Fifth International Workshop for the Design of the ANDES Underground Laboratory, Buenos Aires, Argentina, 29-30 June 2017

Astroparticle physics in underground labs:

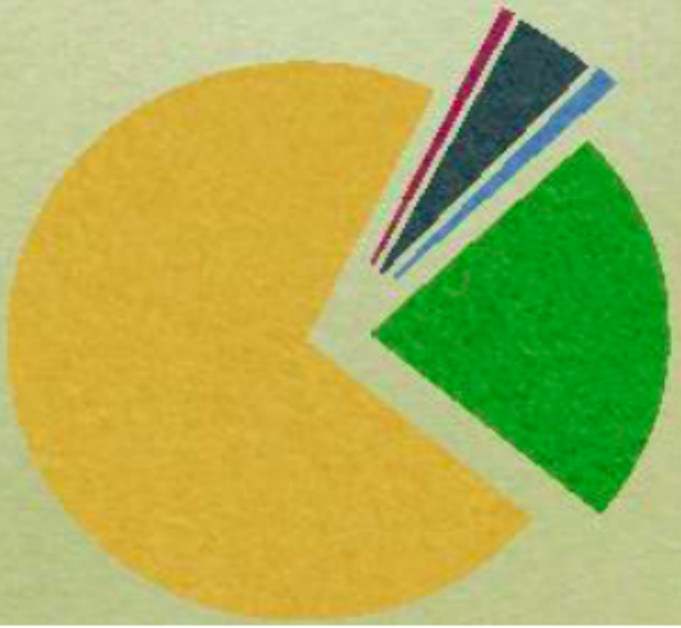
a survey and future needs

Antonio Masiero

INFN and Univ. of Padua

5 numbers, 5 indications of physics beyond the Standard Models of Particle Physics and Cosmology: **NEUTRINO MASSES**, **DM**, **DE**, **ANTIMATTER** AND **VACUUM ENERGY**

- *Stars and galaxies are only ~0.5%*
- *Neutrinos are ~0.1–1.5%*
- *Rest of ordinary matter (electrons, protons & neutrons) are 4.4%*
- *Dark Matter 23%*
- *Dark Energy 73%*
- *Anti-Matter 0%*
- *Higgs Bose-Einstein condensate ~10^{62}%??*



Courtesy of H. Murayama

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**.

… 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.); **ν mass hierarchy** (the race: see fig.); ν CP violation (new long baseline ν exps.); **ν masses** (direct exps., amazing input from cosmology)

… and a thrilling decade in front of us

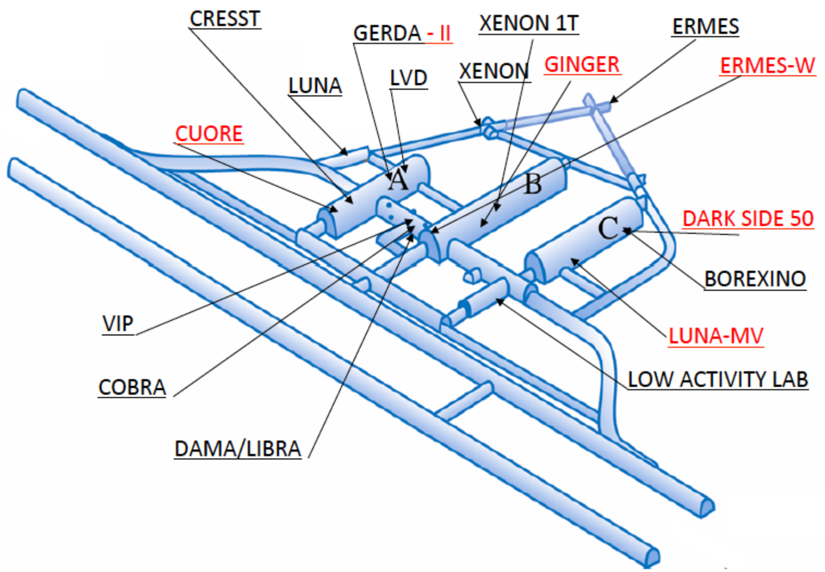
- **CMB** in the post-Planck (satellite) era → tremendous progress in ground, balloon and space exps.

- Shedding (an impressive amount of) light on the **dark side of the Universe**: **DM** → multi-ton exps. towards the ultimate ν 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

Underground labs: a quickly growing family

Underground activities in EU

LNGS Activities



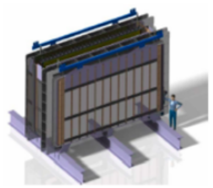
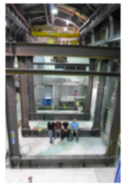
Stefano Ragazzi – INFN LNGS & UNIMIB

- GINGER
  - Ring-laser to probe Lense-Thirring effect
- Cosmic Silence
  - Study effect of very low radiation doses on cells, fleas, …
  - Test Linear No Threshold model
- ERMES-W
  - Primary resources, global geodynamic…
- VIP
  - Test Pauli Exclusion Principle

Modane Underground Laboratory

Fundamental physics:

- Neutrino: double beta decay (SuperNEMO), EcHo (ν mass)
- Dark matter (EDELWEISS, LUMINEU, SEDINE, MIMAC)
- Nuclear structure (TGV, SHIN)
- General Relativity test with Optical atomic clock

SupernEMO demonstrator installation in progress

Multidisciplinary activities

- Ultra low radioactivity measurements
  Environmental sciences, applications, expertises
- Logical test failures in nano/micro-électronics
- Biology

LSC Experiments

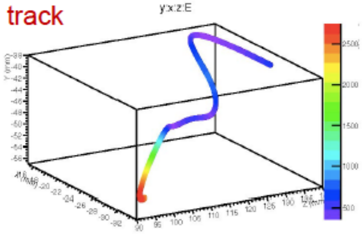
- Experiments under construction

✓ ANAIS	DM (NaI, Annual modul.)
✓ ROSEBUD	DM (Scintill. bolometers)
✓ ArDM	DM (2phase Ar TPC) 800 kg
✓ NEXT	$0\nu2\beta$ (Enr ^{136}Xe gas TPC)
✓ BiPo	$0\nu2\beta$ (screening for S-NEMO)
✓ SuperK-Gd	screening for Super-K-Gd
✓ **GEODYN**	**Geodynamics**

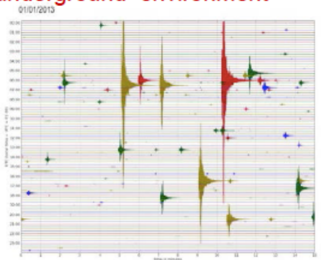
-Expressions of Interest

✓ CUNA	Nuclear astrophysics ✓New 300 m² facility in project
✓ **GOLLUM**	**Characterising subterranean bacterial**

NEXT prototype. Cs electron track



GEODYN small magnitude aftershocks, in low background underground environment



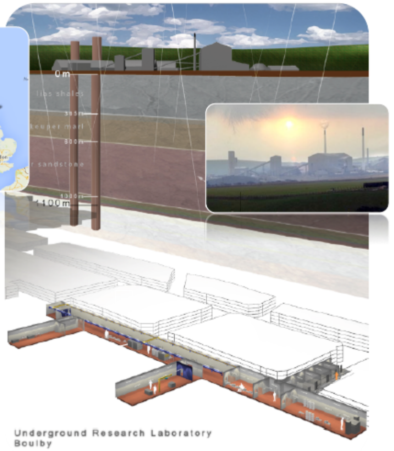
Stefano Ragazzi – INFN LNGS & UNIMIB

Boulby Underground Laboratory

The UK's deep underground science facility operating in a working potash and salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL



Boulby Palmer lab. >800m² floor space. Operating since 2001

S.M.Paling - Boulby@stfc.ac.uk

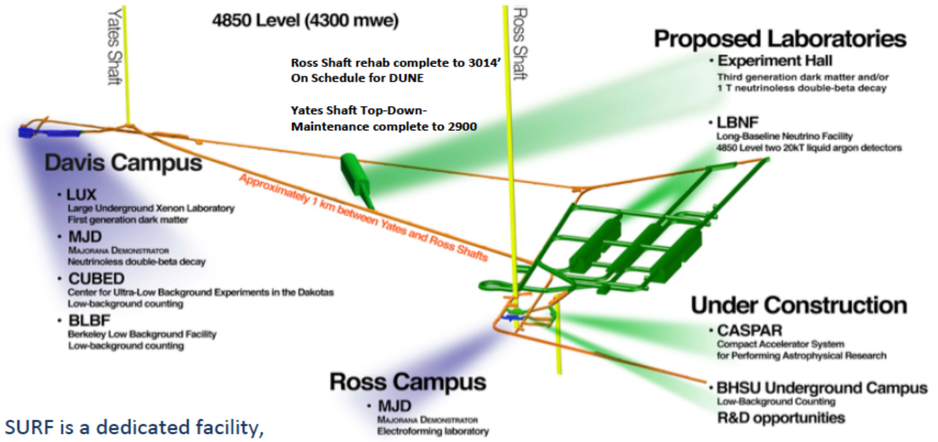
Underground activities in the US and Canada

Current Science Program

SNOLAB

Experiment	Neutrino	Dark Matter	Other	Space Allocated	Satus
CEMI			Mining Data Centre	Surface Facility	In Construction
COUPP-4		X		J-Drift	Completed
DAMIC		X		J-Drift	Operational
DEAP-1		X		J-Drift	Completed
DEAP-3600		X		Cube Hall	In Construction
DEAP- 50T/CLEAN		X		Cube Hall	Expression of Interest
DMTPC		X		Ladder Labs	Expression of Interest
Ge-1T	X			Cryopit	Expression of Interest
nEXO	X			Cryopit	Feasibility Phase
HALO	X			HALO Stub	Operational
MiniCLEAN		X		Cube Hall	In Construction
NEWS		X		Cryopit?	Expression of Interest
PICASSO-III		X		Ladder Labs	Completed
PICO-2L		X		J-Drift	Operational
PICO-60		X		Ladder Labs	Operational
PICO-250		X		Ladder Labs	Expression of Interest
PINGU			Test Facility	Ladder Labs	Expression of Interest
PUPS			Seismicity	Various	Completed
SNO+	X			SNO Cavern	In Construction
SuperCDMS		X		Ladder Labs	In Preparation
U-Laurentian			Genomics	External Drifts	Operational

SURF 4850L Physics Laboratories



SURF is a dedicated facility, created originally with the support of the NSF, UCB, South Dakota, and Private Donations and since 2010 supported by the DOE-HEP and continued exceptional strong support by South Dakota

Heise, AIP Conf. Proc. **1604** 331 (2014); also arXiv:1401.0861v1 (2014)
Lesko, Euro Phys J Plus **127**, 107 (2012)

Sanford Underground Research Facility

- Site is well characterized and science programs functioning smoothly in the facility
  - LUX – Dark Matter – well into 300 day long run
  - MAJORANA DEMONSTRATOR – $0\nu\beta\beta$ preparing for first physics runs
  - BioGeoEng on going investigations
- Expansions to accommodate additional science progressing well
  - CAM @ BHUC (Low Background Assay) near Ross (2015) - outfitting
  - Caspar Nuclear Astrophysics near Ross (2015) – installation begun
  - LZ G2 Dark Matter in the Davis Campus (2017) – preparing CD2
  - LBNF/DUNE on the 4850L near Ross Shaft (2017) – completed CD1R
- Additional space available on the surface and underground for other experiments and collaborations

…and in Asia

Current Experiments in Kamioka

Center for Gravitational Wave (Op. by Univ. of Tokyo)

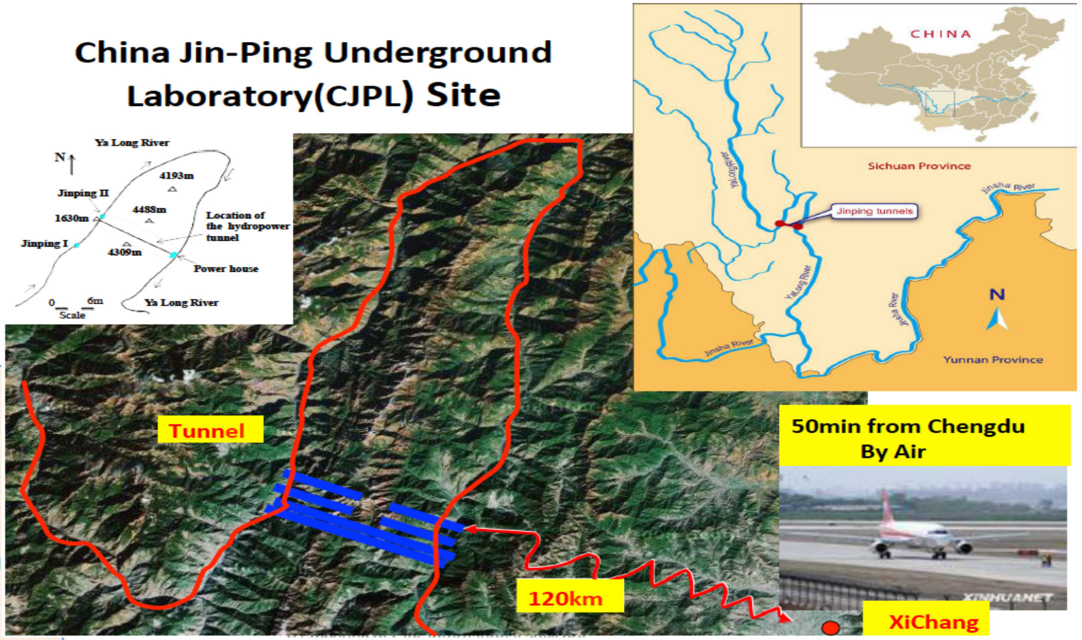
- KAGRA (Large Cryogenic Gravitational-wave Telescope)
  - **Under construction.**
  - Commissioning will start in 2015.
  - Cryogenic run from 2017.

Neutrino Science Center (Op by Tohoku Univ.)

