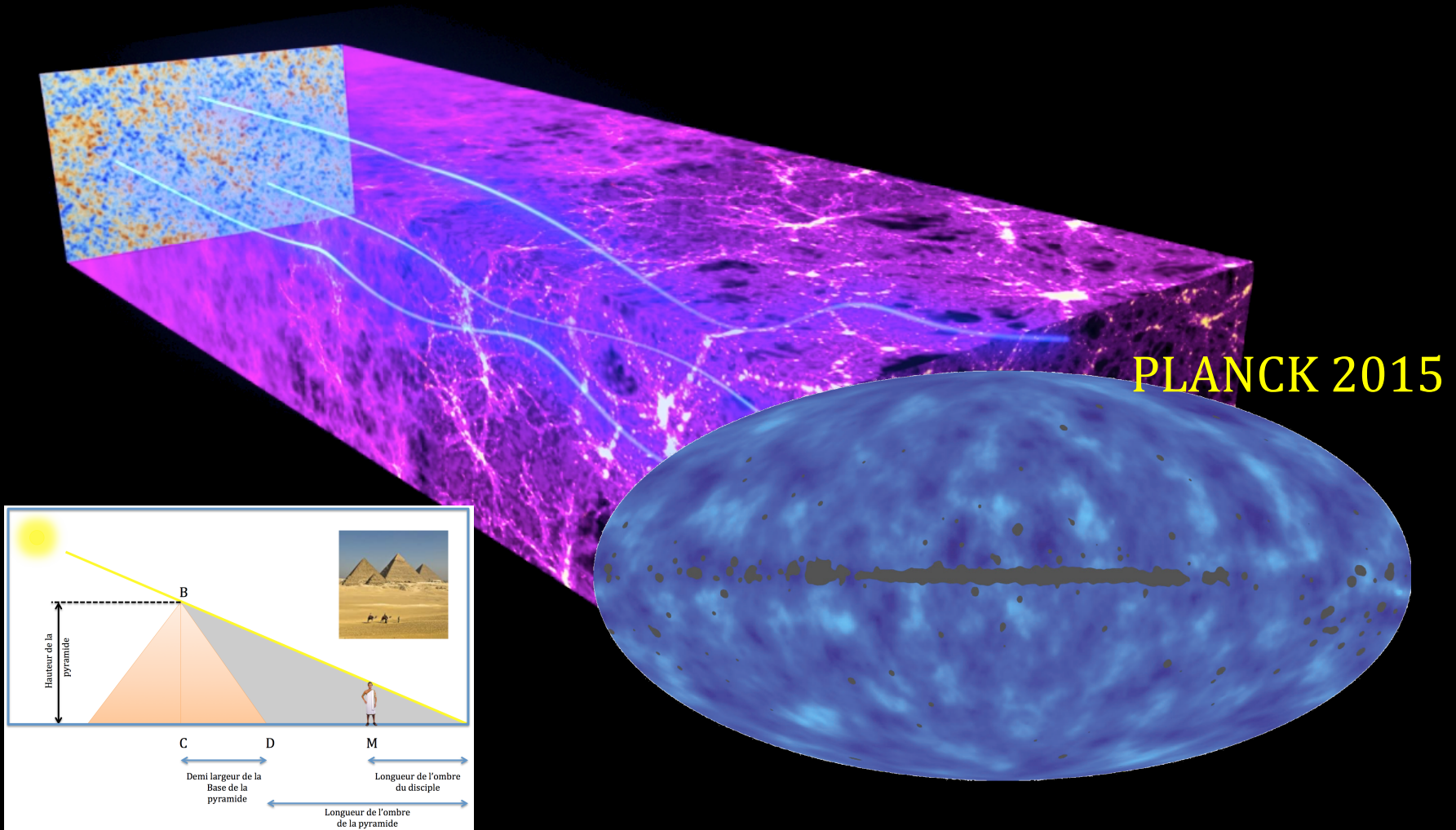
*If the minimal neutrino sector, with $\Sigma m_\nu = 58$ meV and $N_{\text{eff}} = 3.046$, is **not** robustly detected, it would imply something is “broken” in another aspect or aspects of cosmology, including possibly: non-constant dark energy, a non-power-law primordial perturbation spectrum, extra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

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

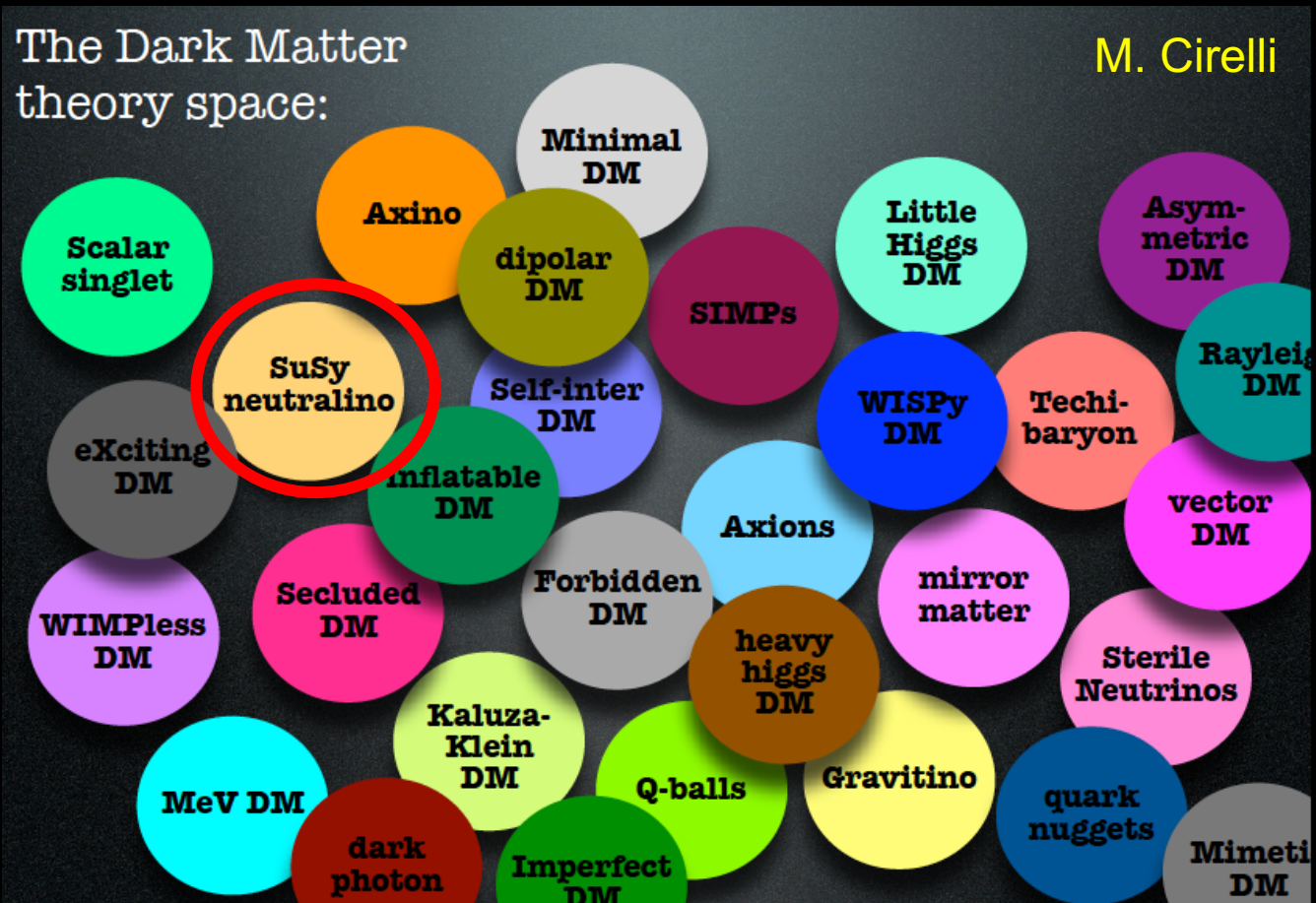
Not a competition with ν experiments but comparison portal to new physics for both Standard Models.

The “ultimate” repetition of the “cosmological experiment of Thales at the shadow of the Pyramid

Primordial CMB light and gravitational lensing probe matter (incl. dark matter) in the Universe



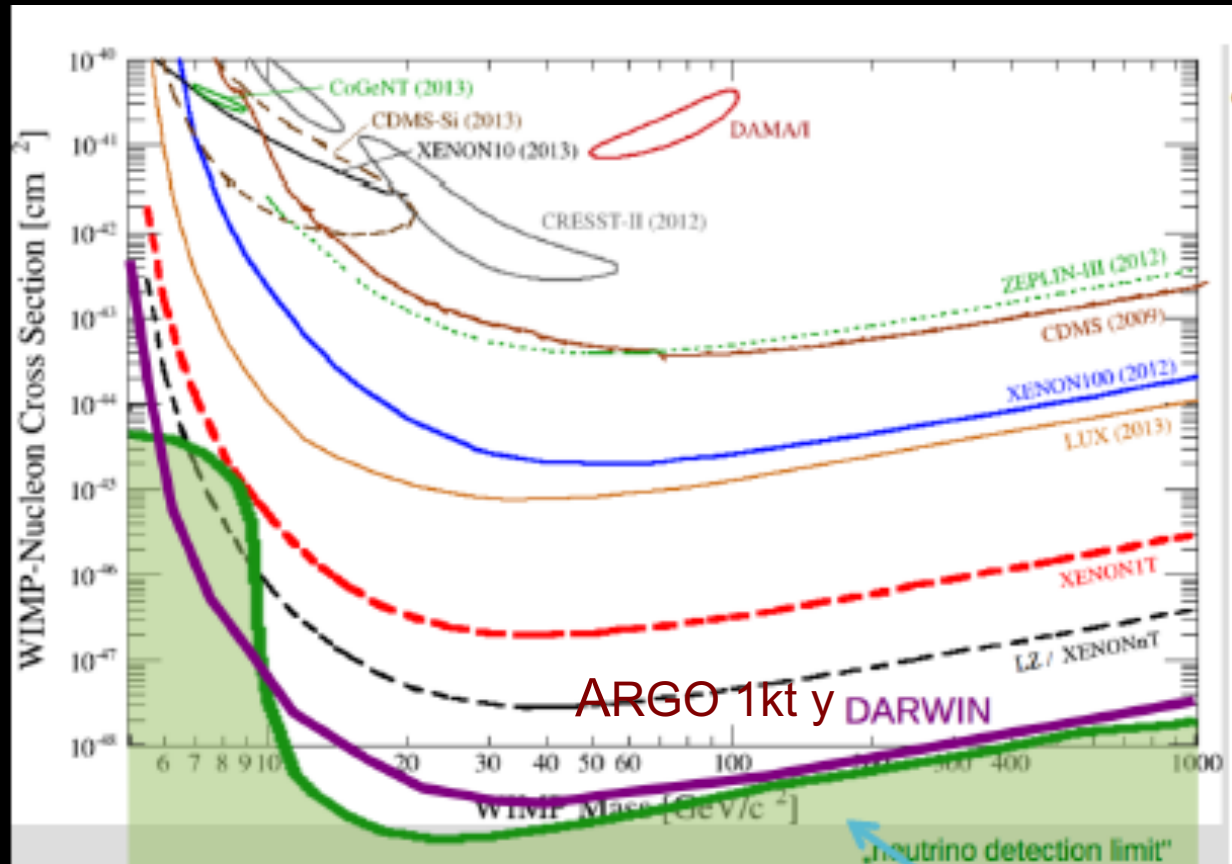
Cosmology and dark matter



- 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.
- I AM STILL A BELIEVER IN WIMPS