- KamLAND
- KamLAND-ZEN (double beta decay of ^{136}Xe)
- **Increasing Xe136 content**

Kamioka Observatory (Op. by Univ. of Tokyo)

- Super-Kamiokande
  - Precise oscillation studies by atmosph and solar neutrinos.
  - Evidence for ν_e appearance (T2K)
  - **June 2015 - Dissolve 0.1% Gd for anti-neutrino physics in future.**
- XMASS (Dark Matter: liq. Xenon)
  - 1st phase detector completed
  - **Improvement of the detector**
- CANDLES (Double beta)
  - Detector completed
  - Commissioning
- NewAGE (Dark Matter)
  - Directionality
- CLIO (prototype of KAGRA)
- Geo-physics
  - Laser strain meter
  - Superconductive gravity meter



CJPL-II possible users

- CDEX-1T (Ge DM+DBD Exp.)
- PandaX-1T (Xe DM Exp.)
- LAr DM experiment led by IHEP
- Nuclear astroparticle physics-JUNA
- Solar neutrino experiment
- ……

Masayuki Nakahata Aug 2015

What are underground labs aiming at

- ***Basic research***: **dark matter, neutrino physics** (neutrino-less double beta decay, solar and atmospheric neutrinos), **nuclear astrophysics**, **precision tests of general Relativity, fundamental properties of Quantum Mechanics**

- ***Interdisciplinary research***: **geophysics** (geo-neutrinos, seismology), **environmental studies, life sciences, materials science**

AstroParticle Physics European Consortium

***APPEC GENERAL ASSEMBLY** of the presidents/directors of the agencies/institutions active in EU astroparticle physics*

+ CERN ESO ECFA observers

APPEC *functional centers*

APC - Paris/F
Roadmapping, Common Calls, Interdisciplinary

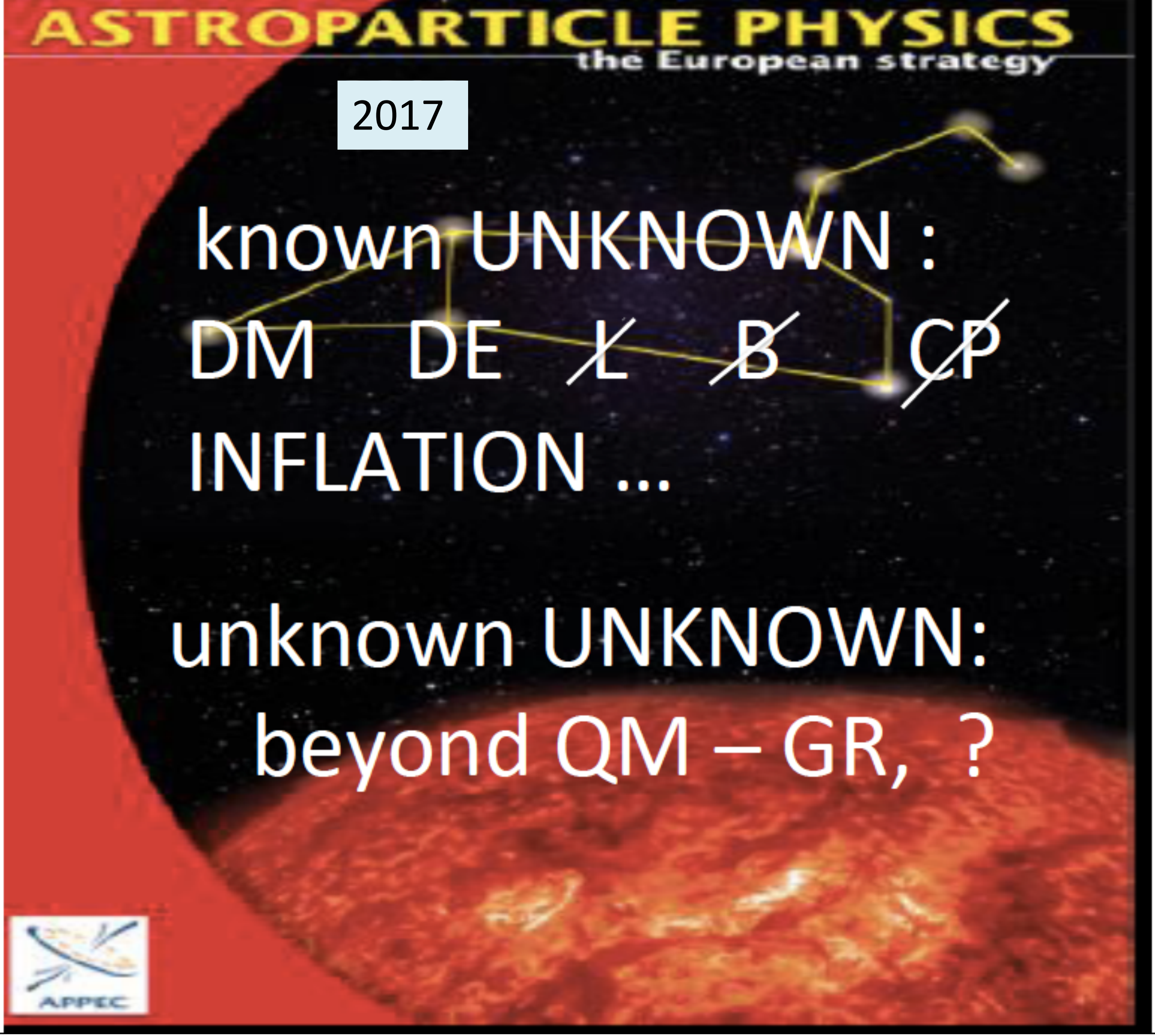
DESY - Hamburg/D
Management, Computing & Industry

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

Outreach, Web pages
STFC – Swindon/UK

Scientific
Advisory
Committee

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


ASTROPARTICLE PHYSICS
the European strategy
2017
known UNKNOWN :
DM DE $\not{L}$ $\not{B}$ $\not{CP}$
INFLATION …
unknown UNKNOWN:
beyond QM – GR, ?
APPEC

From the new APPEC roadmap recommendations

Underground Science: medium scale dark matter and neutrino experiments

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

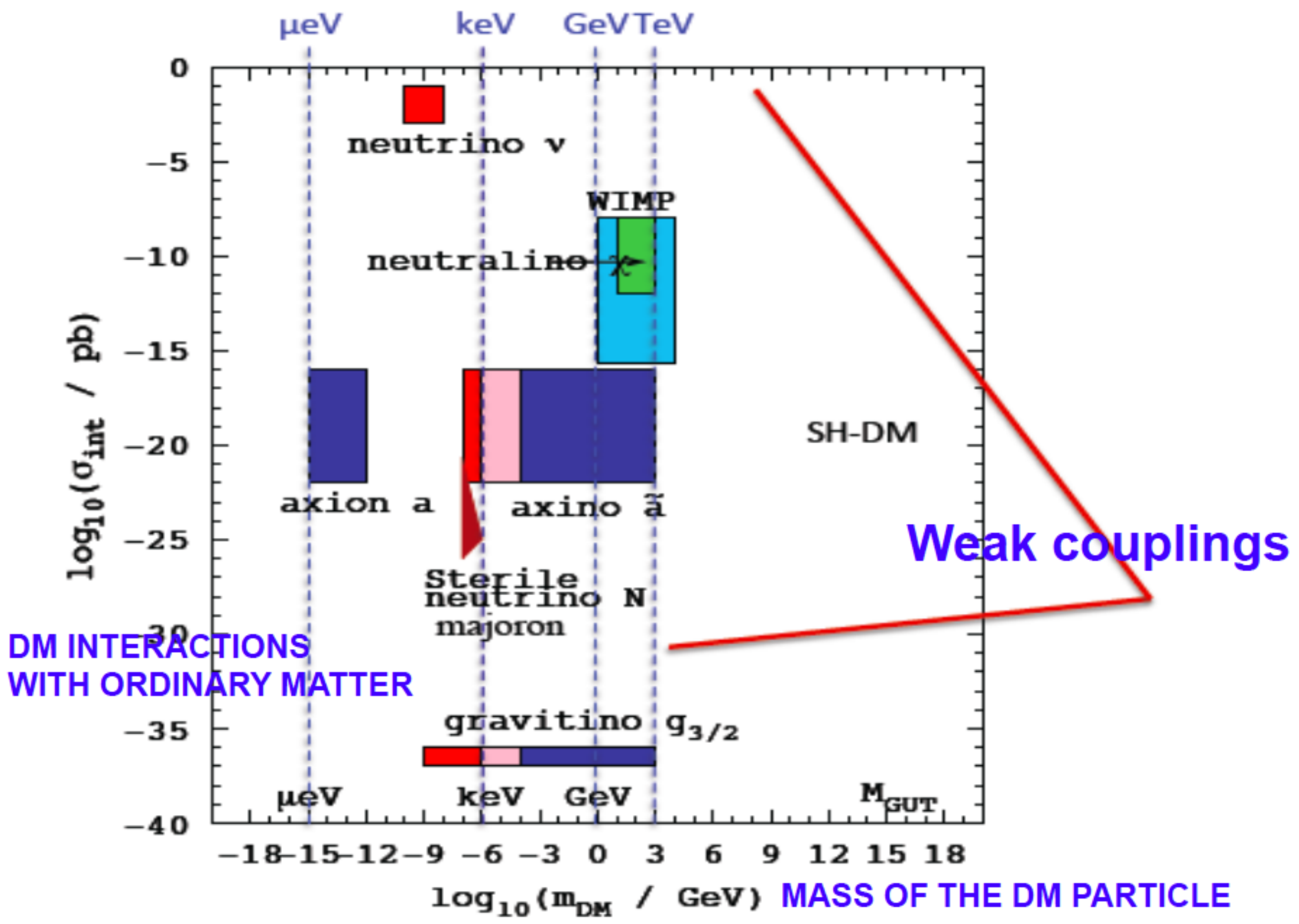
6. *APPEC strongly supports the present range of direct neutrino mass measurements and searches for neutrino-less double beta-decay. Guided by the results of running experiments and in consultation with its global partners, APPEC intends to converge on a roadmap for the next generation of neutrino mass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

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

TEN COMMANDMENTS TO BE A “GOOD” DM CANDIDATE

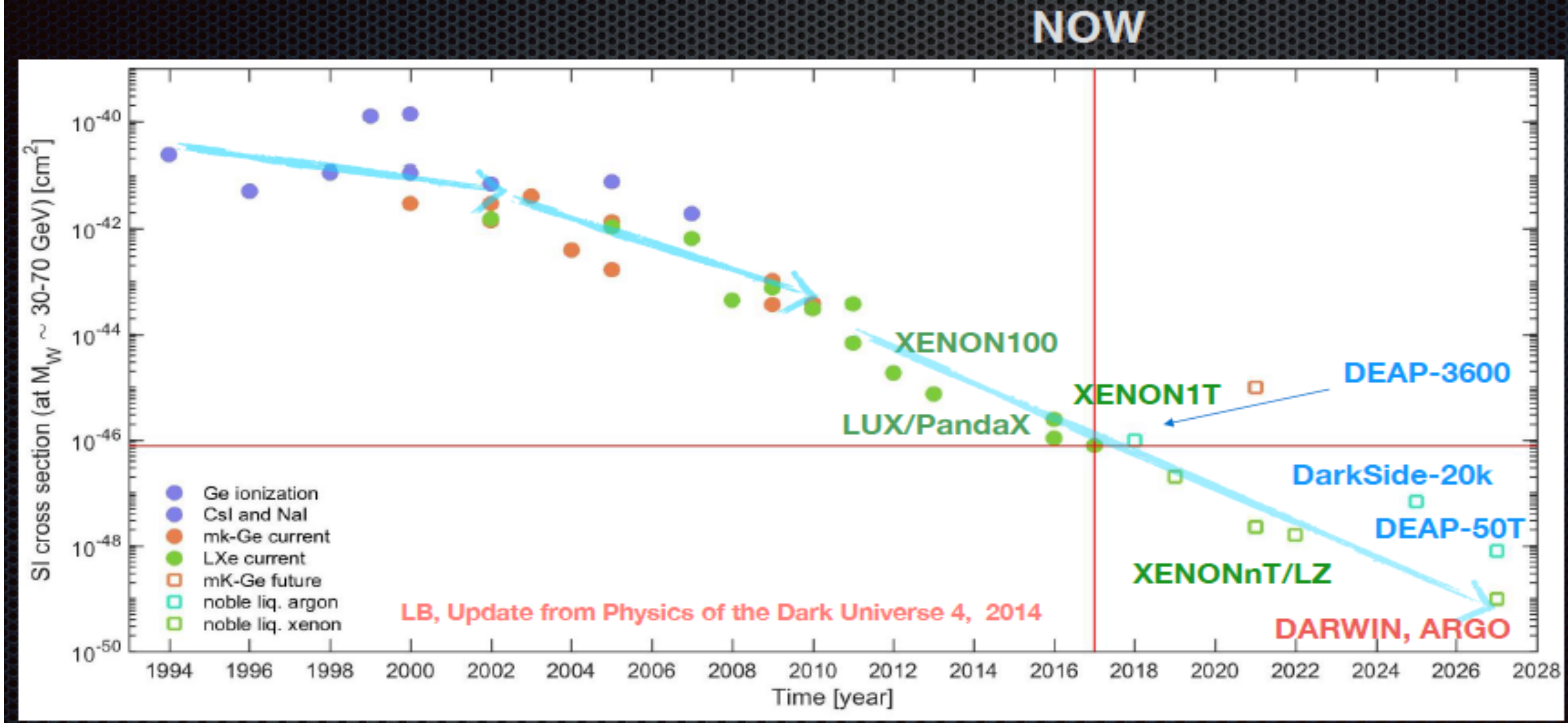
BERTONE, A.M., TAOSO

- TO MATCH THE APPROPRIATE RELIC DENSITY
- TO BE COLD
- TO BE NEUTRAL
- TO BE CONSISTENT WITH BBN
- TO LEAVE STELLAR EVOLUTION UNCHANGED
- TO BE COMPATIBLE WITH CONSTRAINTS ON SELF – INTERACTIONS
- TO BE CONSISTENT WITH DIRECT DM SEARCHES
- TO BE COMPATIBLE WITH GAMMA – RAY CONSTRAINTS
- TO BE COMPATIBLE WITH OTHER ASTROPHYSICAL BOUNDS
- “TO BE PROBED EXPERIMENTALLY”


μeV
keV
GeV
TeV
neutrino ν
WIMP
neutralino χ
SH-DM
axion a
axino ã
Weak couplings
Sterile neutrino N
majoron
DM INTERACTIONS
WITH ORDINARY MATTER
gravitino $g_{3/2}$
μeV
keV
GeV
M_{GUT}
$\log_{10}(\sigma_{int}$ / pb)
0
−5
−10
−15
−20
−25
−30
−35
−40
−18
−15
−12
−9
−6
−3
0
3
6
9
12
15
18
$\log_{10}(m_{DM}$ / GeV)
MASS OF THE DM PARTICLE