Future sensitivities dark matter

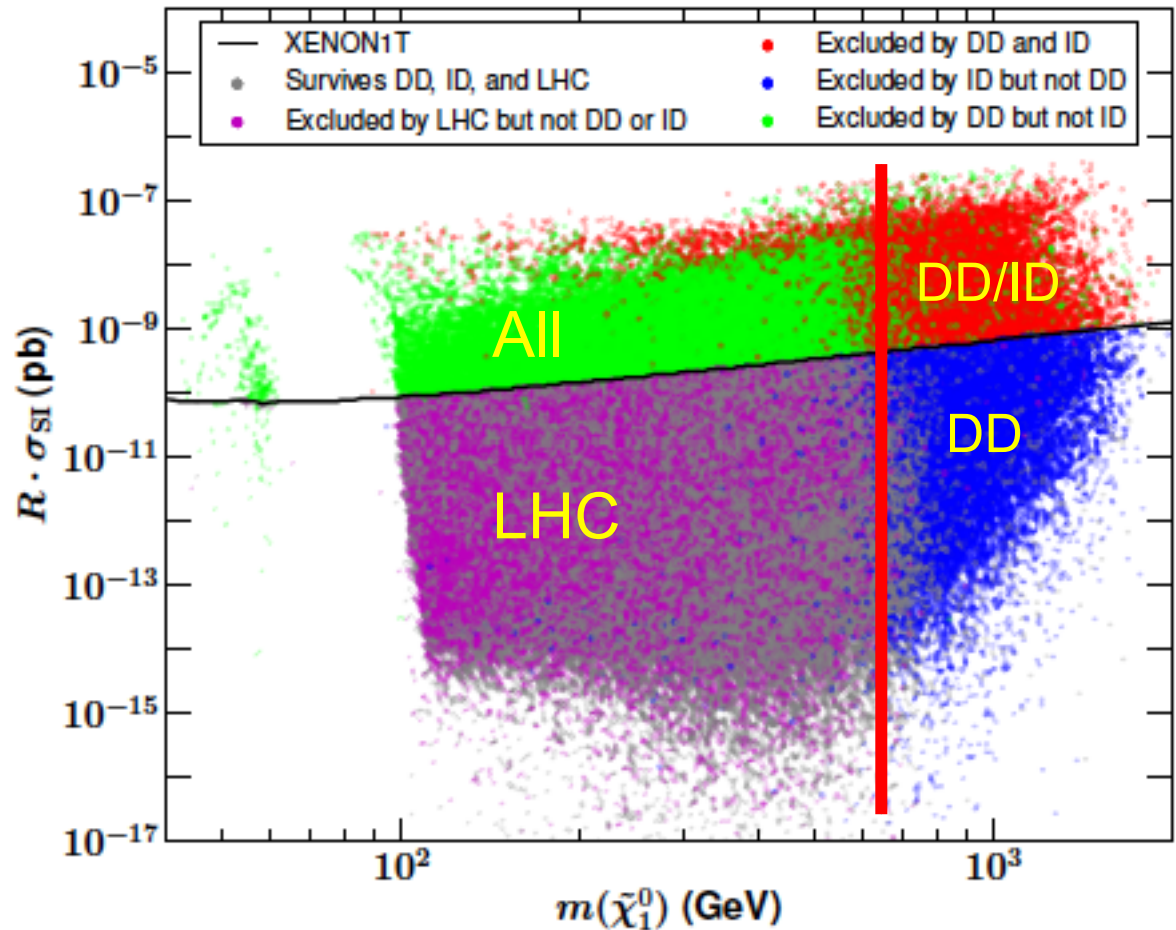
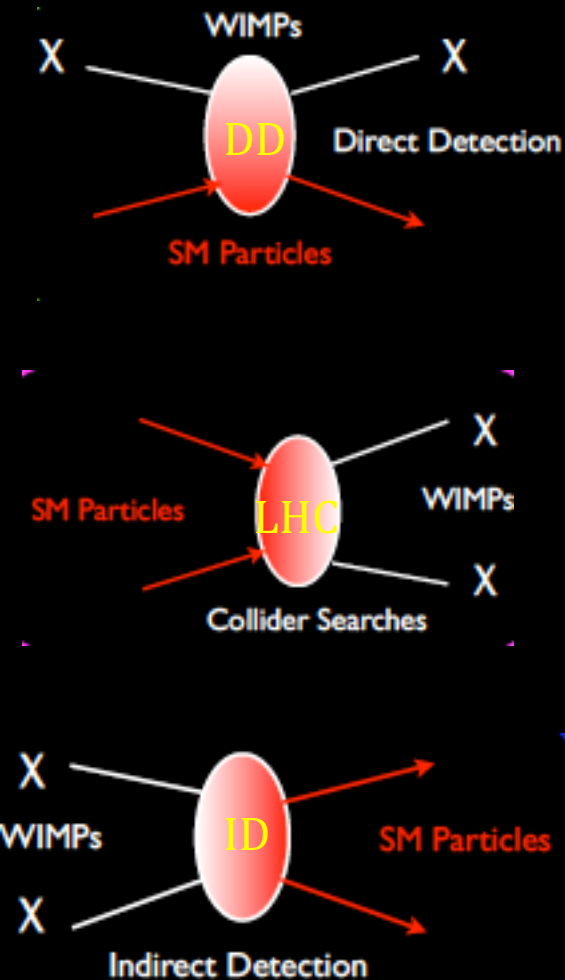
- G2 will reach 10^{-47} cm² at 100 GeV in 2020-2025
- G3 will approach neutrino floor ca 2030
- Extreme purities needed:
 - 1 event/ton/year
- Complementarity with Bolometers and CCD
- Beyond the neutrino floor → directionality and annual modulation



Wimp mass

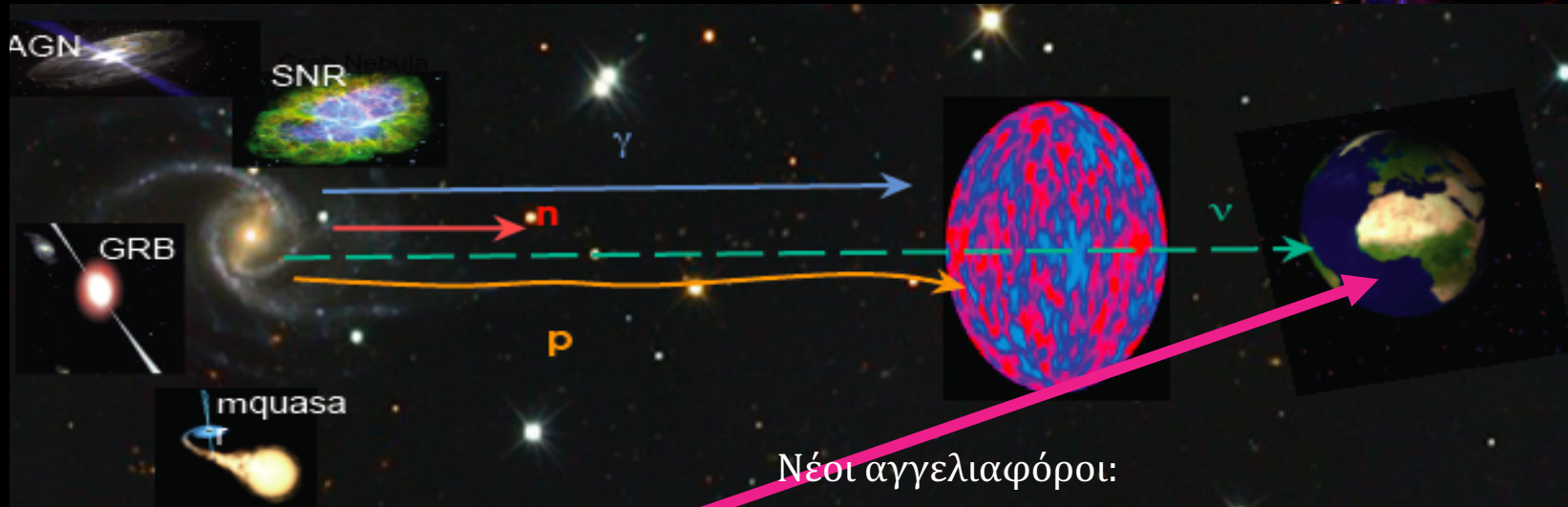
- ✓ *APPEC SAC → Decide ca 2019-20 G3 multi-ton experiment.*
- ✓ *Costs and scales make global coordination imperative*

Complementarity between Direct Detection (DD), Indirect Detection (ID), LHC

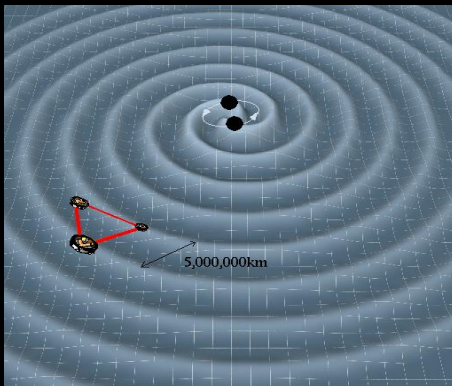


*Complementarity with LHC, also in case of high WIMP masses
rationale for next collider*

Η μελετη των βιαιων φαινομενων γινεται με τη καινουργια αστρονομια “πολλαπλων αγγελιαφορων”



- Φωτόνια υψηλής ενέργειας
- Νετρίνα
- Βαρυντικά κύματα
- Φορτισμένα σωματίδια, πολυ υψηλής ενέργειας
- Αργότερα, σωματίδια σκοτεινής ύλης?



Dark matter and energy, neutrinos do not suffice to understand the formation of structure, we also need to understand the regulating role of violent phenomena

60 χρόνια πριν *Conférence Chapel Hill Janvier 1957*

In January 1957, the U.S. Air Force sponsored the *Conference on the Role of Gravitation in Physics*, a.k.a. the Chapel Hill Conference, a.k.a. GR1.

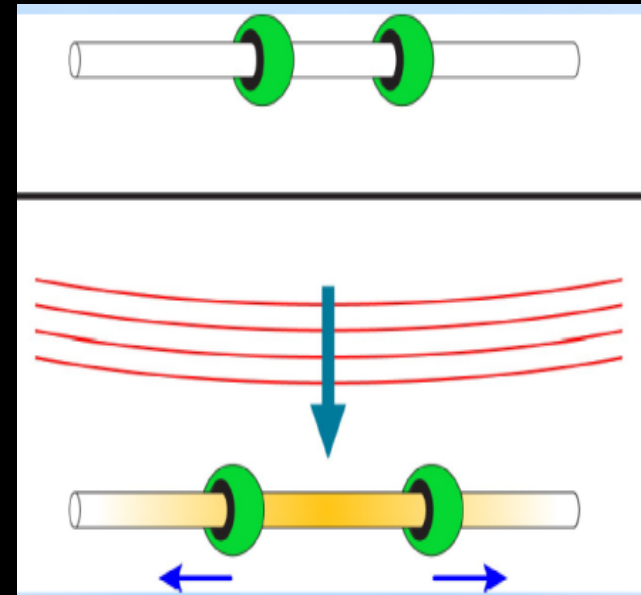
The organizers were Bryce and Cecile DeWitt. 44 of the world's leading relativists attended.



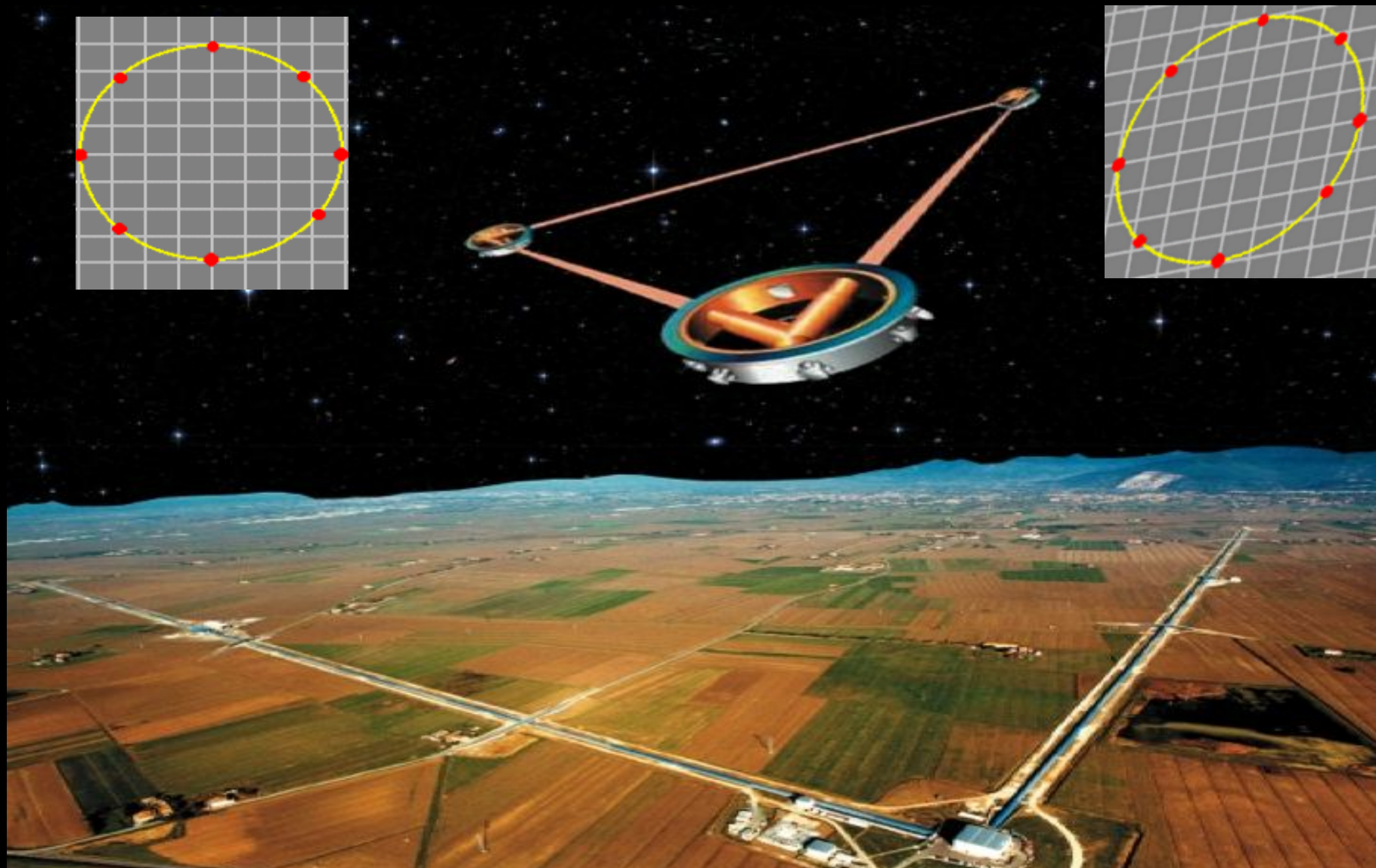
The “gravitational wave problem” was solved there, and the quest to detect gravitational waves was born.

(Pirani, Feynman and Babson)

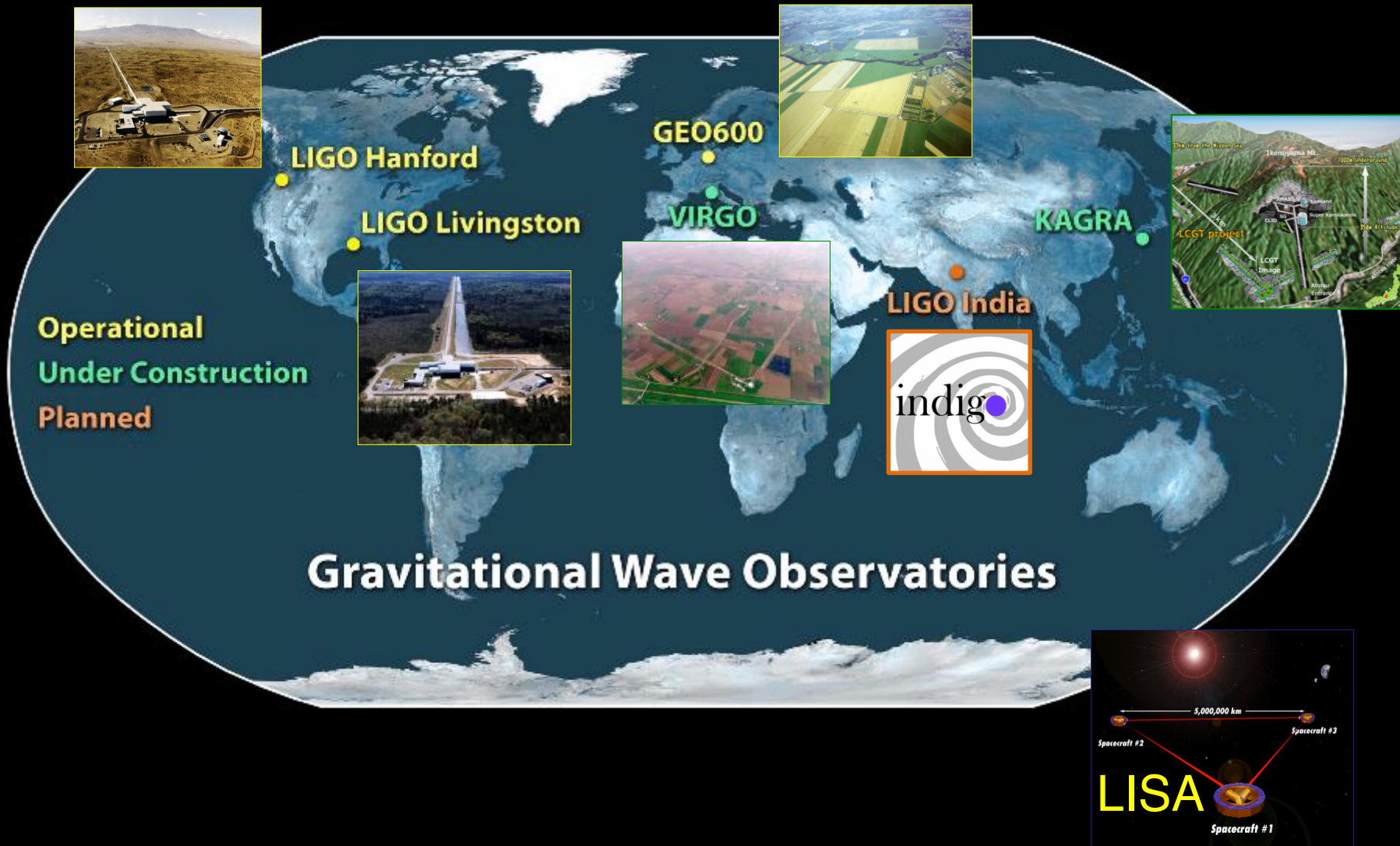
Sticky bead argument (Feynman)



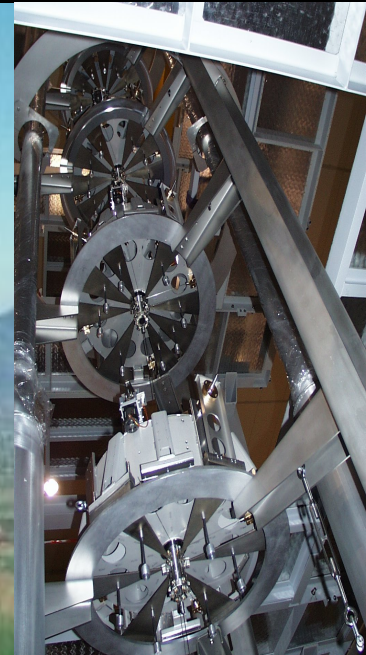
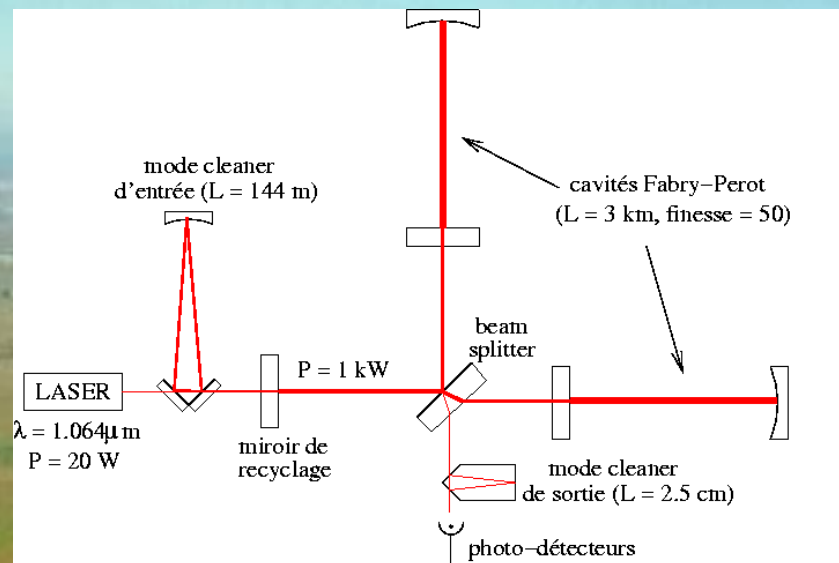
Βαρυντικές αντεννες στη γη (LIGO/VIRGO 2000's) και το διαστημα (LISA 2030's)