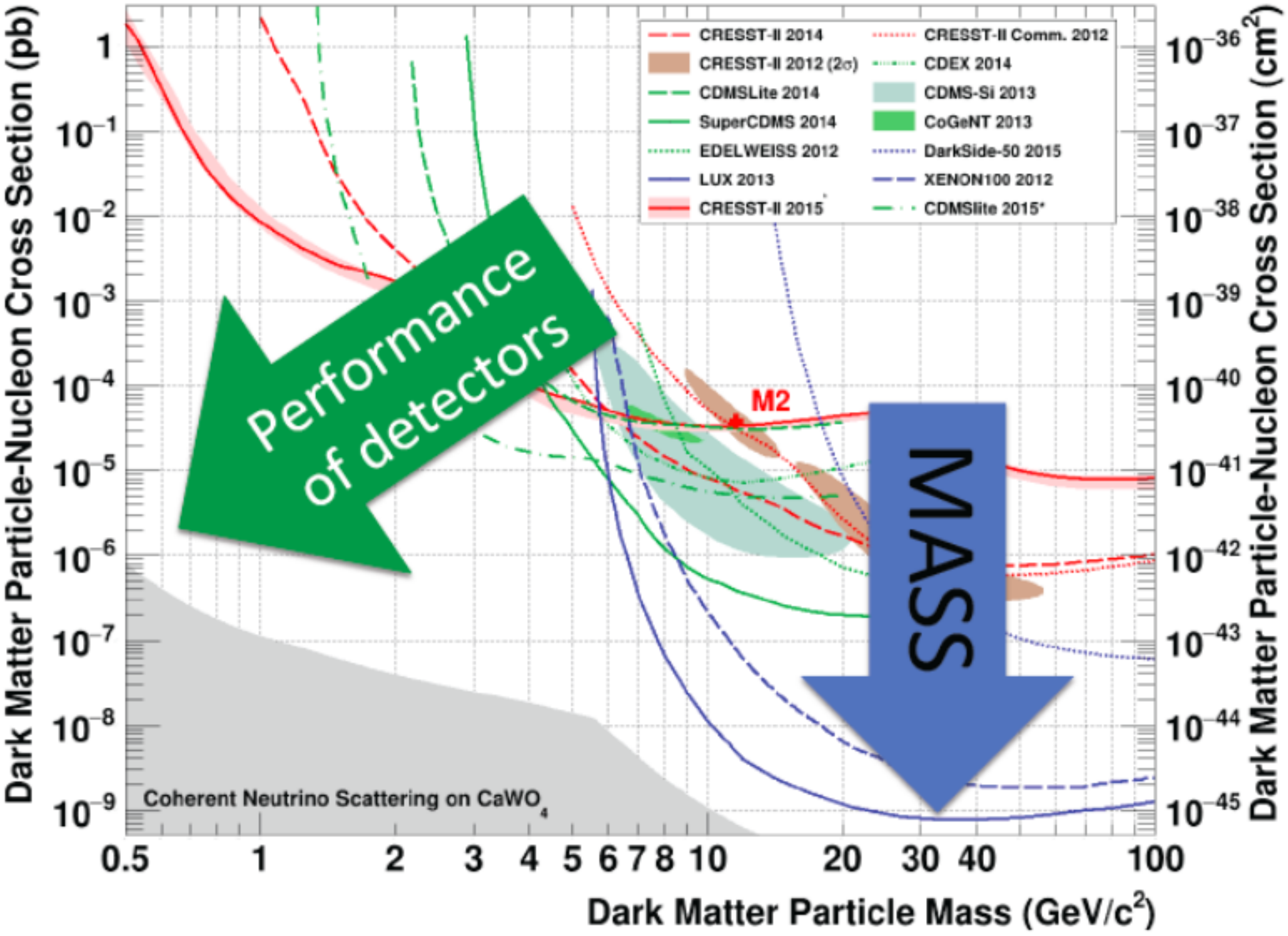
L. Baudis, Varenna 2017

Direct detection evolution

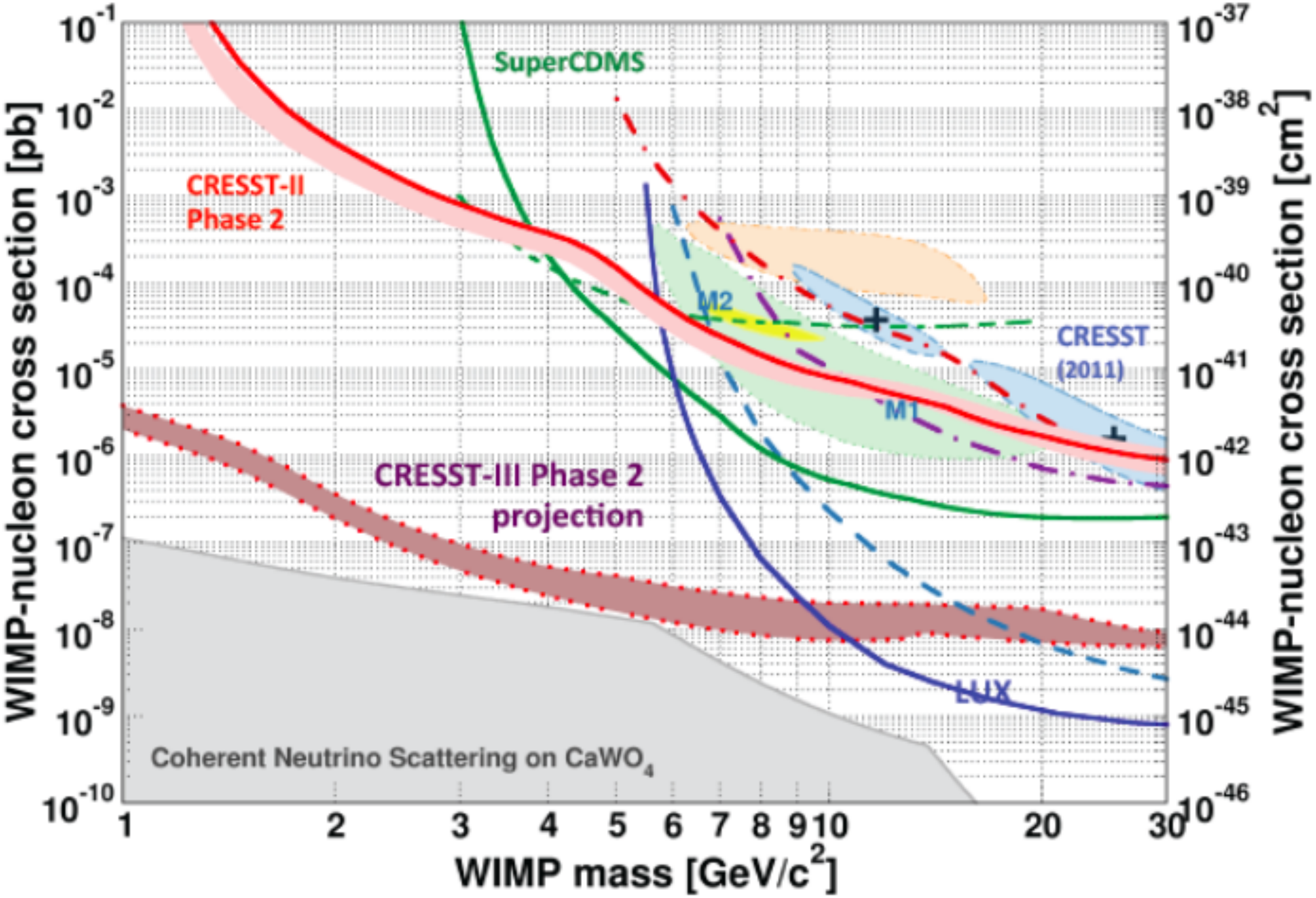


Constraints on the scattering cross section on nucleons

Future of Dark Matter Searches

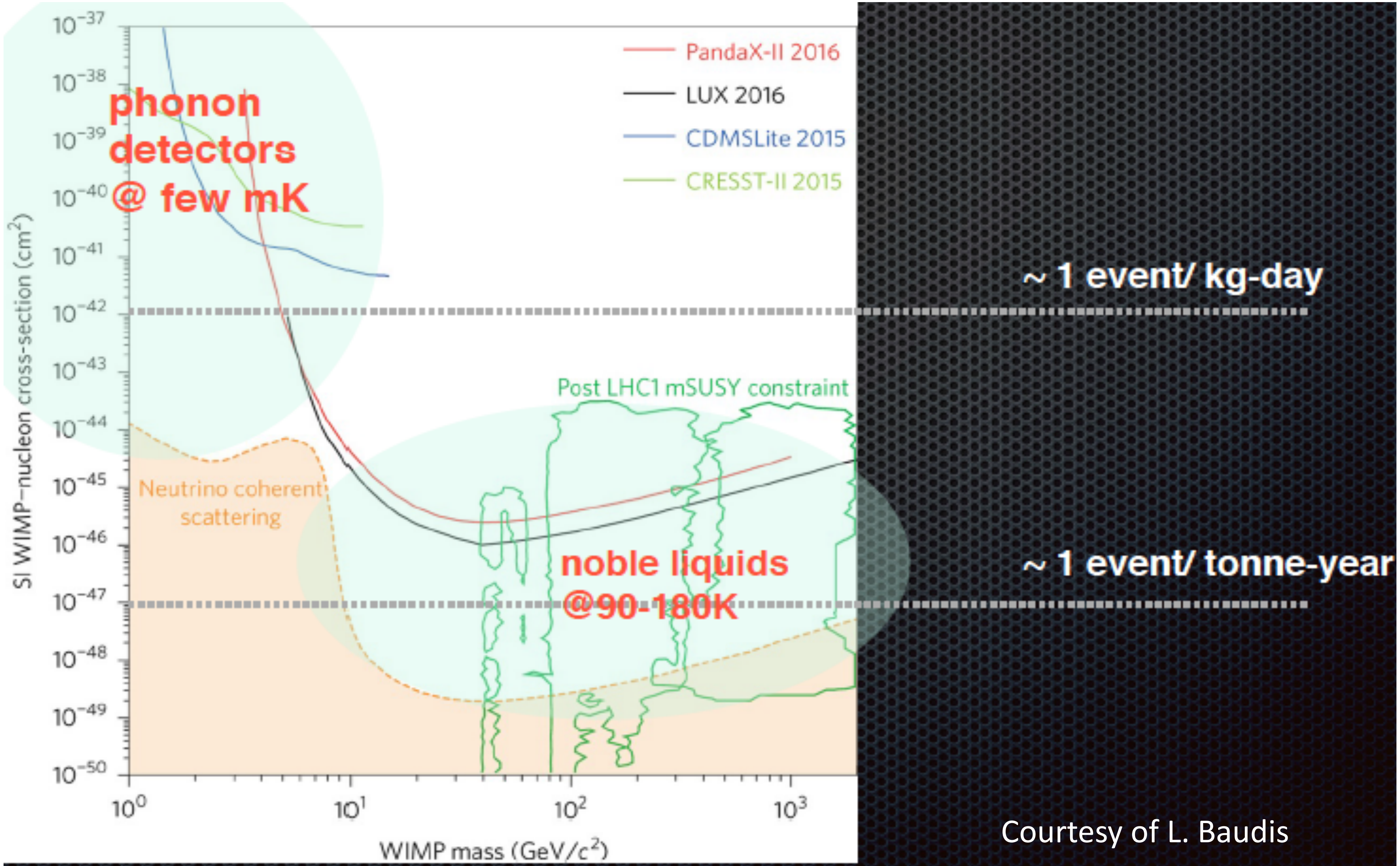


CRESST-III Phase 2



100 x 24g detectors of improved quality operated for 2 year ≈ 1000 kg-days (net)

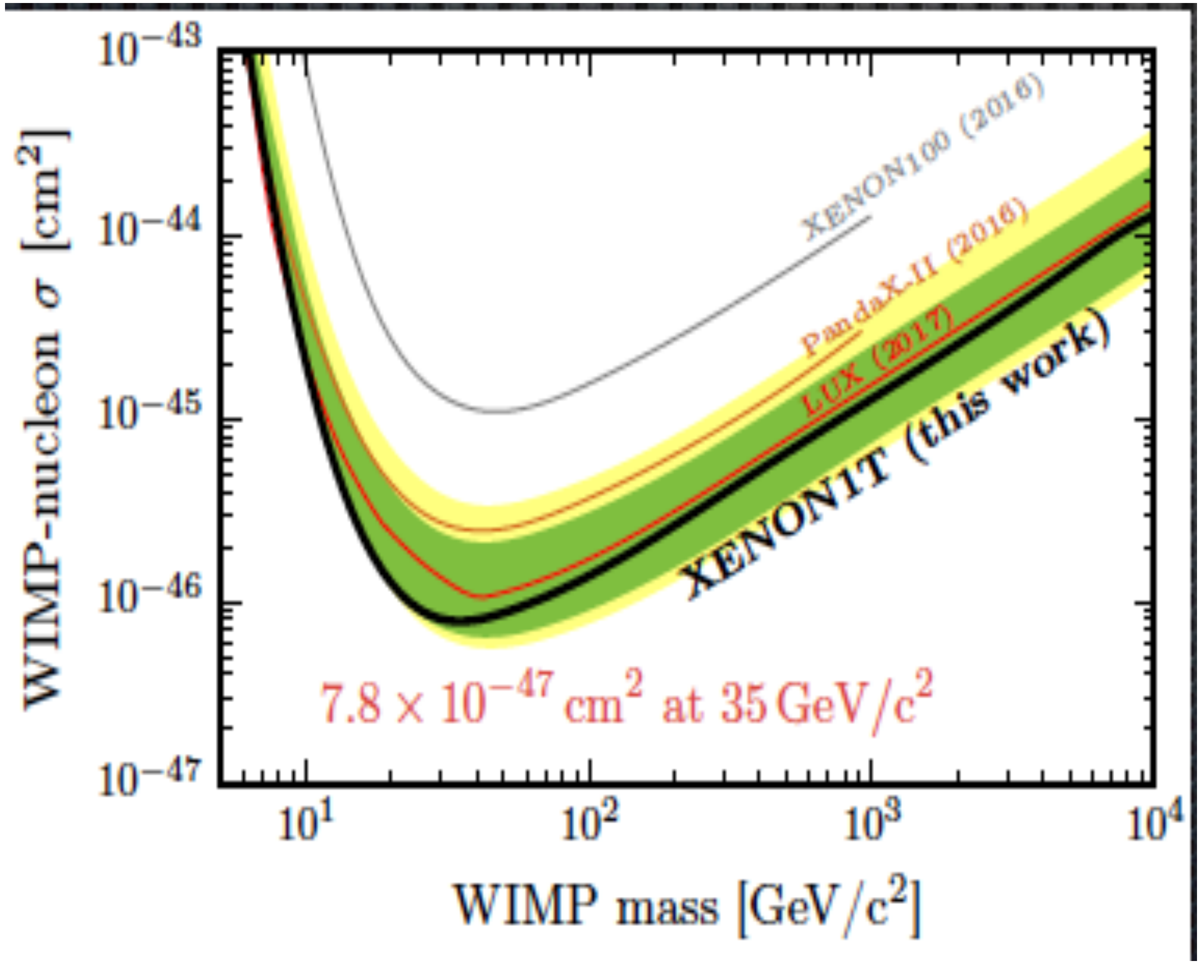
Updated status of GeV-10s of GeV WIMPS searches at May 2017