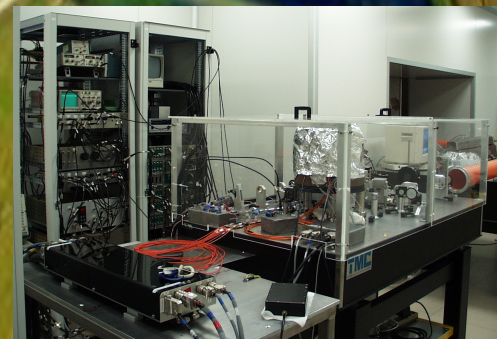
Παγκόσμιο δίκτυο ανιχνευτών



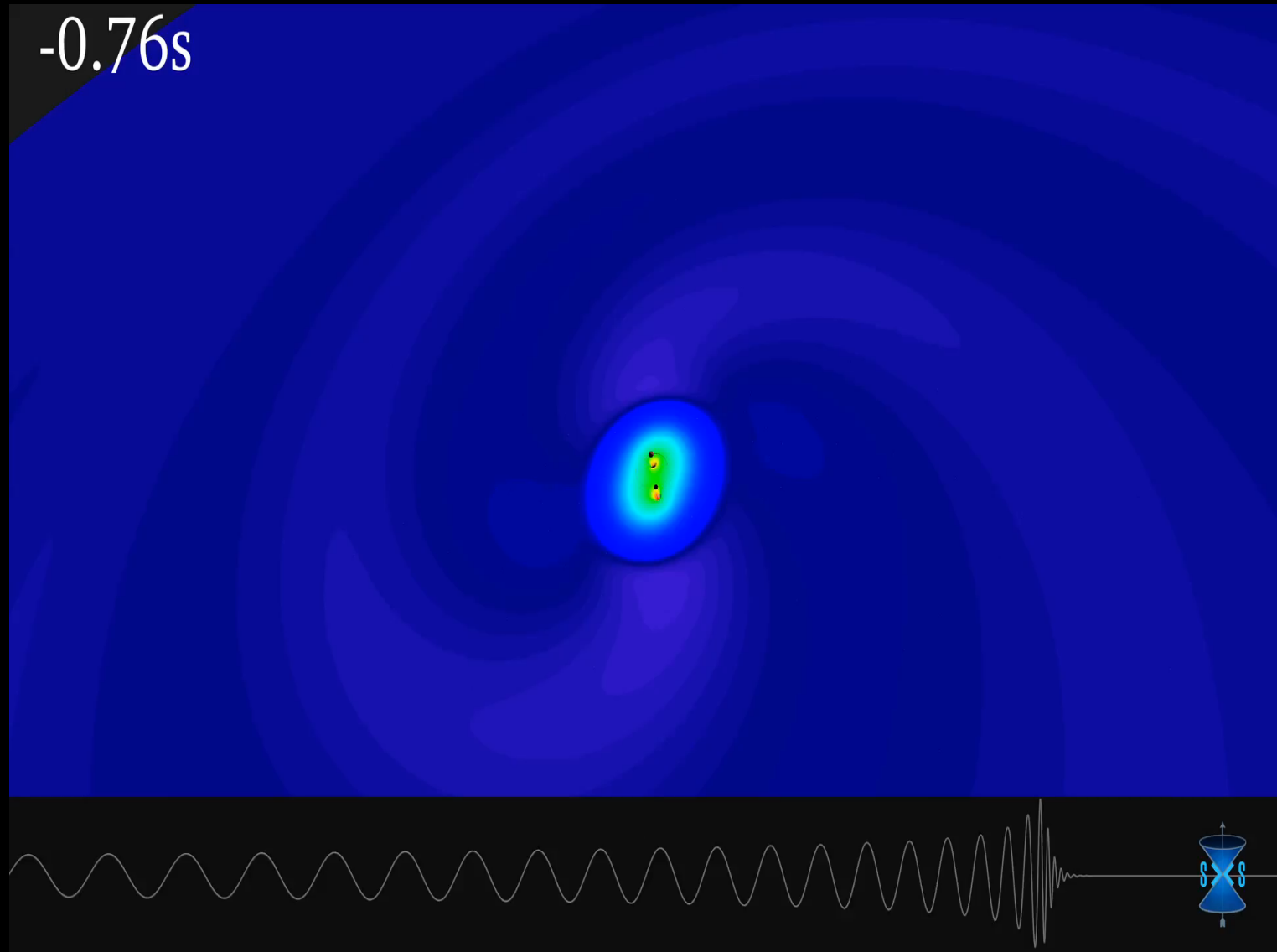
Εκπληκτική τεχνολογία



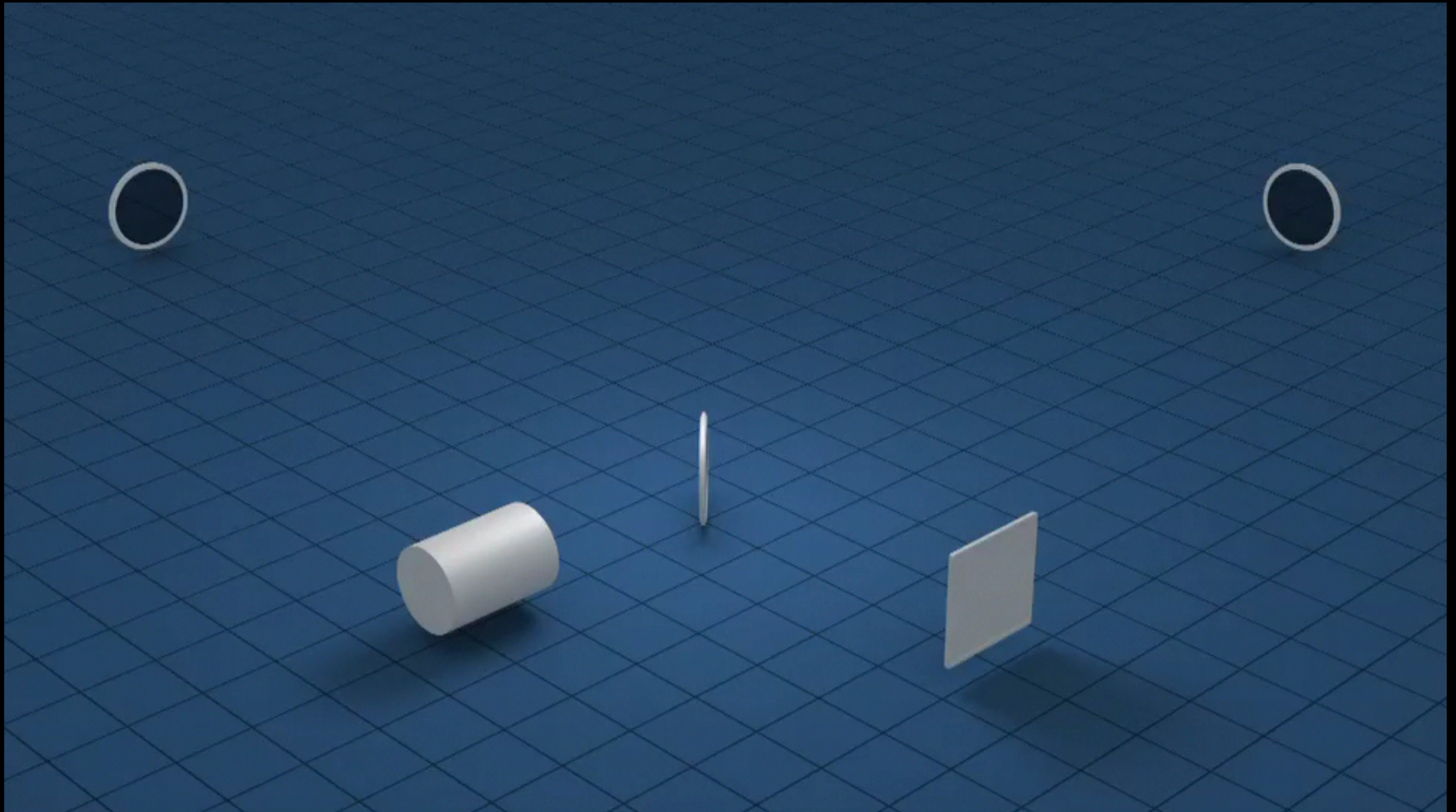
Ανίχνευση μιας αλλαγής 10^{-18} m
H το 1/1000 της διαμέτρου ενός πρωτονίου