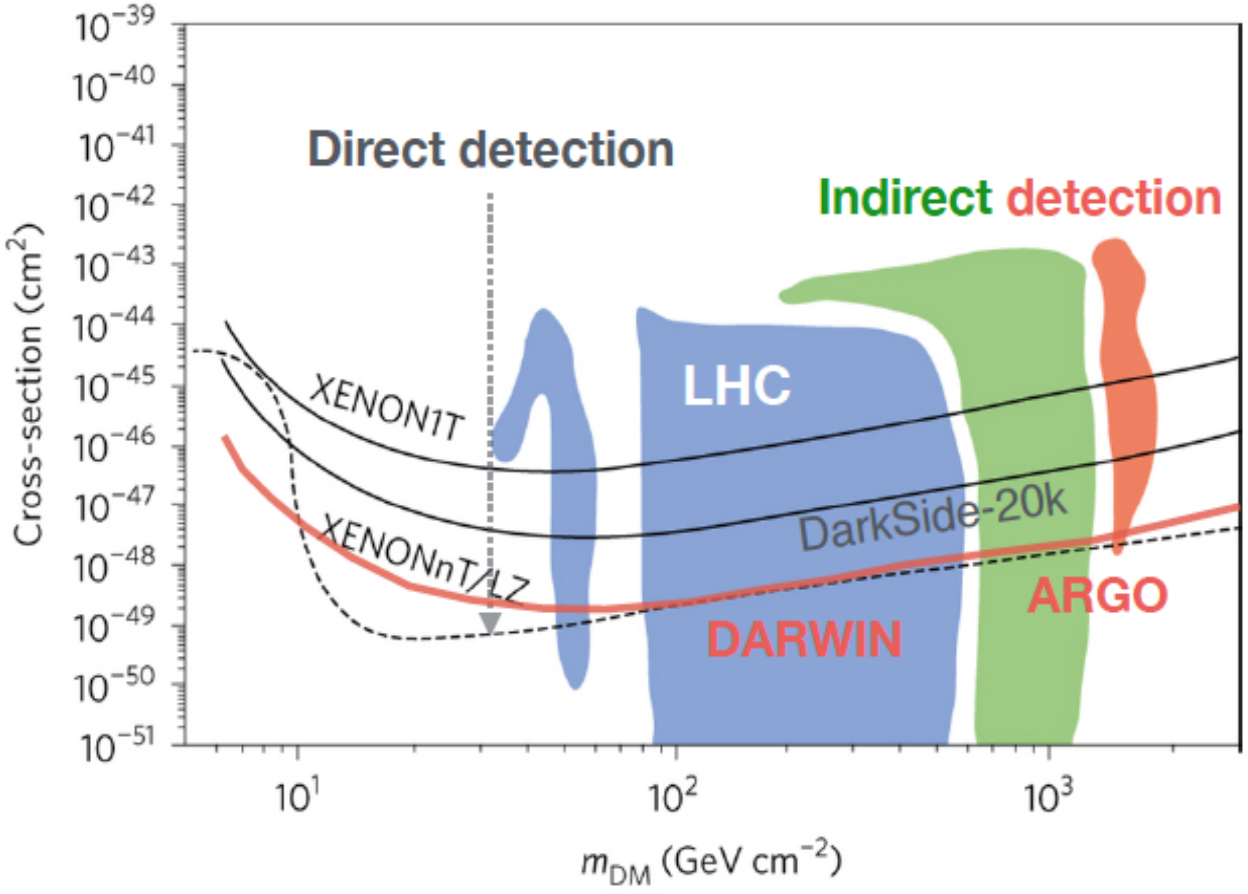


Courtesy of L. Baudis

Nature physics, March 2017

The Guinness of **SENSITIVITY IN WIMP SEARCHES**: **present and future**





Adapted after Nature physics, March 2017

For the last ~30 years we have been focusing on the WIMP scenario

Our experimental effort is strongly focused on the WIMP!

New production mechanisms and mediation schemes often imply a hidden dark sector. Possibly with complex dynamics

Such hidden sectors often include low scale particles, below the GeV scale.

Very different from the WIMP paradigm!!

A special place to enhance the N-S emispheres complementarity:

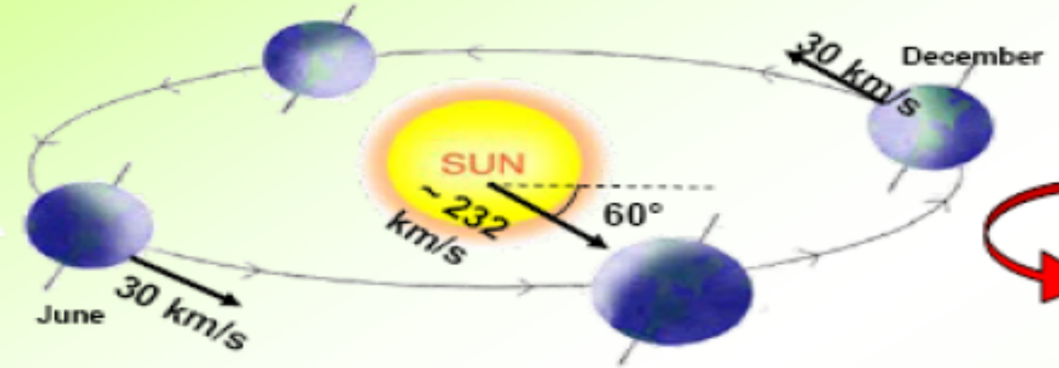
the annual modulation of the WIMP signal

R. Bernabei

The annual modulation: a model independent signature for the investigation of Dark Matter particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions would point out its presence.

Drukier, Freese, Spergel PRD86
Freese et al. PRD88



- v_{sun} ~ 232 km/s (Sun velocity in the halo)
- v_{orb} = 30 km/s (Earth velocity around the Sun)
- $\gamma = \pi/3$
- $\omega = 2\pi/T$ T = 1 year
- t_0 = 2nd June (when $v_\oplus$ is maximum)

$$v_\oplus(t) = v_{sun} + v_{orb}\cos\gamma\cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k}\cos[\omega(t-t_0)]$$

Expected rate in given energy bin changes because the annual motion of the Earth around the Sun moving in the Galaxy

Requirements of the annual modulation

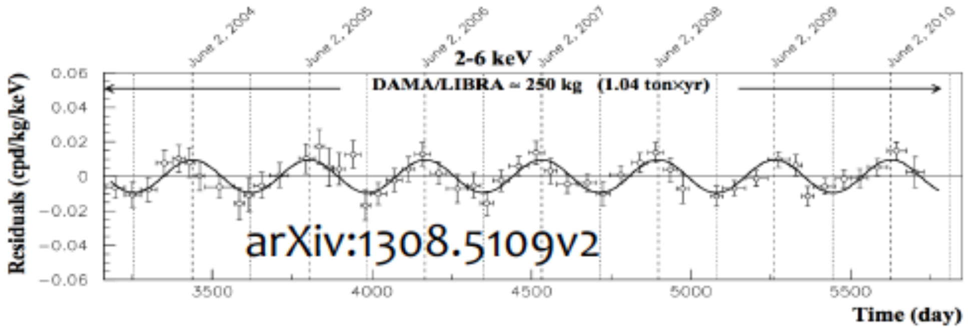
1) Modulated rate according cosine
2) In a definite low energy range
3) With a proper period (1 year)
4) With proper phase (about 2 June)
5) Just for single hit events in a multi-detector set-up
6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

The DM annual modulation signature has a different origin and, thus, different peculiarities (e.g. the phase) with respect to those effects connected with the seasons instead

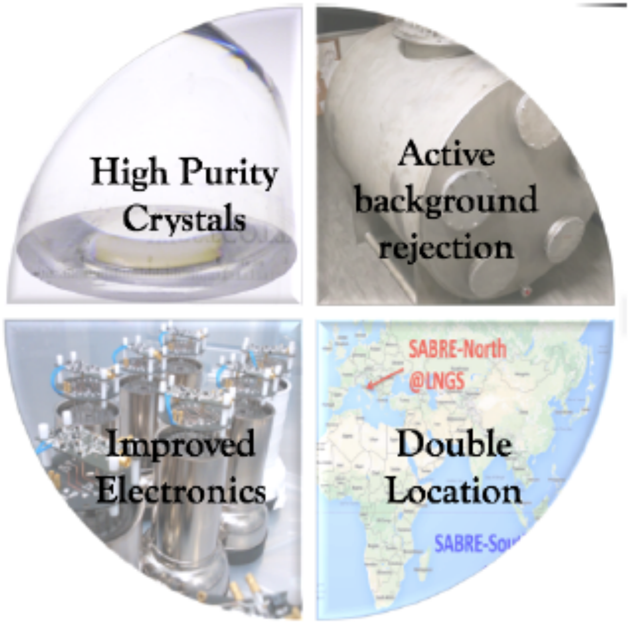
Sodium-iodide with Active Background REjection

Goal: search for annual modulation compatible with Galactic Dark Matter interactions

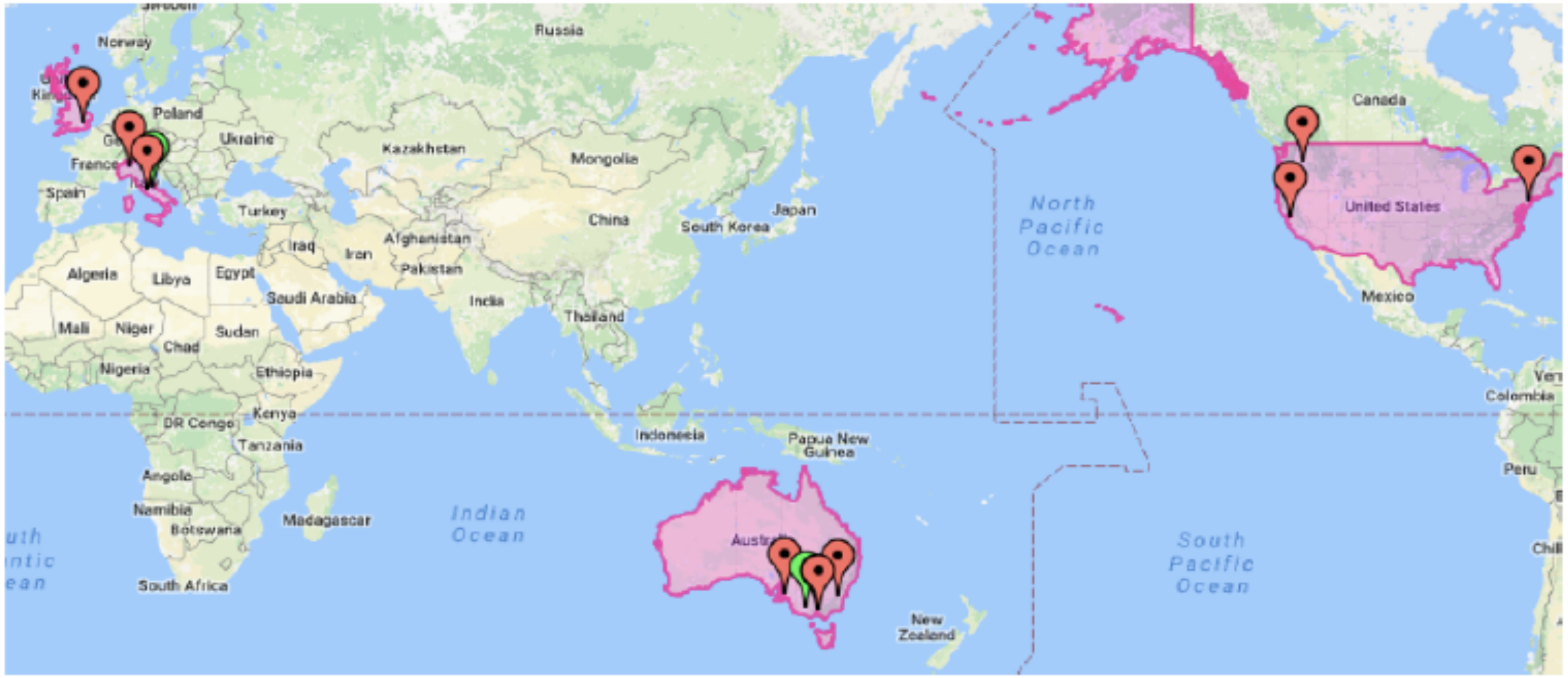


- Strong modulation observed by DAMA/LIBRA with 250Kg of NaI(Tl) crystals
- Null results with other techniques (see Xenon100/LUX results)

SABRE's key features



The Collaboration



Adelaide University, ANSTO
Australian National University
Swinburne University
University of Melbourne

Imperial College London

LNGS & GSSI
INFN Rome
University of Milano & INFN

LLNL
PNNL
Princeton University

Going beyond the SM:
the NEUTRINO MASS

A. GIULIANI,

Cosmology, **single** and **double β decay** measure different combinations of the neutrino mass eigenvalues, constraining the **neutrino mass scale**

In a standard three active neutrino scenario:

$$\Sigma \equiv \sum_{i=1}^{3} M_i$$

← **cosmology**
simple sum
pure kinematical effect

$$\langle M_\beta \rangle \equiv \left(\sum_{i=1}^{3} M_i^2 \, |U_{ei}|^2 \right)^{1/2}$$

← **β decay**
incoherent sum
real neutrino

$$\langle M_{\beta\beta} \rangle \equiv \left| \sum_{i=1}^{3} M_i \, |U_{ei}|^2 e^{i\alpha_i} \right|$$

← **double β decay**
coherent sum
virtual neutrino
Majorana phases

Info from Planck: Neutrino # and mass

$\Sigma m_\nu < 0.23$ eV (95% CL)

$N_{eff} = 3.15 \pm 0.23$

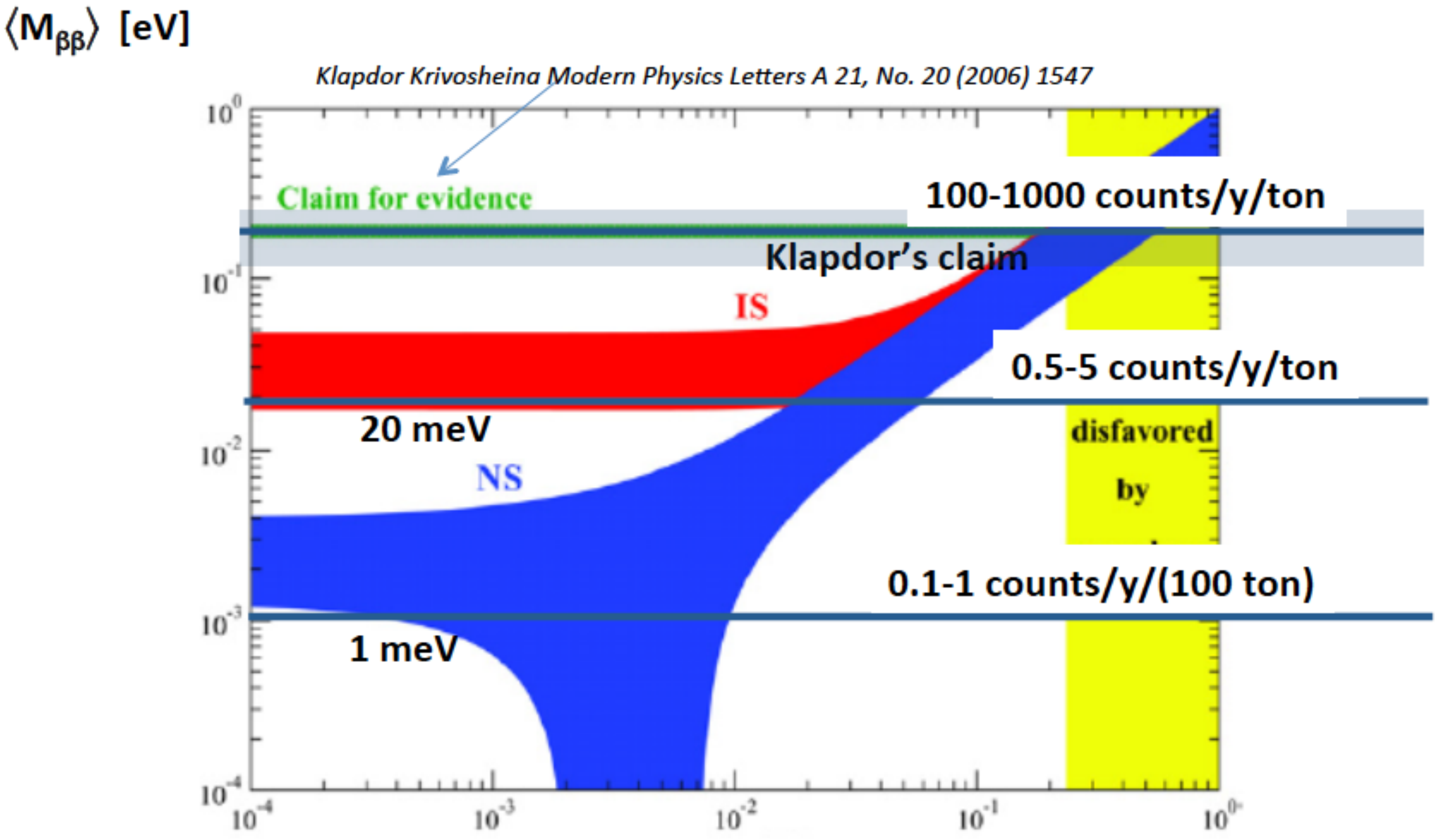
Planck + Lyman alpha

$\Sigma m_\nu < 0.14$ eV (C.L)

Prospects for PLANCK + EUCLID

$\Delta m_\nu \sim 0.03$ eV & $\Delta N_\nu \sim 0.08$

Three challenges for 0ν-DBD search



Current experiments and ongoing R&D activities suggest that three main routes (**Xe**, **Ge**, **bolometers)** can allow achieving this objective

Programmatic issues. Due to the high enrichment cost (in the 20–80 MEuro range), it is unlike that there will be more than one next-generation experiment in Europe. Two may be possible with an important American or in general extra-European participation. The next two-three years will be crucial to define the technology of these future searches; essential indications will come from the performance – especially the background levels – achieved by current-generation projects. Europe-based experiments and R&D activities are at the forefront in all the options outlined above. A large investment in Europe – of the order of 60-80 MEuro – will be necessary to support next-generation searches starting from 2018-2019.