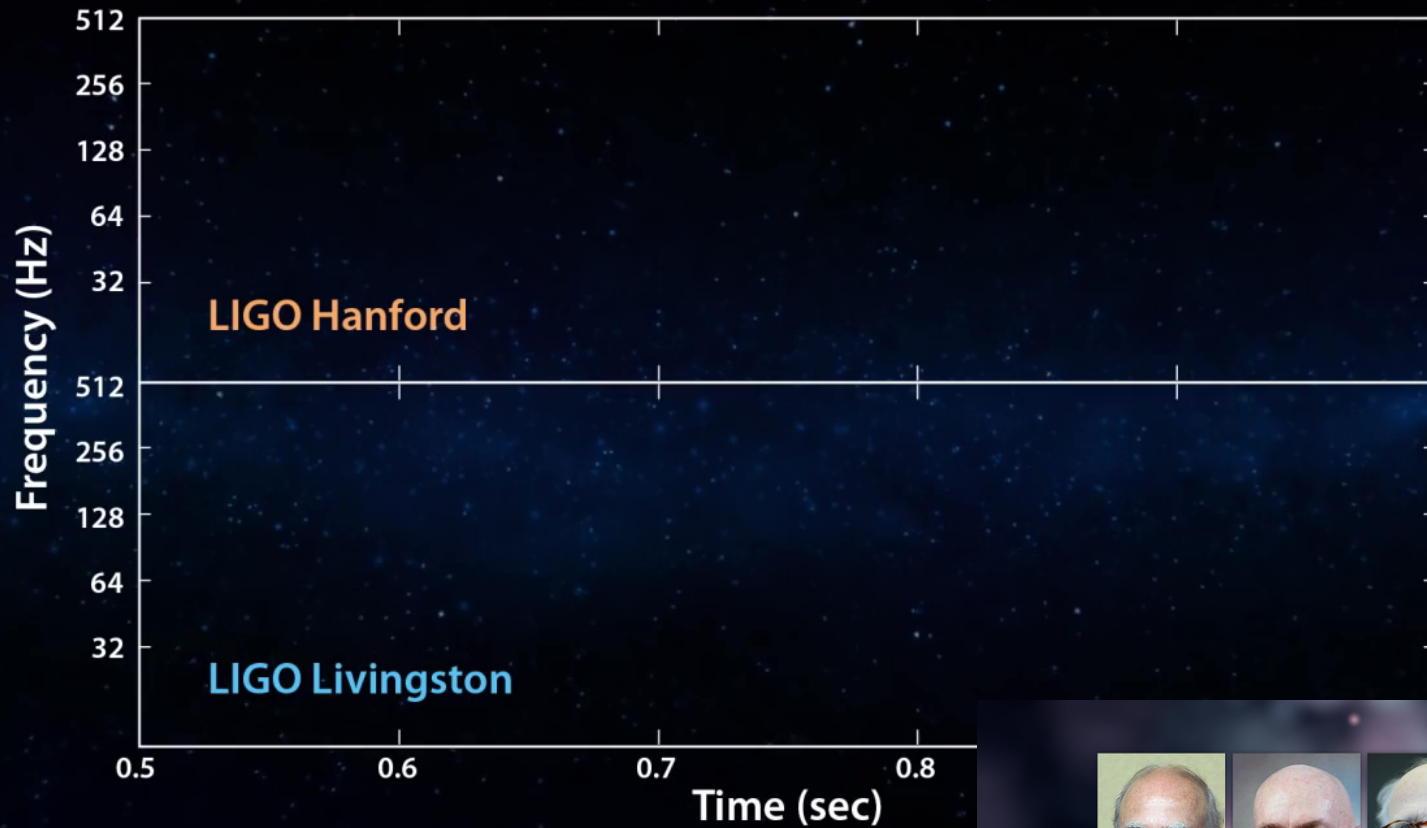
συγχωνευση μελανων οπων



Μεθοδος ανιχνευσης



14 Septembre 2015 LIGO: ο ηχος της συγχωνευσης δυο μελανων ΟΠΩΝ

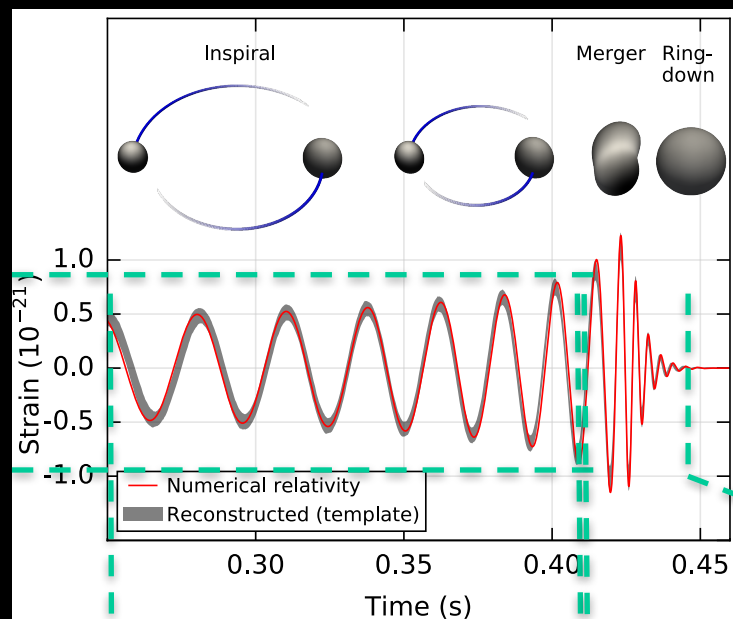


2017 Nobel Prize in Physics



Τι μας λει το σημα για την πηγη ;

Πλατος
Αποσταση
Γωνια αποκλισης



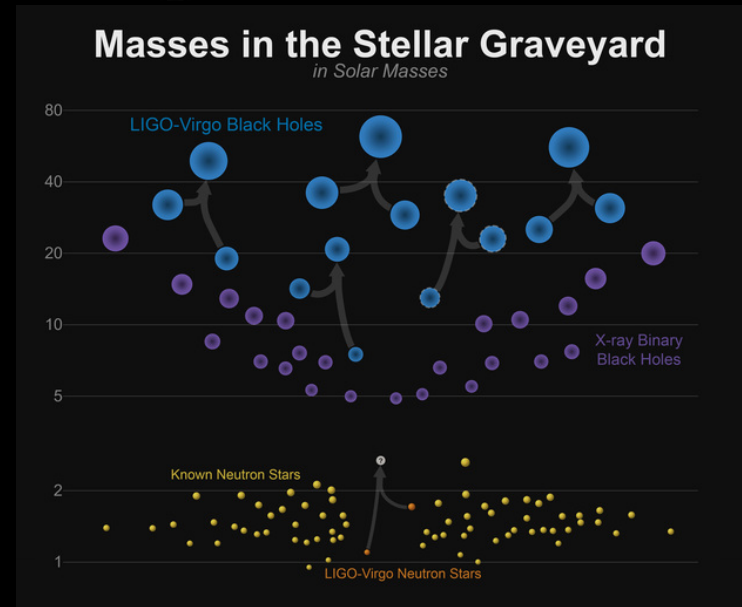
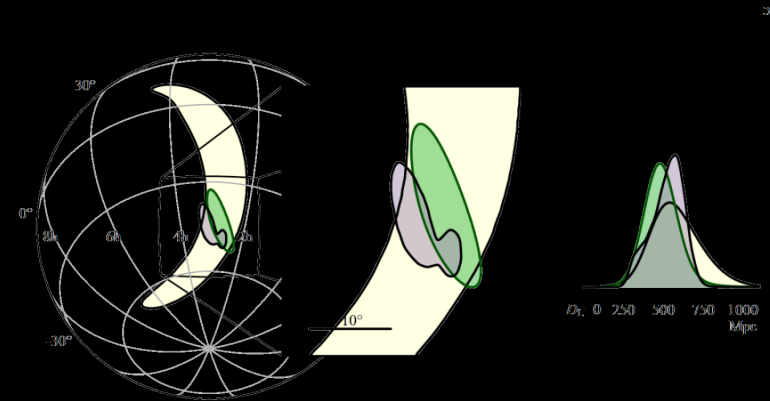
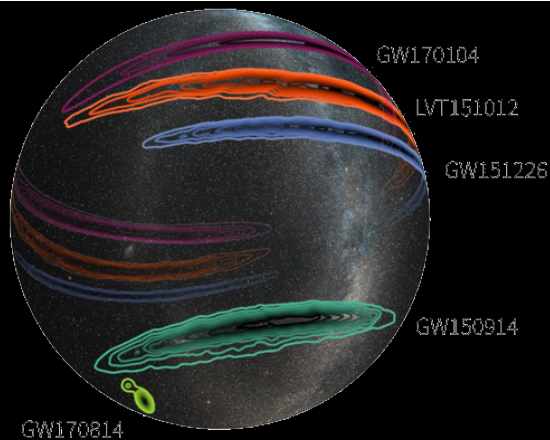
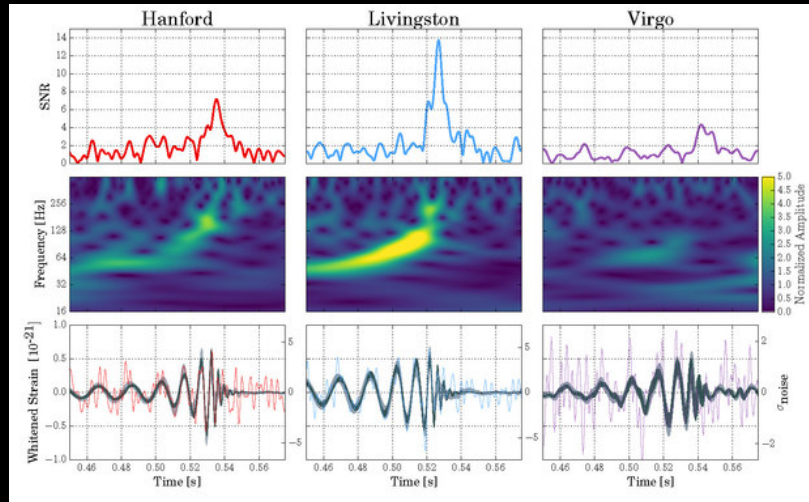
Εξελιξη
συχνοτητας

Chirp μαζα
Λογος μαζας
Αρχικο σπιν

Συχνοτητα και
χρονος αποσβεσης

Τελικη μαζα
Τελικο σπιν

14 Αυγούστου 2017 4^η συγχωνευση μελανων οπων Ταυτοχρονη ανιχνευση LIGO/VIRGO



Γιατι αυτες οι μεγαλες μαζες ; PBH (Αρχεγονες μαυρες
τρυπες; υποψηφιες για μερος της σκοτεινης υλης)