A. Giuliani in the APPEC SAC roadmap preparatory work

Towards the ZERO BACKGROUND: considerations from the SAC of APPEC and the underground physics WG of the What Next INFN

- **TODAY**: **bulk screening** of the materials (mainly gamma-spectroscopy); surface screening (mainly alpha-spectroscopy) ; installation protocols defined by the previous experience → so far only "precautionary" techniques, **the actual level of background is discovered only when data taking starts** (and surprises are certainly not rare …)

- **TOMORROW**: **sharing infrastructures** (0νββ, DM, solar ν) for bulk screening; surface screening and Radon permeation; bulk and surface screening making use of the same detectors used in the actual experiments today; **material production and crystal growth inside our physics facilities (?)**

- **The scale of the new 0νββ and DM exps. demand profound changes in our strategies** (similarly to what happened in particle physics with the advent of the new LEP, CDF, BaBar, LHC detectors) → **THE QUALITY OF THE Research Infrastructures FOR THE SEARCH OF RARE EVENTS MUST MATCH WITH THE NEW REQUIRED STANDARDS**

New strategies for neutrinoless double-beta decay:
the DOE-NSF initiative

Charge Letter

This letter is to request that the DOE/NSF Nuclear Science Advisory Committee (NSAC) Subcommittee on Neutrinoless Double Beta Decay (NLDBD) provide additional guidance to the DOE and NSF regarding an effective strategy for implementing a possible second generation U.S. experiment on neutrino-less double beta decay capable of reaching the sensitivity necessary to determine whether the neutrino is a Majorana or Dirac particle under the inverted-hierarchy mass scenario.

Subcommittee Membership

R. McKeown (Chair)
F. Calaprice
V. Cirigliano
P. Cushman
D. Geesaman (ex-officio)
G. Greene
J. Hardy
D. Hertzog
M. Kamionkowski
K. Langanke
K. Scholberg
H. Sobel
S. Vigdor

Science Assessment

"…it is important to remember that NLDBD has a unique role in potentially addressing the issue of Dirac vs. Majorana nature of neutrinos. The Subcommittee remains convinced that the scientific case for pursuing NLDBD experiments at the ton-scale is very compelling."

Neutrinoless Double Beta Decay

Robert D. McKeown

Other technical issues have more open-ended R&D requirements to address. In these cases the allocation of resources will be more difficult to assess. In any case, the longer term future of NLDBD will require continued R&D effort. **The subcommittee strongly urges continuation of longer term R&D necessary for the future development of the subject in addition to the support of shorter term R&D aimed at a near future downselect.**

It was noted by the subcommittee that there are several common R&D topics that would benefit several different techniques. It seems in these cases that a coordinated approach could be a more efficient use of resources. **The subcommittee suggests that the funding agencies consider an approach that would encourage several groups to work together on these common goals.**

0νββ: plans of APPEC to implement the roadmap recommendation

- Ask the SAC to proceed to the formation of a small group of experts constituting the analogue of the NSAC subcommittee for 0νββ with a similar mandate:
  "**guidance to APPEC regarding an effective strategy for implementing a next generation EU experiment on 0νββ capable of reaching the sensitivity necessary to determine whether the neutrino is a Majorana or a Dirac particle under the inverted mass-hierarchy scenario**"

The cosmic origin of the elements
excellent opportunities for underground labs

- **Aim**: **comprehension of the physical processes that have determined and determine the synthesis of the elements starting from the very early Universe up to nowadays. Individuation of the astronomical sites where such processes have been and are active.**
- **By-products**: comprehension of the **origin of life**, from Carbon to the most complex bio-molecules
- **Inter-disciplinary Astro-Particle approach**: to tackle and (possibly) solve the many open problems in the comprehension of nucleosynthesis demands a **broad integration of competences from experimental and theoretical nuclear physics to stellar evolution and study of spectrum of stars, galaxies, diffused mater at various redshifts.**

Strong interest of APPEC in the interplay between ***Geosciences and Astroparticle Physics***:
one of the "Global Workshop" initiatives of APPEC is devoted to this subject with a workshop in Paris next Nov.-Dec.

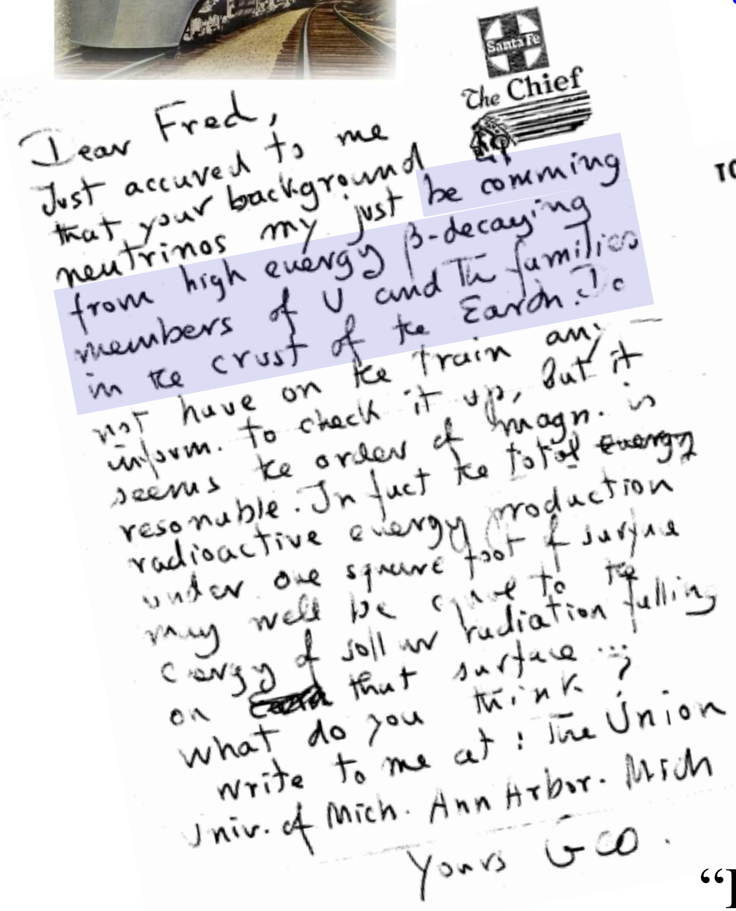
- In the last years there appeared many areas of natural synergy between Geosciences and Astroparticle Physics.
- Earth and Astroparticle sciences share a mutual scientific culture based on common objects of study, methods and approaches.
- First, the geosphere, a direct object of study of the geosciences, is both the target and the detecting medium for astroparticle observatories,
- Then, they both deal with complex natural systems at a much larger scale than the human, deploy large sensor networks in sometimes hostile environments (sea, desert, underground, space);
- Use long series of precise observations acquired over a range of time scales;
- Extreme dating is a discovery instrument,
- They develop models relying on the state of the art in fundamental physics, chemistry, biology and informatics.
- They finally use large data manipulation and worldwide networking, including the distribution of alerts.
- The aim of the proposed workshop is to explore the possible common grounds and combine the scientific expertise of both fields, involving key PIs of the respective fields together with the main agencies funding them, in order to promote original interdisciplinary research and education projects.

S. Katsanevas

- Seismology
  - Seismic precursors using gravitational wave technology
  - Cold atom interferometry
  - Ocean floor seismology (standard, acoustic)
  - Dense seismic grids
- Muon Imaging
  - Volcano muon tomography
  - Archaeology, prospection
- Neutrino Imaging
  - Geoneutrinos and Earth Neutrino radiography
- Deep ocean
  - Parameter monitoring (salinity, temperature, gases, nutrients, radioactivity) and bioimaging
- Deep Underground science
  - Extreme dating
  - Subsurface microbiology, extremophiles
- Space
  - Planetary science
  - Space weather
  - Nanosatelites

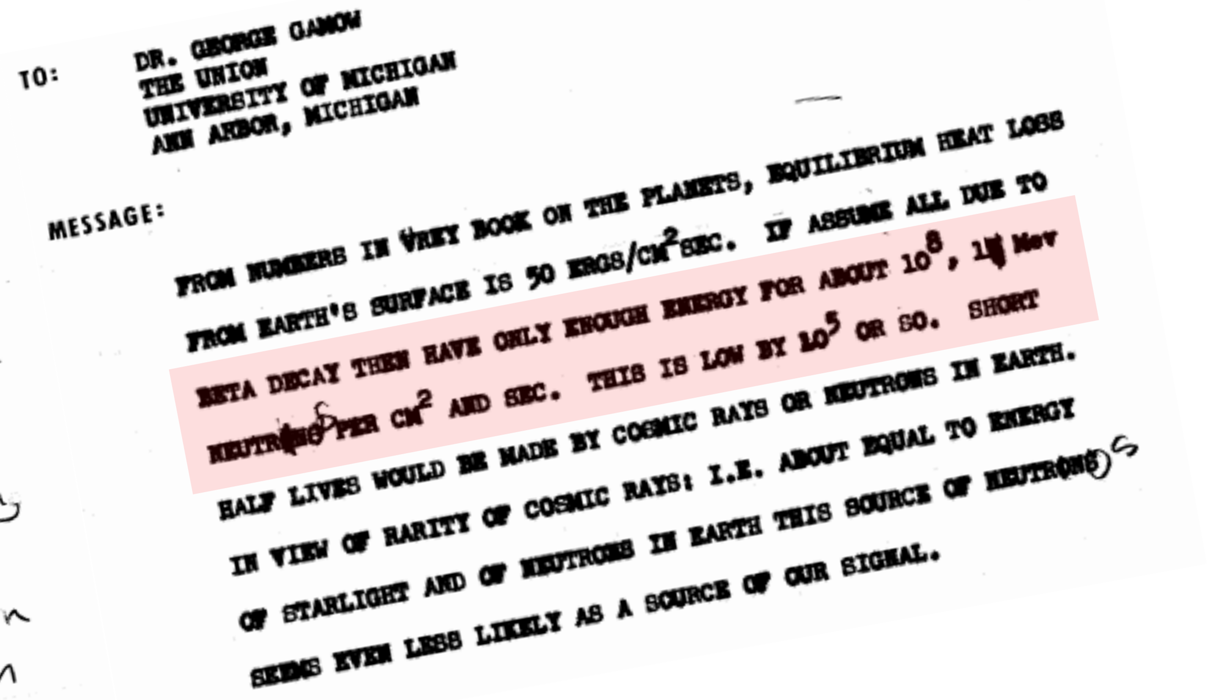
Geo-neutrinos born on board of the Santa Fe Chief train

In 1953 G. Gamow wrote to F. Reines: “It just occurred to me that your background may just be coming from high energy beta-decaying members of U and Th families in the crust of the Earth.”



The Chief

Dear Fred,
Just accured to me
that your background
neutrinos my just be comming
from high energy β-decaying
members of U and Th families
in the crust of the Earth. I do
not have on the train any
inform. to check it up, but it
seems the order of magn. is
resonable. In fact the total ~~energy~~
radioactive energy production
under one square foot of surface
may well be equal to the
energy of soll. radiation falling
on ~~earth~~ that surface ..
what do you think?
write to me at: The Union
Univ. of Mich. Ann Arbor. Mich
Yours Geo.



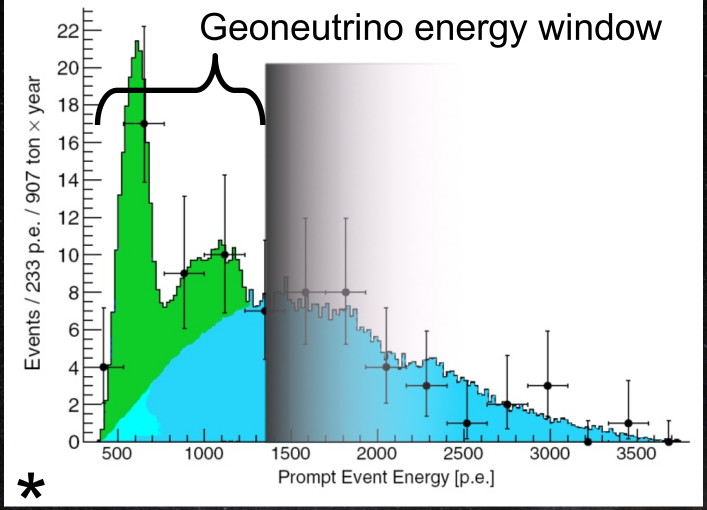
TO: DR. GEORGE GAMOW
THE UNION
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

MESSAGE: FROM NUMBERS IN VERY BOOK ON THE PLANETS, EQUILIBRIUM HEAT LOSS FROM EARTH'S SURFACE IS 50 ERGS/CM^{2}SEC. IF ASSUME ALL DUE TO BETA DECAY THEN HAVE ONLY ENOUGH ENERGY FOR ABOUT 10^8, 1 Mev NEUTRINOS PER CM^2 AND SEC. THIS IS LOW BY 10^5 OR SO. SHORT HALF LIVES WOULD BE MADE BY COSMIC RAYS OR NEUTRONS IN EARTH. IN VIEW OF RARITY OF COSMIC RAYS; I.E. ABOUT EQUAL TO ENERGY OF STARLIGHT AND OF NEUTRONS IN EARTH THIS SOURCE OF NEUTRONS SEEMS EVEN LESS LIKELY AS A SOURCE OF OUR SIGNAL.