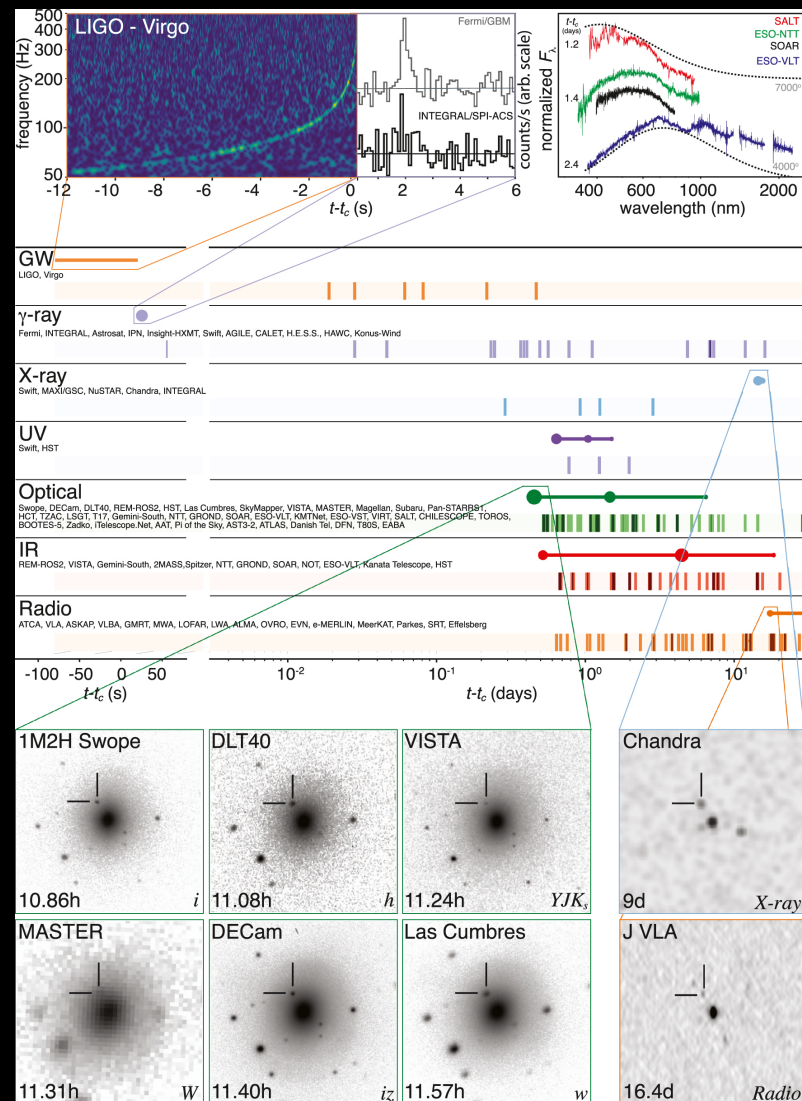
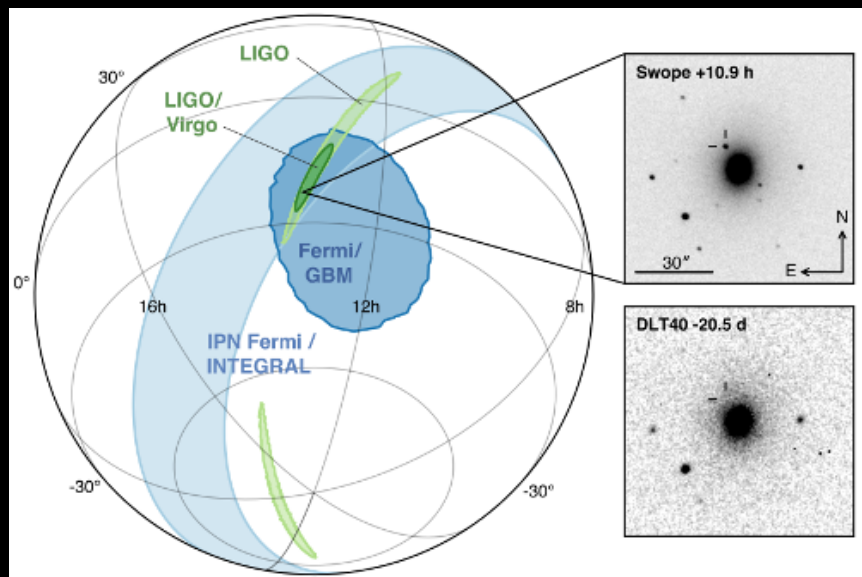
17 Αυγούστου 2017 1^η συγχωνευση αστερων νετρονιων
Ταυτοχρονη ανιχνευση LIGO/VIRGO
και 70 παρατηρητηρια στη γη και το διαστημα σε ολο το κοσμο

<https://youtu.be/e7LcmWiclOs>

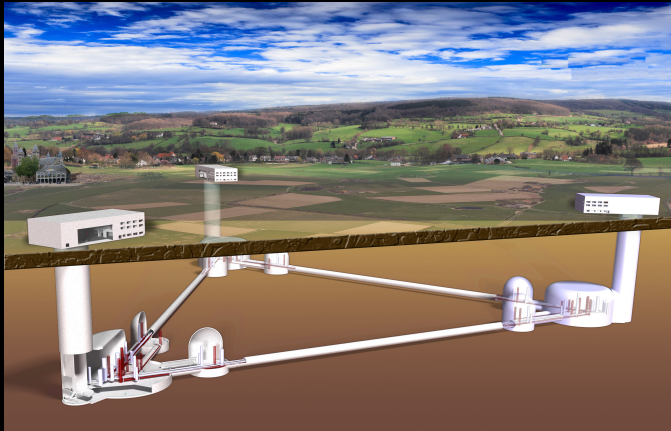
17 Αυγούστου 2017 1^η συγχωνευση αστερων νετρονιων

Ταυτοχρονη ανιχνευση LIGO/VIRGO

και 70 παρατηρητηρια στη γη και το διαστημα σε ολο το κοσμο

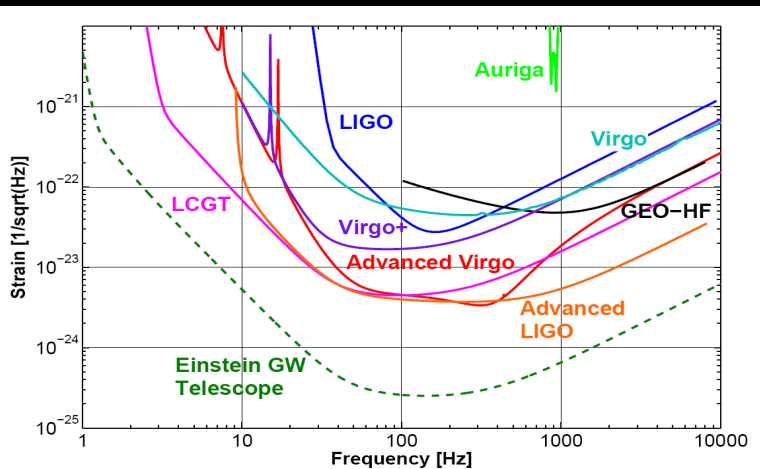
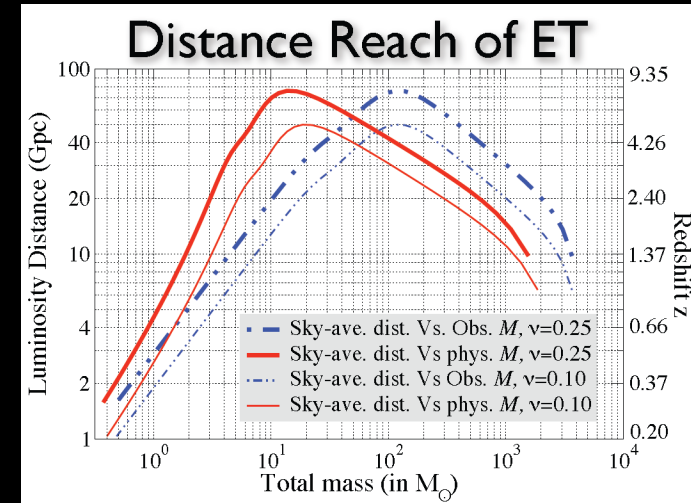


Longer term future on ground Einstein Telescope (ET)

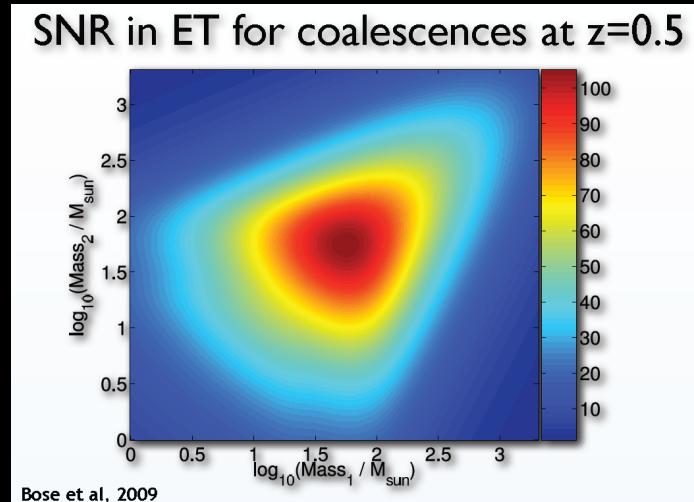


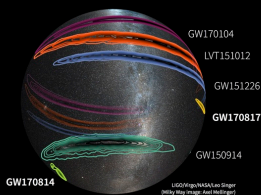
ET will observe binary systems of massive stars:

At cosmological detection distance



Frequently, with high SNR

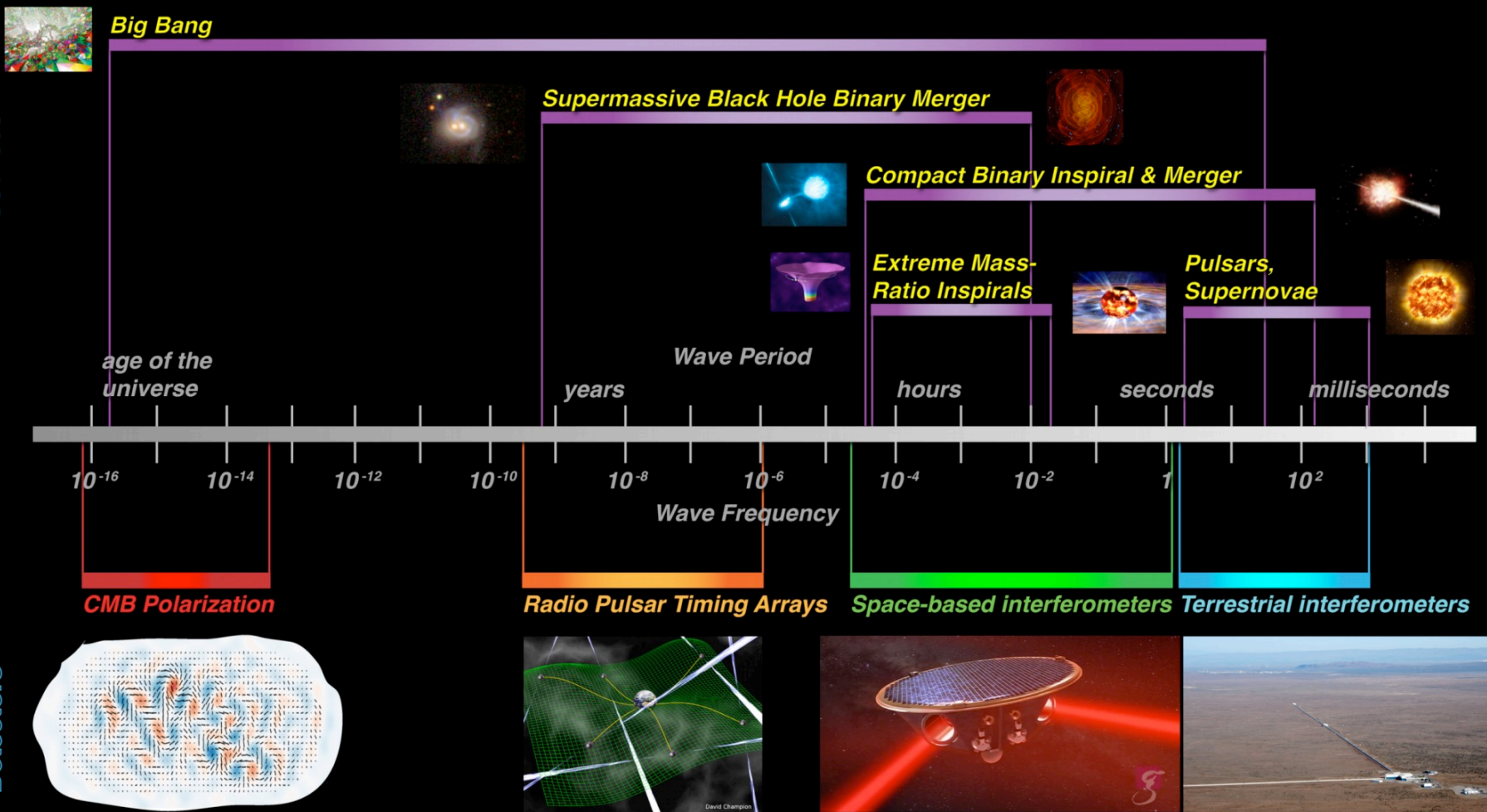




Gravitational Waves

Ground-Space complementarity

The Gravitational Wave Spectrum



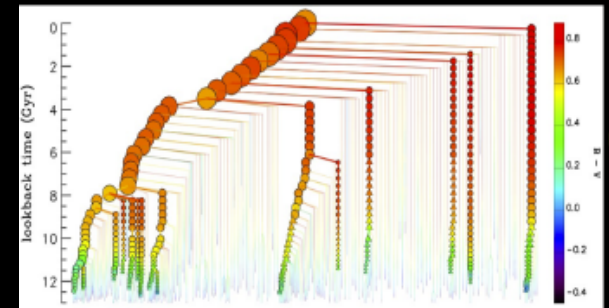
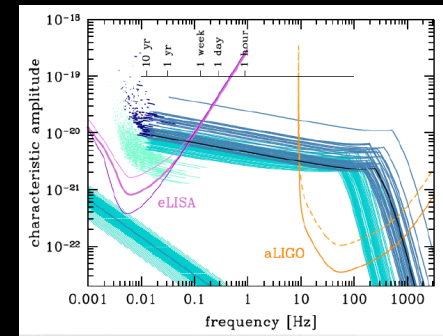
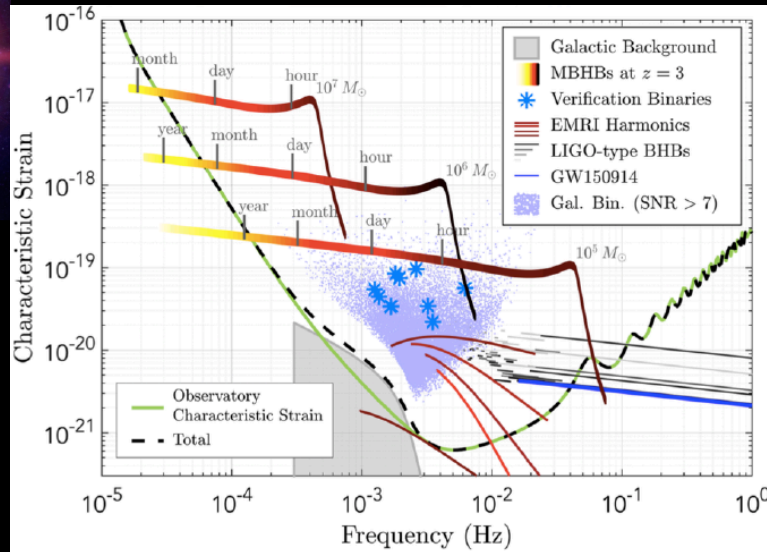
LISA

advVIRGO



Longer term future in space

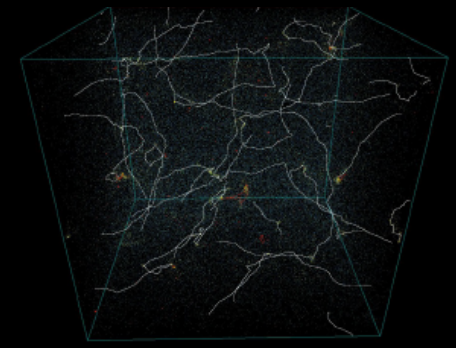
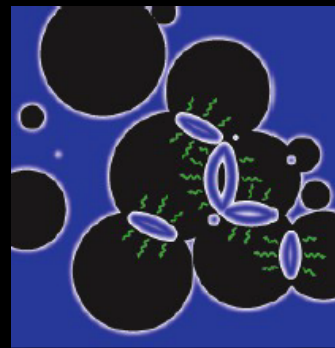
LISA



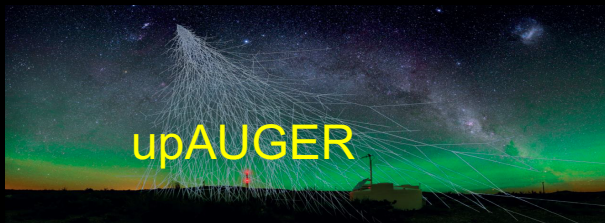
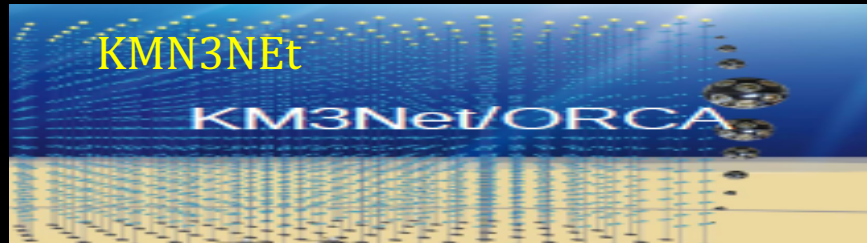
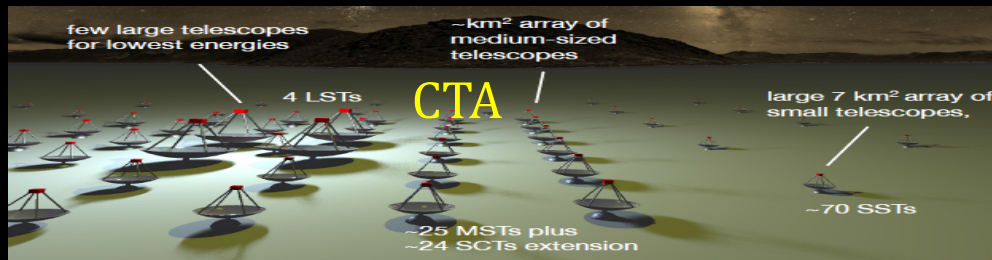
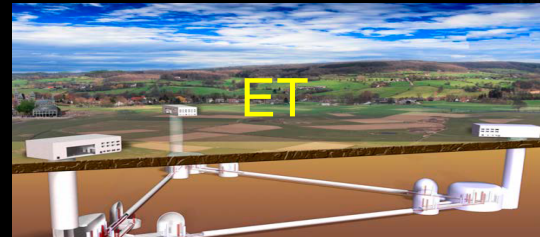
From De Lucia et al 2006

LISA (ESA L3: 2034)

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



Multi-messenger Universe



Large-scale multi-messenger infrastructures

To improve understanding of our Universe, APPEC identified as a very high priority those research infrastructures that exploit all confirmed high-energy 'messengers' (cosmic particles that can provide vital insights into the Universe and how it functions). These messengers include gamma rays, neutrinos, cosmic rays and gravitational waves. European coordination is essential to ensuring timely implementation of such infrastructures and enabling Europe to retain its scientific leadership in this field.

UHECR R&D ground + Space

2018

2020

2022

2024

2026

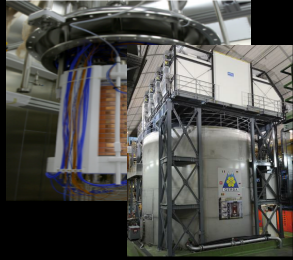
2030

2032

2034

2036

Mesure of the Universe (Cosmology, DM, neutrinos)



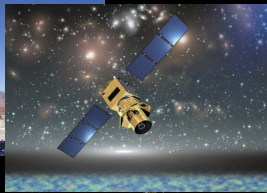
Roadmap for underground science
multiton DM and ton scale DBD ca
2019-2020

Medium-scale Dark Matter and neutrino experiments

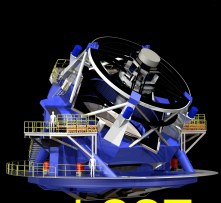
APPEC considers as its core assets the diverse, often ultra-precise and invariably ingenious suite of medium-scale laboratory experiments targeted at the discovery of extremely rare processes. These include experiments to detect the scattering of Dark Matter particles and neutrinoless double-beta decay, and direct measurement of neutrino mass using single-beta decay. Collectively, these searches must be pursued to the level of discovery, unless prevented by an irreducible background or an unrealistically high demand for capital investment.

Synergies with astronomy, particle physics and cosmology

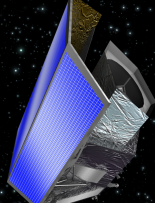
To shed light on neutrino mixing and the neutrino mass hierarchy, APPEC is a long-term proponent of experiments using natural neutrinos from the Sun and from Earth's atmosphere as well as neutrinos from nuclear reactors and accelerators. Recognising the increasingly interdisciplinary reach of astroparticle physics, APPEC has broadened the scope of its roadmap to include explicitly two topics referred to in its 2008 science vision: the CMB and Dark Energy. These are flourishing fields of research, as demonstrated by Nobel Prizes awarded in 2006 and 2011. They not only complement core astroparticle physics topics but also yield stringent constraints on neutrino masses and on the role of neutrinos in the early Universe. So far in these recommendations, the focus has been on projects primarily funded by European astroparticle physics agencies. By contrast, for the three topics addressed in this subsection, the main funding is likely to come from US and Asian agencies or from the European particle physics and astronomy communities.