F. Reines answered to G. Gamow:
“Heat loss from Earth’s surface is 50 erg cm^{-2} s^{-1}.
If assume all due to beta decay than have only enough energy for about 10^8 one-MeV neutrinos cm^{-2} and s.”

Courtesy of F. Mantovani

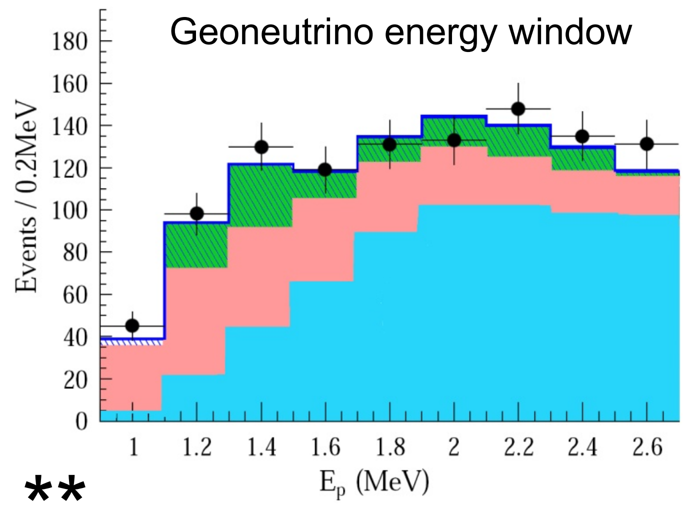
KamLAND and Borexino results

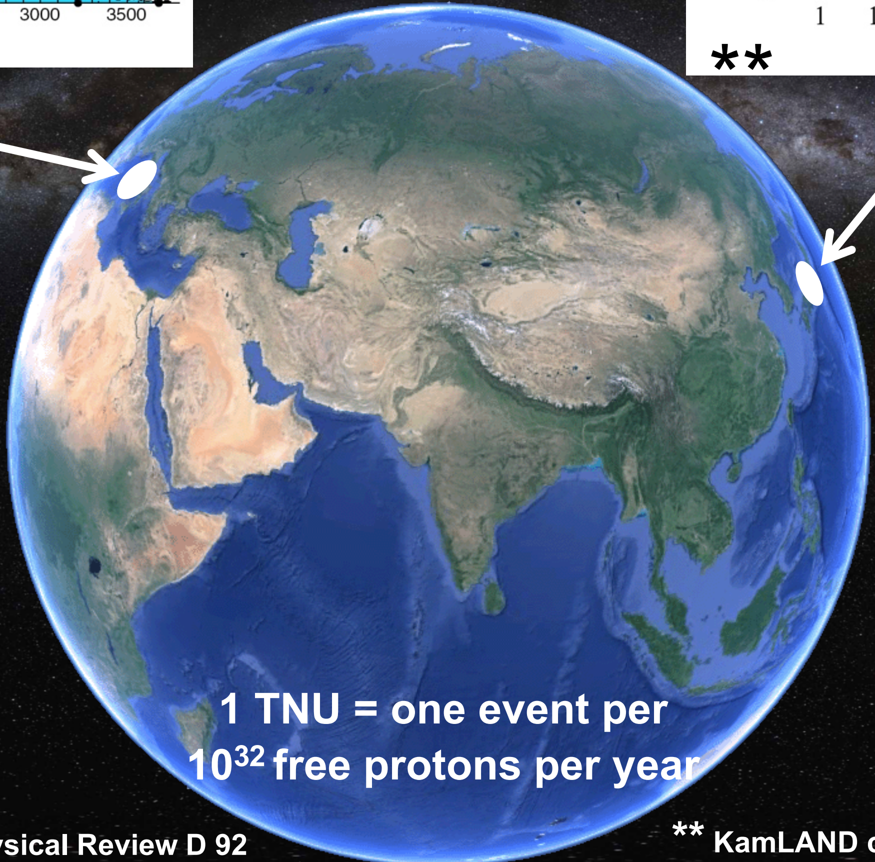


Geoneutrinos

Background

Reactor antineutrinos





Borexino

- Period: 2007 – 2015
- Geo-ν events: $23.7^{+7.4}_{-6.3}$
- Signal: $43.5^{+14.5}_{-12.8}$ TNU

KamLAND

- Period: 2002 – 2012
- Geo-ν events: 116^{+28}_{-27}
- Signal: 30 ± 7 TNU

1 TNU = one event per 10^{32} free protons per year

F. Mantovani

* Borexino collaboration, 2015 - Physical Review D 92

** KamLAND collaboration, 2013 - Phys. Rev. D 88

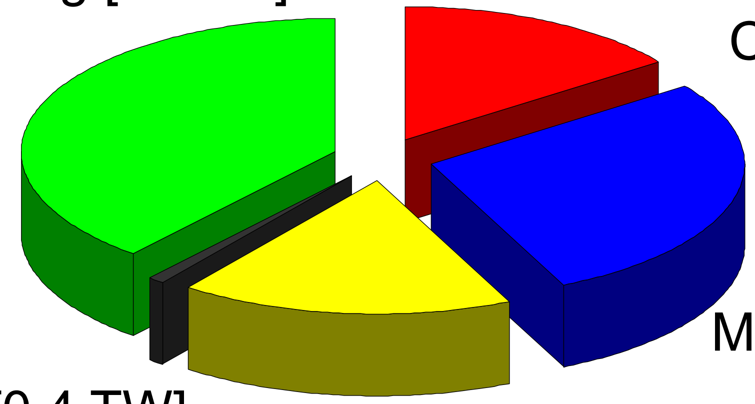
"Energetics of the Earth and the missing heat source mystery"*

F. Mantovani

- The debate about the terrestrial heat flow is still open: H_{Earth} = (30 - 49)TW
- The BSE canonical model, based on cosmochemical arguments, predicts a radiogenic heat production ~ 20 TW

	Global heat loss [TW]
Williams and von Herzen [1974]	43
Davies [1980]	41
Sclater et al. [1980]	42
Pollack et al. [1993]	44 ± 1
Hofmeister et al. [2005]	31 ± 1
Jaupart et al. [2007] *	46 ± 3
Davies and Davies [2010]	47 ± 2

NEUTRINO GEOSCIENCE review 2013 G. Bellini, A. Ianni, L. Ludhova, F. Mantovani, W. F. NcDonough



* D. L. Anderson (2005),Technical Report, www.MantlePlume.org

**Jaupart, C. et al. - Treatise on Geophysics, Schubert G. (ed.), Oxford :Elsevier Ltd., 2007.

DETECTORS R&D

*APPEC stimulates and supports a range of detector R&D projects through **targeted common calls and technology fora that bring scientists and industries together**.*

*APPEC encourages consortia to apply for **EU (technology) grants** such as achieved by SENSE for low-level light-sensor technologies. APPEC welcomes the ATTRACT initiative, which aims to accelerate development of particle-radiation detector and imaging technologies for the science community and for the wider market*

Worldwide underground labs: a prototype for
G R I Global Research Infrastructure

- Together with the Gravitational Waves Observatories, the astroparticle physics Underground Laboratories constitute an excellent opportunity to give rise to a **global network of research infrastructures** known as GRI, namely a **globally distributed research facility where all labs act in a synergic and coordinated way as a single network**

- **Individuation of common, shared objectives** (for instance next-generation huge exps. For DM searches, neutrinoless double beta) → **distribution of the tasks avoiding overlaps, expensive redundancies, useless competitiveness**

- Crucial to always foresee space to **smaller-scale projects prompted by innovative, original ideas**. The global approach must guarantee diversification and also high-risk high-gain initiatives

Welcome to the club!

BACKUP SLIDES

Astroparticle Physics in Europe

Many of the next-generation astroparticle physics research infrastructures require **substantial capital investment** and for Europe to remain competitive in this rapidly evolving global research field – on the ground as well as in space – a clear, collective and ***resource aware*** **strategy is essential**.

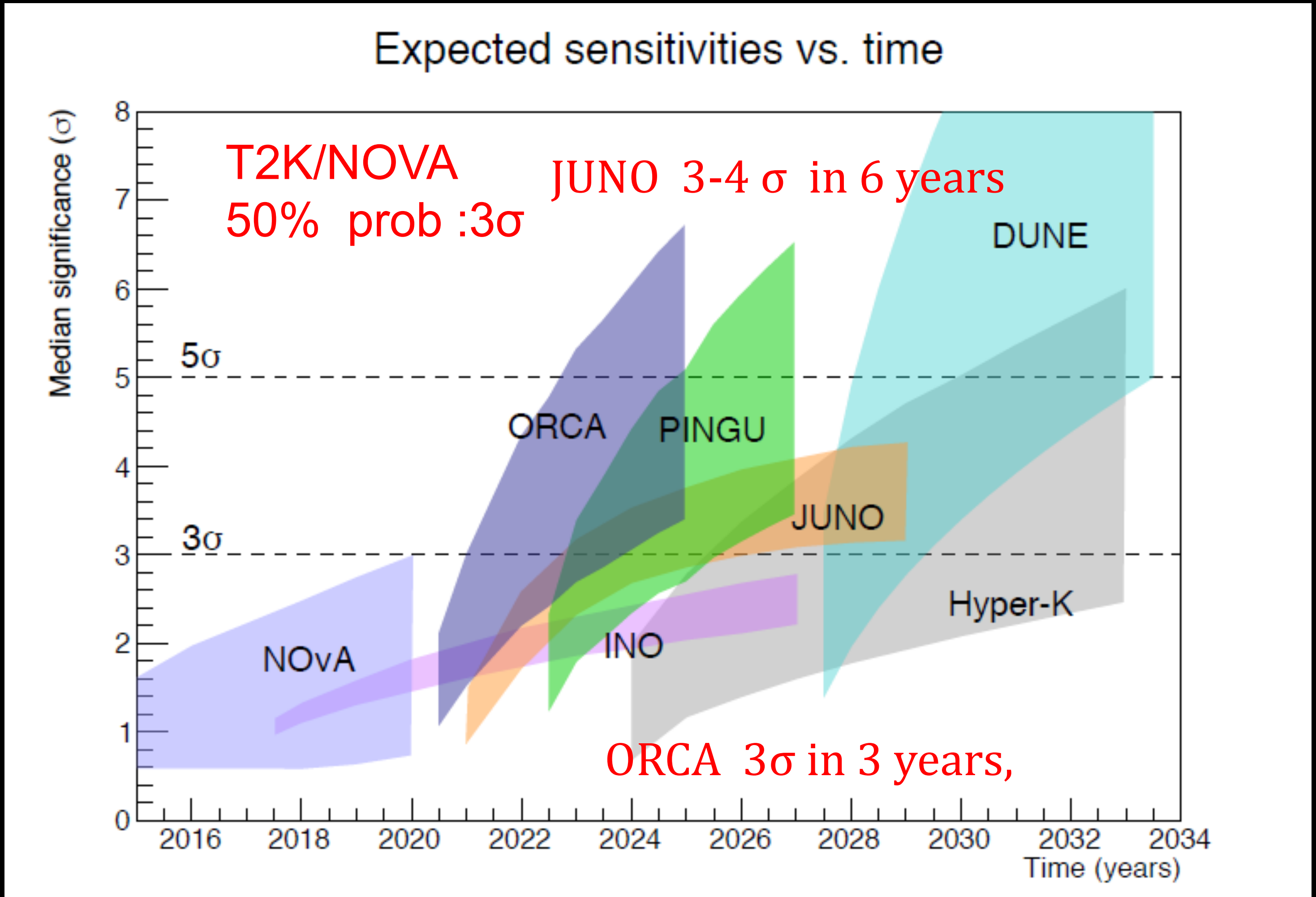
As opposed to its progenitors, as a relatively new field European astroparticle physics does **not** profit from a natural and strong inter-governmental organisation like CERN, ESO and ESA to drive the field

Germanio	Bolometri		Scintillatori
LSGe (Large Scale Germanium) activities	Te, enrichment Cherenkov e discr. α	Bolometri scintillanti	Borexino con ^{136}Xe
GERDA e Majorana molto probabilmente evolveranno in un esperimento a grande scala (>250 kg) che combini il meglio delle loro tecnologie	Attivita' diversificate che stanno confluendo in uno schema coerente (CUORE-IHE→CUPID)		Difficile da conciliare al momento con il physics plan di Borexino-SOX

Cosa ha fatto (e può fare) What Next per loro?

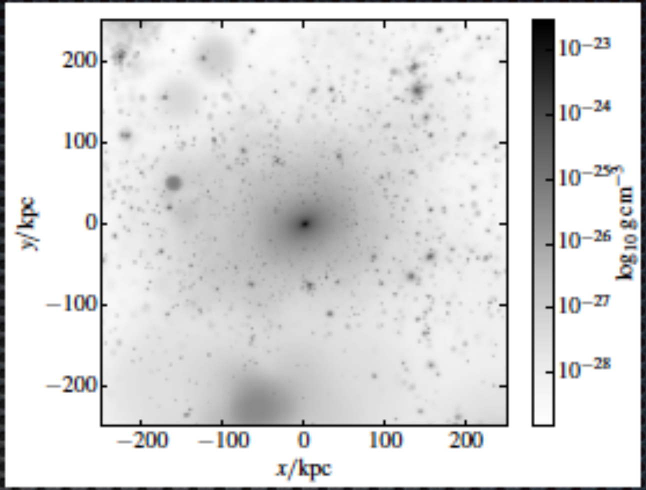
- Mettere in rilievo le sinergie con la Dark Matter dal punto di vista delle infrastrutture e delle facilities di sviluppo
- Mantenere viva l'attenzione sugli sviluppi non convenzionali (soprattutto sui rivelatori traccianti: negative ion TPC, scintillatori) [una situazione analoga alla DM direzionale…]

Mass hierarchy
Atmospheric, Reactor, Accelerator

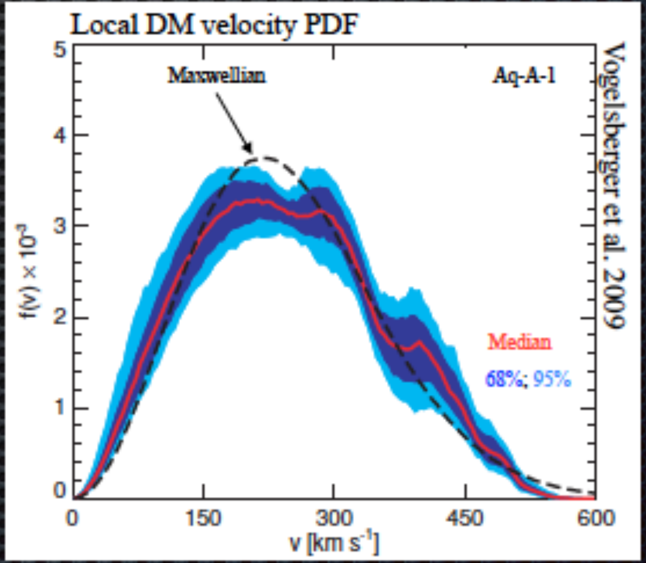


3σ 2023-25 5σ 2030

Flux of dark matter particles:

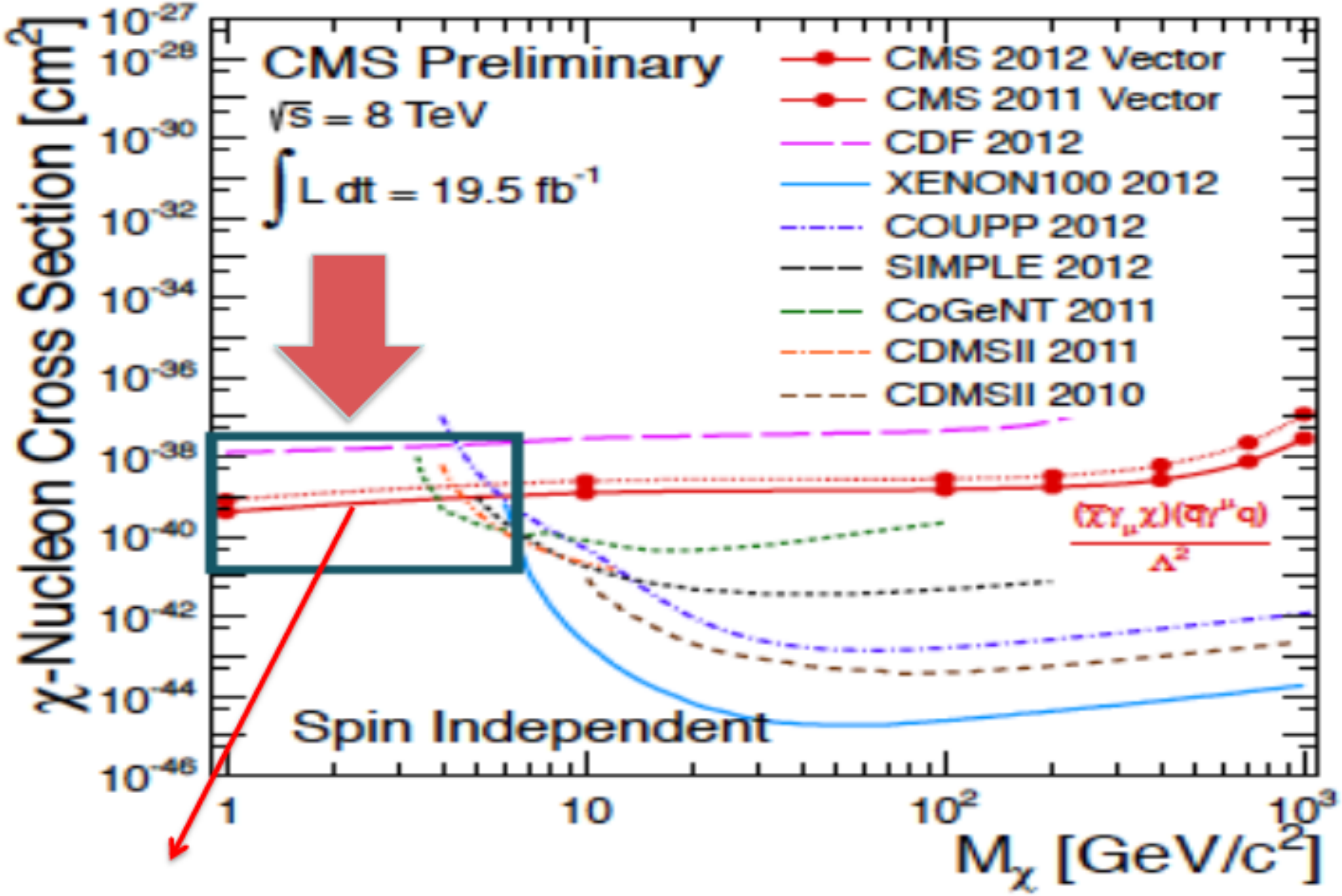


$$\phi = \frac{\rho_{dm}}{m_{dm}} \times \langle v \rangle$$



~ 10 millions through your hand, every second

- UG Physics is exciting since > 50 years
  - Physics BSM found un UG lab before SM assessed
- Several deep UG science labs worldwide
- Space availability is non going to be a major issue
- New labs in the southern hemisphere are a welcome addition

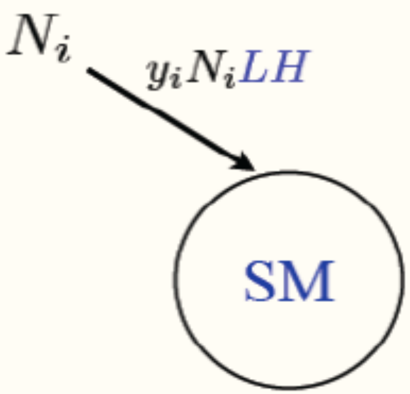


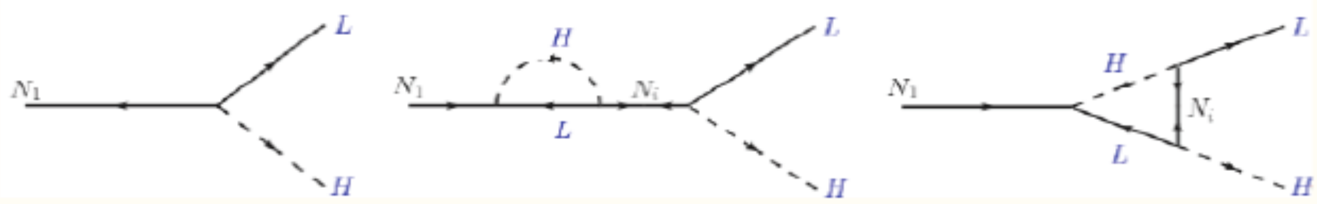
Relevant to intensify the efforts here: ex. **asymmetric DM** with **DM particles of mass~ baryon mass given that ρ_{DM} not much different from ρ_B**

Linking neutrino masses, matter-antimatter-asymmetry and DM

- Thermal Leptogenesis:

[Fukugita,Yanagida,1986;
Review:Davidson,Nardi,Nir,2008]

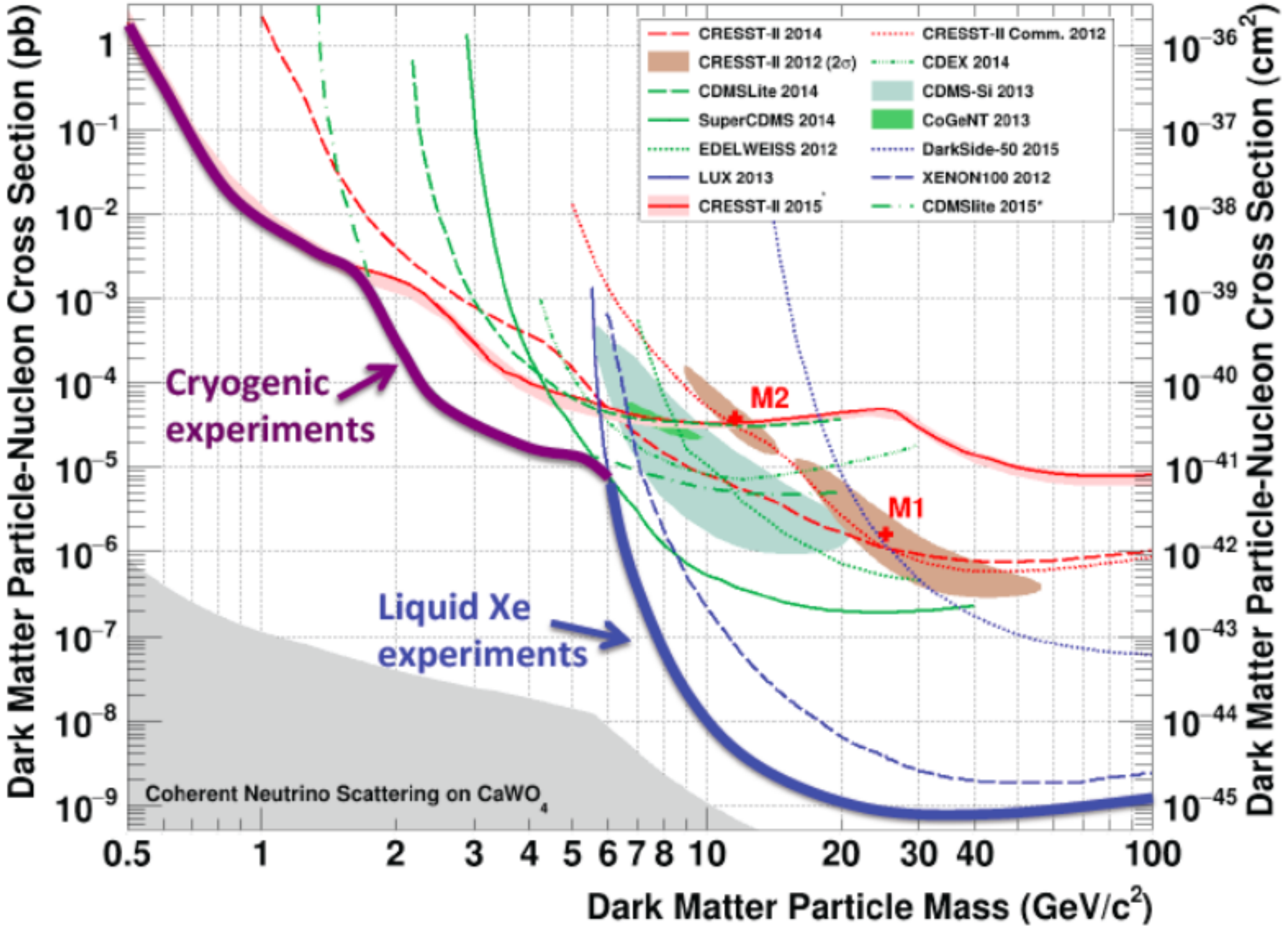




Sakharov's conditions:

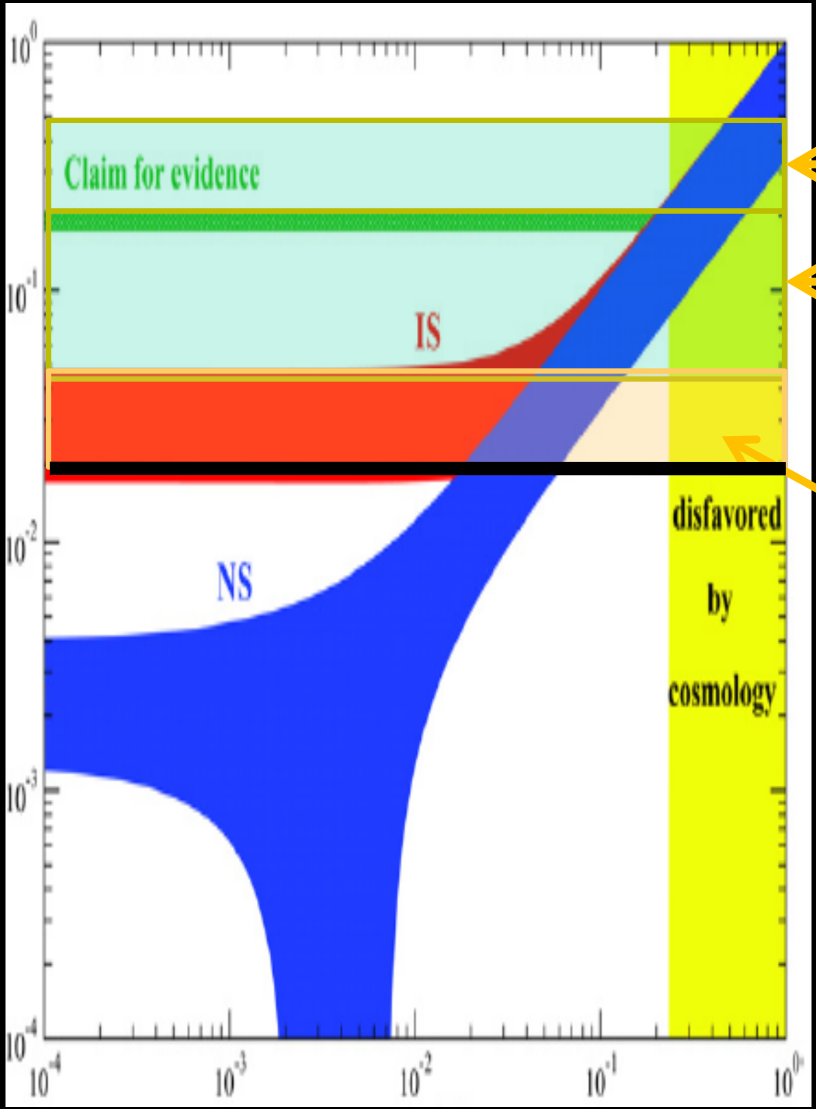
1. **CP Violation:** Complex y_i. Requires at least two N_i's.
2. **Lepton Number Violation:** N_i are majorana.
3. **Departure from T.E.:** Decay out of equilibrium, $\Gamma_{N_1} < H(T = M_1)$.

From GeV to tens of GeV WIMPS: Direct Dark Matter Searches



0νββ future sensitivities

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



20 mEV
0.5-5
evts/y/ton

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

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

Global coordination also needed

Main open issues

Enrichment

Price/ton [M$]

Isotope	Abundance	Price per kg, k$
^{76}Ge	7.61	~ 80
^{82}Se	8.73	$\sim$ ~~120~~ 80
^{100}Mo	9.63	~ 80
^{116}Cd	7.49	~ 180
^{130}Te	34.08	~ 20
^{136}Xe	8.87	~ 5-10
^{150}Nd (?)	5.6	> 200

A. Barabash, arXiv:1109.6423v2

→ Low cost, but global year production is 40 tons

Theory

$$1/\tau \propto g_A^{4}$$

→ = 1.26 (free nucleon)

→ ~ 1 (accounting for quenching)

→ ~ 0.7-0.8 (recent fits)