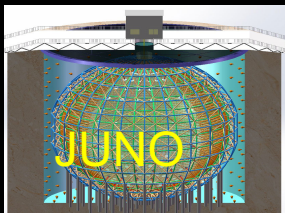
Roadmap for CMB on ground
and space ca 2019-2020



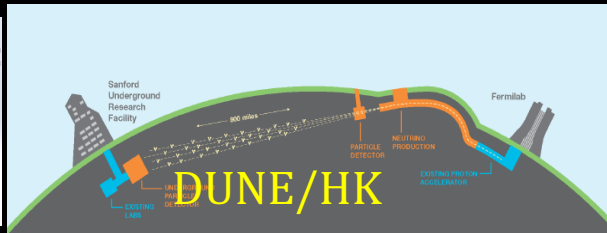
LSST



EUCLID



JUNO



DUNE/HK

2018

2020

2022

2024

2026

2030

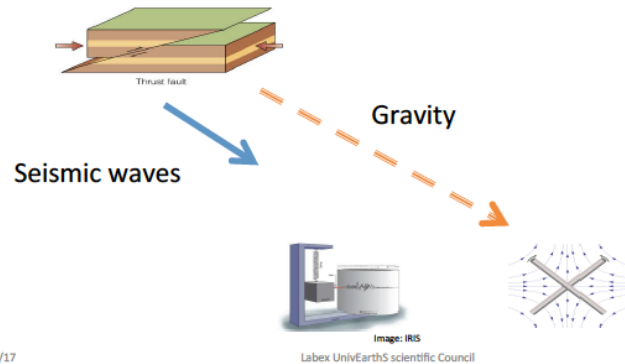
2032

2034

2036

Gravity-based early warning system

Rupture → seismic waves → mass displacement



09/11/17

10

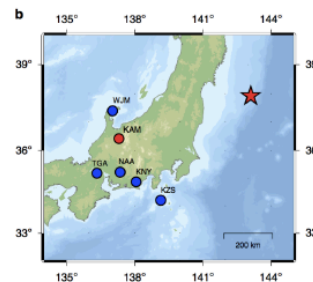
An application'

While gravitational waves change distances by 1/1000 of the diameter of a proton

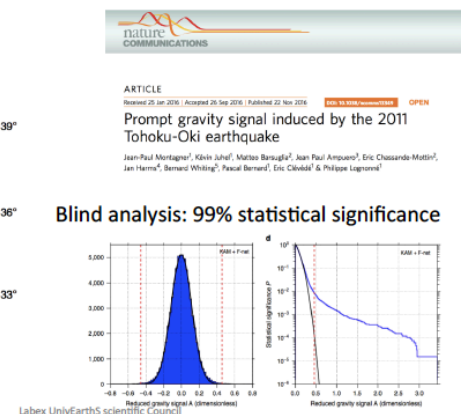
Seismic waves change distances much more

A gravity signal from the Tohoku-oki earthquake:

"First act"



09/11/17



12

2nd act: elastogravity signals

Science

Observations and modeling of the elastogravity signals preceding direct seismic waves

Martin Vallée, Jean Paul Ampuero, Kévin Juhel, Pascal Bernard, Jean-Paul Montagner and Matteo Barsuglia

Science 358 (6367), 1154-1158.
DOI: 10.1126/science.1230748

Gravity gets into the earthquake game

Earthquakes generate large movements of mass, which slightly change the gravity field. We show that gravity perturbations travel faster than seismic waves. We observed these gravity perturbations in seismometer records from the great 2011 Tohoku earthquake. This signal would have allowed an accurate magnitude estimation in minutes, not hours.

Science, this issue p. 1154

GEOPHYSICS

Observations and modeling of the elastogravity signals preceding direct seismic waves

Martin Vallée,^{1*} Jean Paul Ampuero,² Kévin Juhel,¹ Pascal Bernard,¹ Jean-Paul Montagner,¹ Matteo Barsuglia³

After an earthquake, the earliest deformation signals are not expected to be carried by the fastest (*P*) elastic waves but by the speed-of-light changes of the gravitational field. However, these perturbations are weak and, so far, their detection has not been accurate enough to fully understand their origins and to use them for a highly valuable rapid estimate of the earthquake magnitude. We show that gravity perturbations are particularly well observed with broadband seismometers at distances between 1000 and 2000 kilometers from the source of the 2011, moment magnitude 9.1, Tohoku earthquake. We can accurately model them by a new formalism, taking into account both the gravity changes and the gravity-induced motion. These prompt elastogravity signals open the window for minute time-scale magnitude determination for great earthquakes.

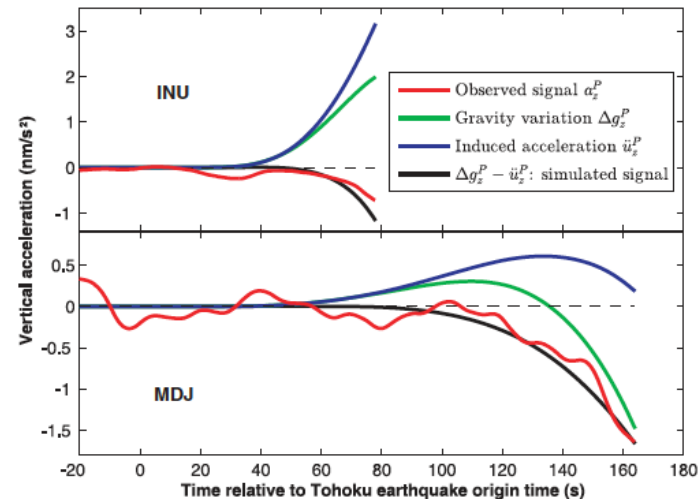
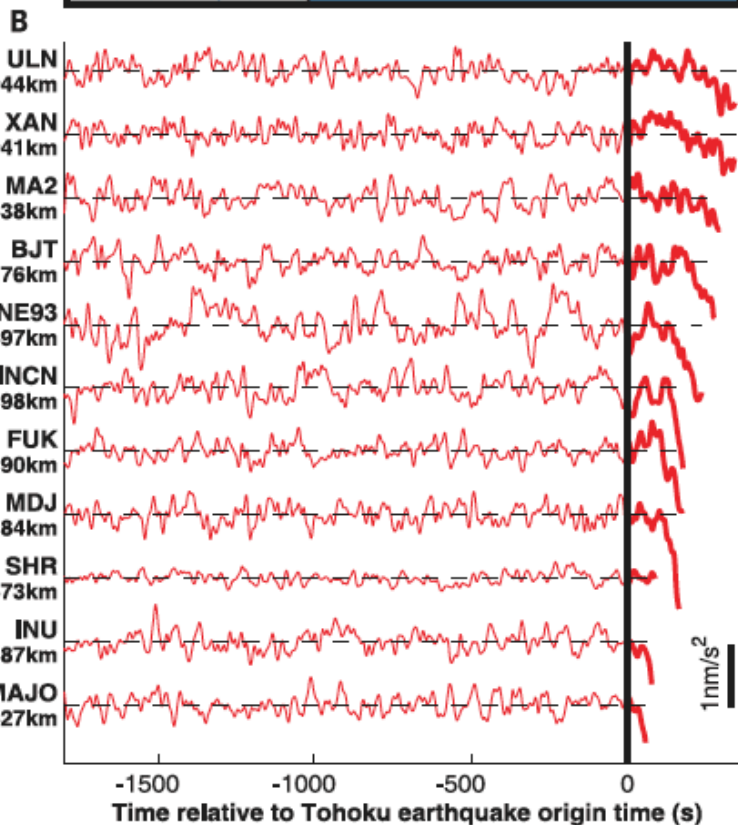


Fig. 2. Reconstruction of the observed elastogravity signals from the effects of the gravity variation and its induced acceleration. Examples at dose distances [INU (GEOSCOPE) station in Japan] and at optimal distances in terms of signal observability [MDJ (IRIS) station in northeast China] are shown. The induced acceleration $\ddot{u}_z^P$ cancels the gravity variation Δg_z^P at early times and can dominate (INU) or only affect (MDJ) Δg_z^P when approaching the P -wave arrival time.

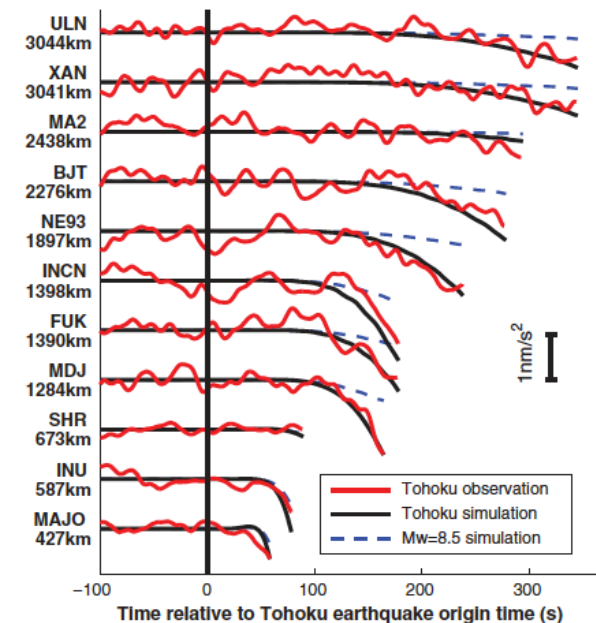


Fig. 3. Agreement between observed and modeled a_z^P signals and influence of the earthquake magnitude. Red (observed) and black (simulated) curves are in good agreement at all distances and azimuths from the Tohoku earthquake. The simulation for a fictitious $M_w = 8.5$ earthquake (dashed blue curve) shows large amplitude differences, directly illustrating the magnitude determination potential existing in these prompt elastogravity signals.

Tohoku analysis: lessons learned

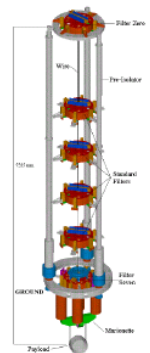
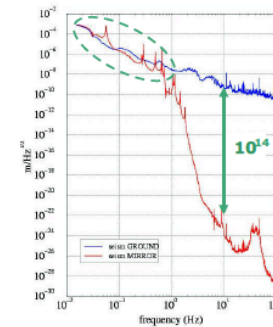
- Seismometers
 - Can detect gravity signals for $M=9$ in $>$ few tens of seconds
 - Signals limited by seismic noise
 - Important role of the gravity induced inertial acceleration in the modeling
- For Tohoku the gravity signal gives the magnitude before conventional system
- To detect $M<9$ in 5-10 seconds new instruments are necessary
 - strainmeters with seismically isolated test masses

A new method
is born

09/11/17

Labex UnivEarthS scientific Coun

Strainmeters with seismically isolated test masses



09/11/17

Labex UnivEarthS scientific Council

20

Εν κατακλειδι:

Ο Φωκιωνας μας διδαξε την
βασικη λειτουργια της
επιστημης:

Να ακολουθουμε πιστα τις
εμπνευσεις μας αλλα και
ειμαστε ετοιμοι να βρισκουμε
που εχουμε κανει το λαθος

Ευχαριστουμε Φωκιωνα
Χρονια πολλα και δημιουργικα

The Unreasonable Effectiveness of Hunting for Where One is Wrong:
How open-minded methods of science could help our societies tackle their difficult challenges

18/10/17
18h30
Amphi Chapsal
27 rue Saint Guillaume
75007 Paris

SciencesPo.
PARIS DIDEROT
U^{SPC}
Université Sorbonne
Paris Cité

2011 Nobel Laureate
Saul Perlmutter discusses
his ideas on Sense and
Sensibility and Science

Agree

Disagree

Undecided