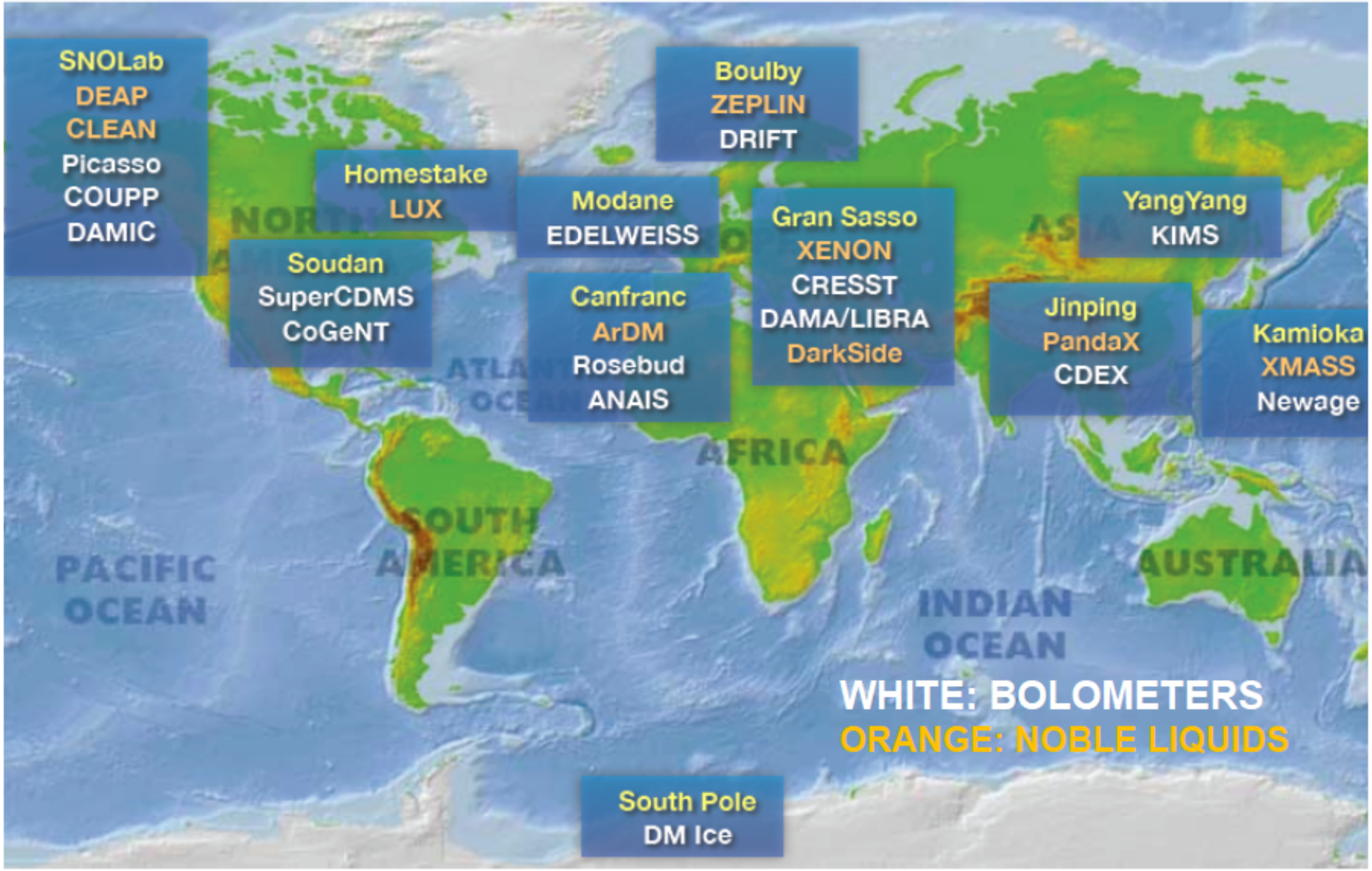
Strong implications (but controversial)

CONNECTION DM – ELW. SCALE

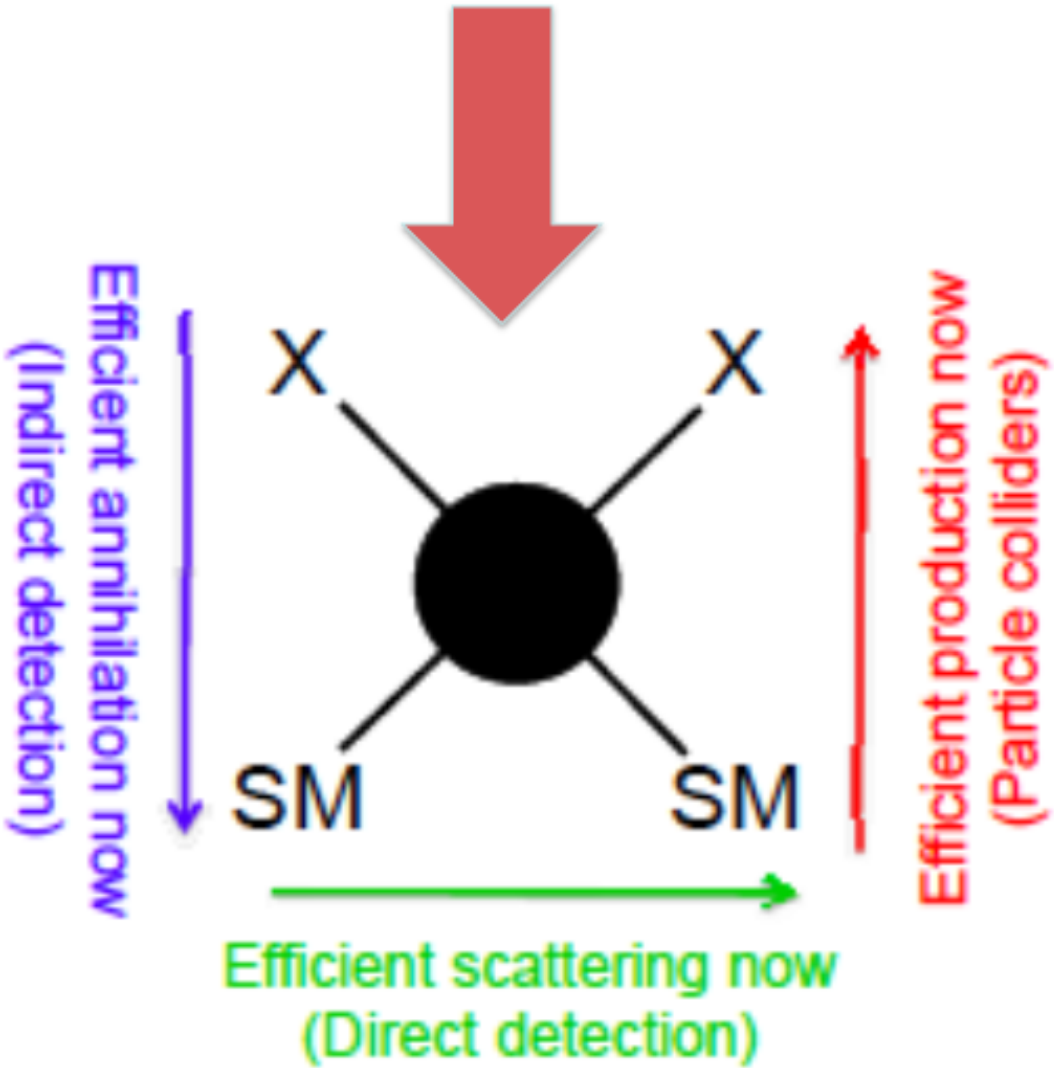
THE WIMP MIRACLE :STABLE ELW. SCALE WIMPs

	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) ENLARGEMENT OF THE SM	(x^μ, θ)	(x^μ, j^i)	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) SELECTION RULE	*R-PARITY LSP*	*KK-PARITY LKP*	*T-PARITY LTP*
→ DISCRETE SYMM.	Neutralino spin 1/2	spin1	spin0
→ STABLE NEW PART.	↓	↓	↓
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

IMPRESSIVE EFFORT TO LOOK FOR WIMPS WORLDWIDE



DM COMPLEMENTARITY: efficient annihilation in the early Universe implies today

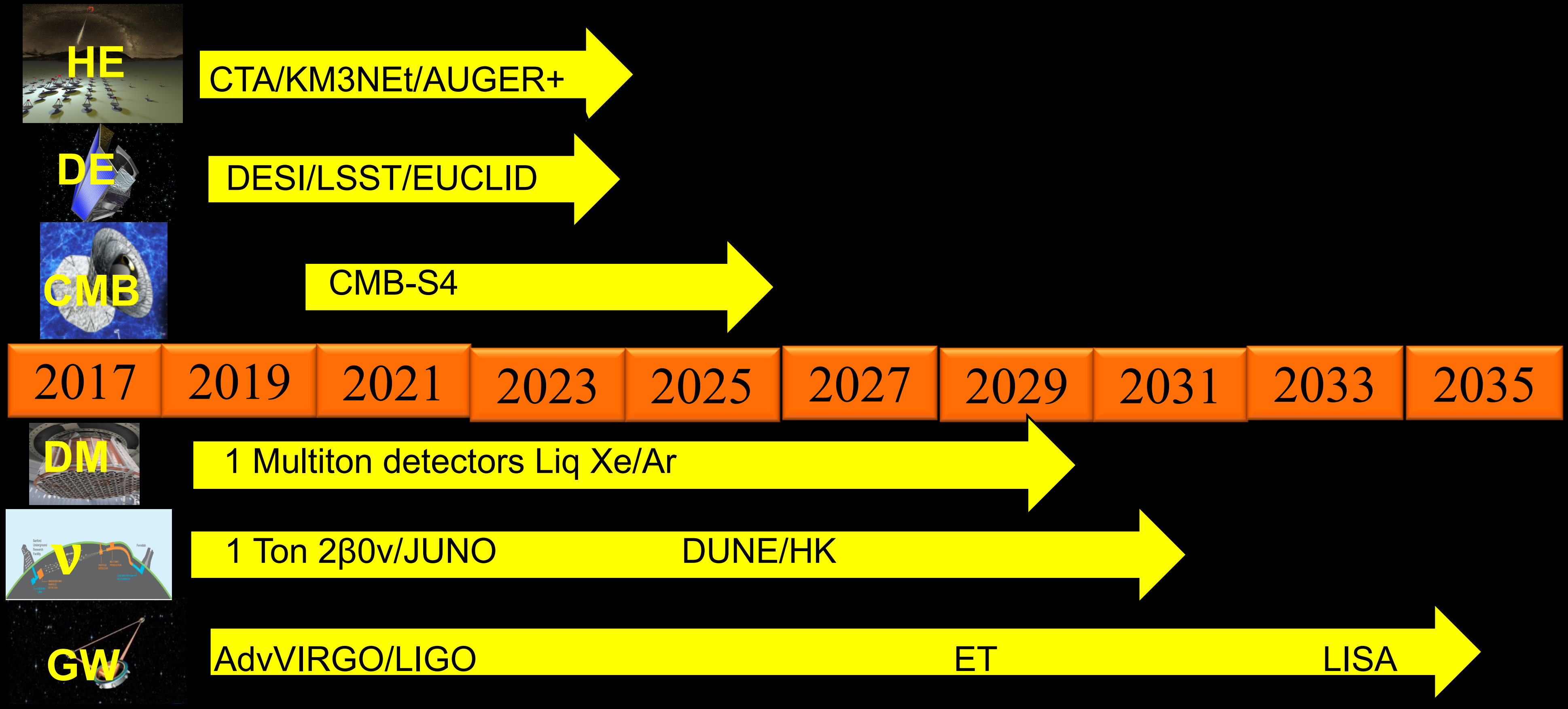


Challenges for next DM, ββ frontiers; Challenges for LNGS

- Attack and cover the IH region → 1-ton neutrinoless ββ
- WIMPS DM : Reach the neutrino background → n-ton exps. n= 20, 50 ?

Need for GLOBAL COORDINATION

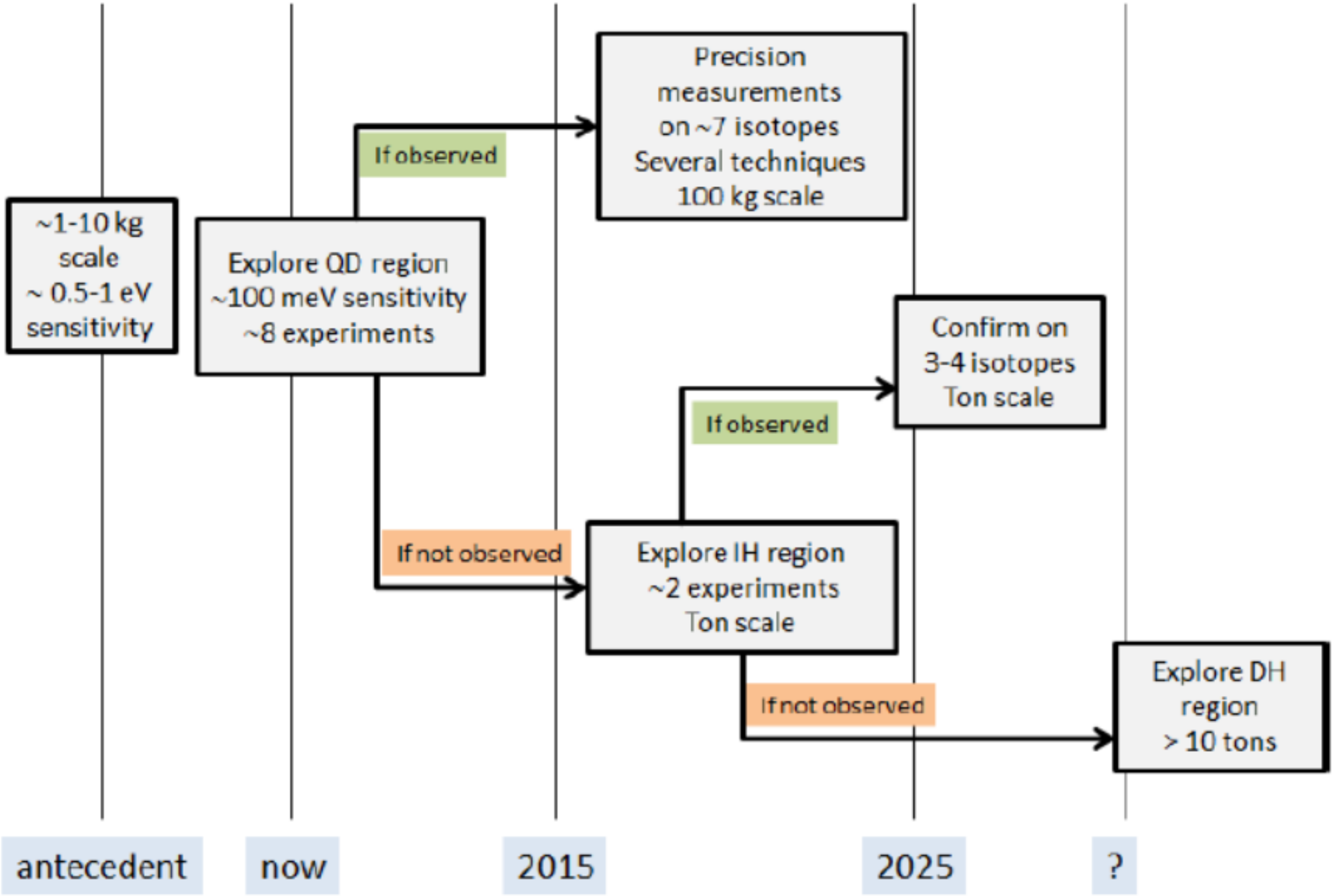
Astroparticle Physics and Cosmology
the next 20 years



S. Katsanevas, 2017

Looking into the crystal ball

GIULIANI 2014 preliminary work for the APPEC roadmap



Computing and Data policies

*APPEC requests all relevant experiments to have their **computing requirements** scrutinised. APPEC will engage with the particle physics and astronomy communities (e.g. within the context of EU-T0) to secure for the future a balance between available European computing resources and needs. Furthermore, APPEC encourages the use of **data format standards to facilitate data access between experiments.** APPEC supports the transition to Open Access publication strategies and encourages the making of data publicly available (i.e. as 'open data') to foster 'citizen science', for example.*

Global Collaboration and Coordination

APPEC will continue to seek collaboration and coordination with its partners ***worldwide*** *– scientists and funding agencies – to advance the* ***design****,* ***construction****,* ***sustainable exploitation*** *(including computing needs) and* ***governance*** *of the* ***next-generation world-class large research infrastructures*** *required to achieve the scientific discoveries of which we all dream.*