Astroparticle Physics

The Grand Picture

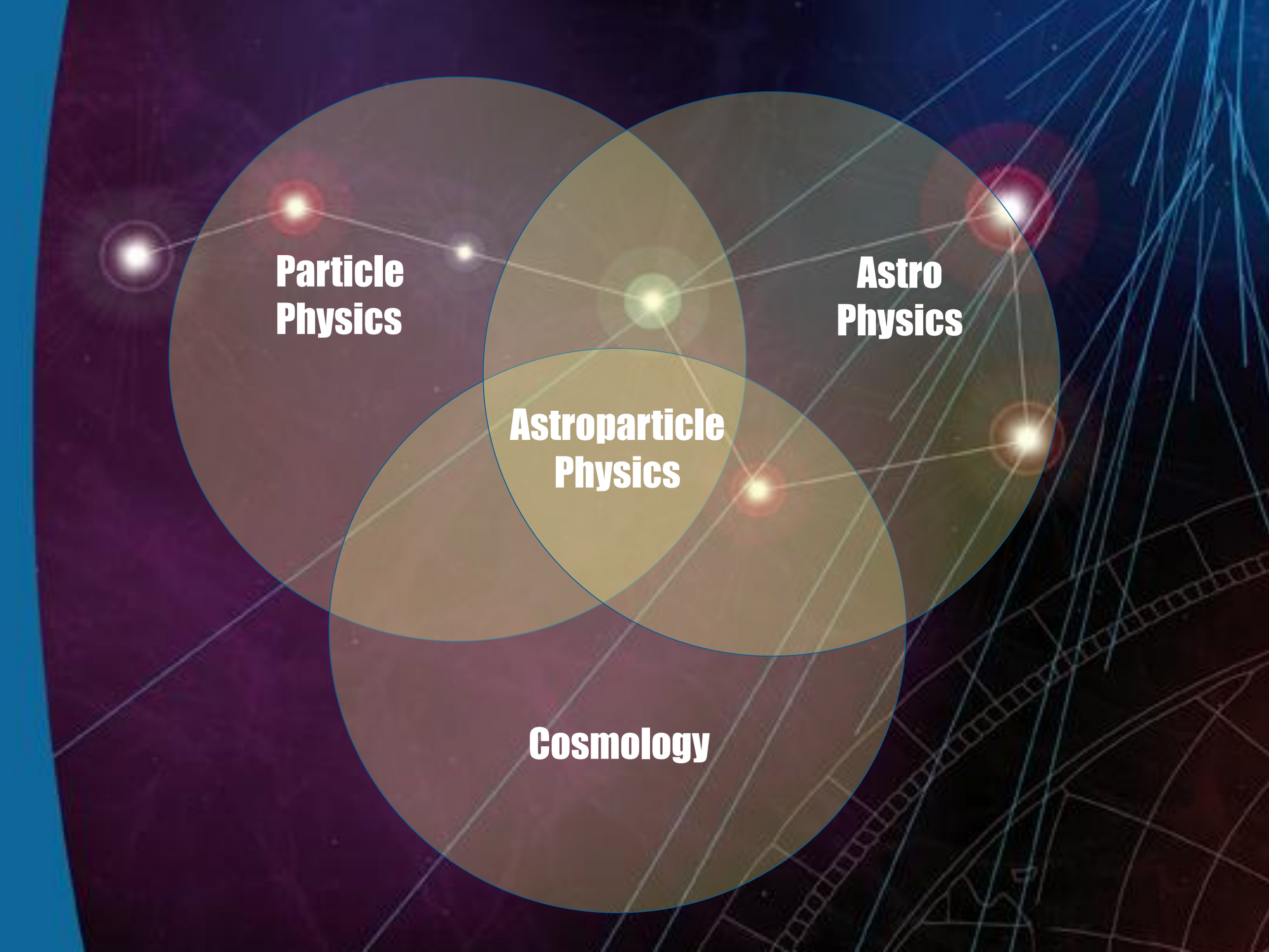
Christian Spiering, DESY

Buenos Aires, Nov.19, 2012

http://www.aspera-eu.org

The Questions of Astroparticle Physics

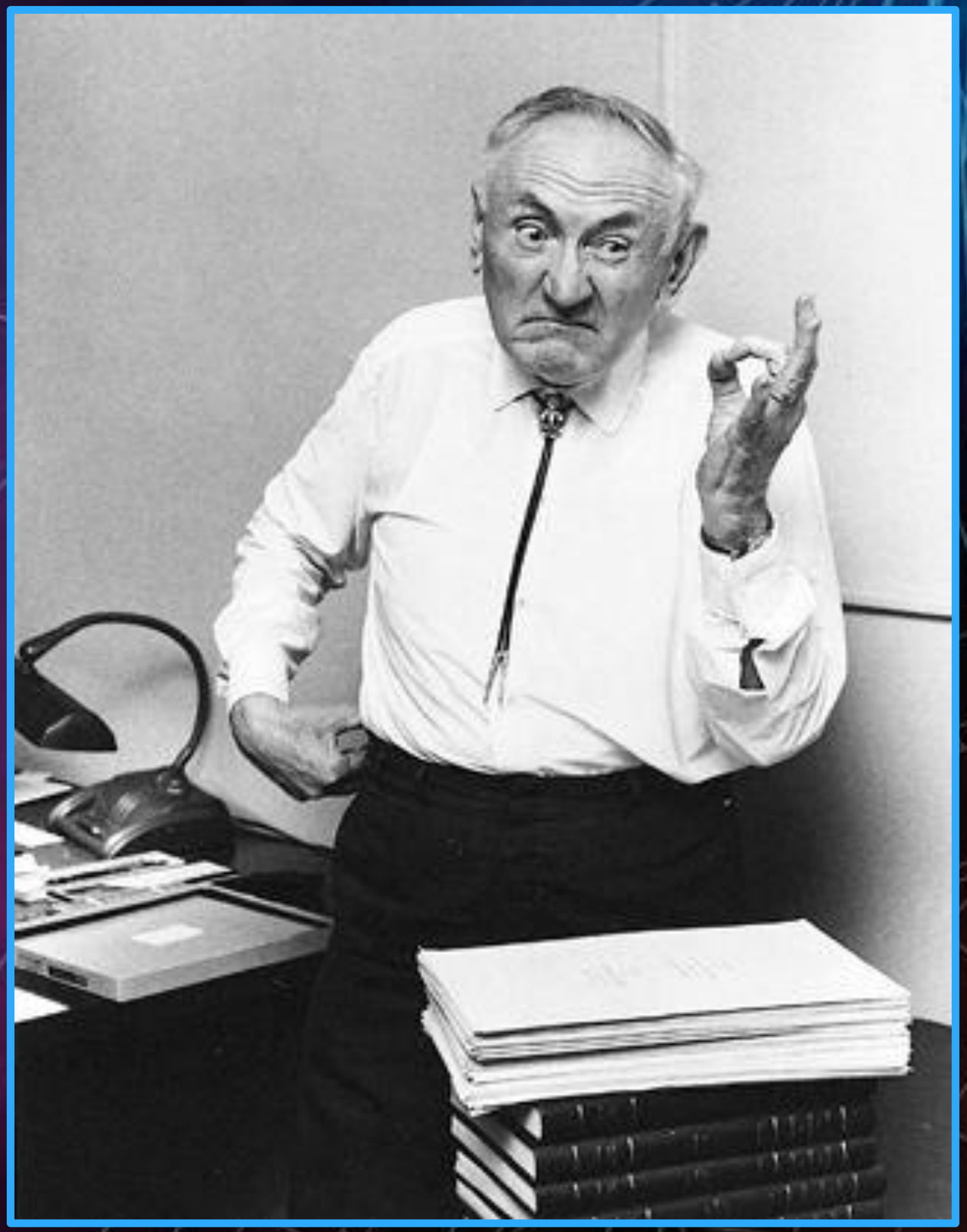
- **Cosmic Inventory** — Dark Matter (+Antimatter), Dark Energy
- **Lifetime of protons** — GUTs & cosmology
- **Neutrinos as particles** — properties, role in cosmic evolution
- **Neutrinos as messengers** — Sun, Earth, Supernova explosions
- **Non-thermal Universe** — origin of cosmic rays, cosmic landscape at high energies
- **Gravitational waves** — violent cosmic processes, nature of gravity


Particle Physics
Astro Physics
Astroparticle Physics
Cosmology

Dark Matter

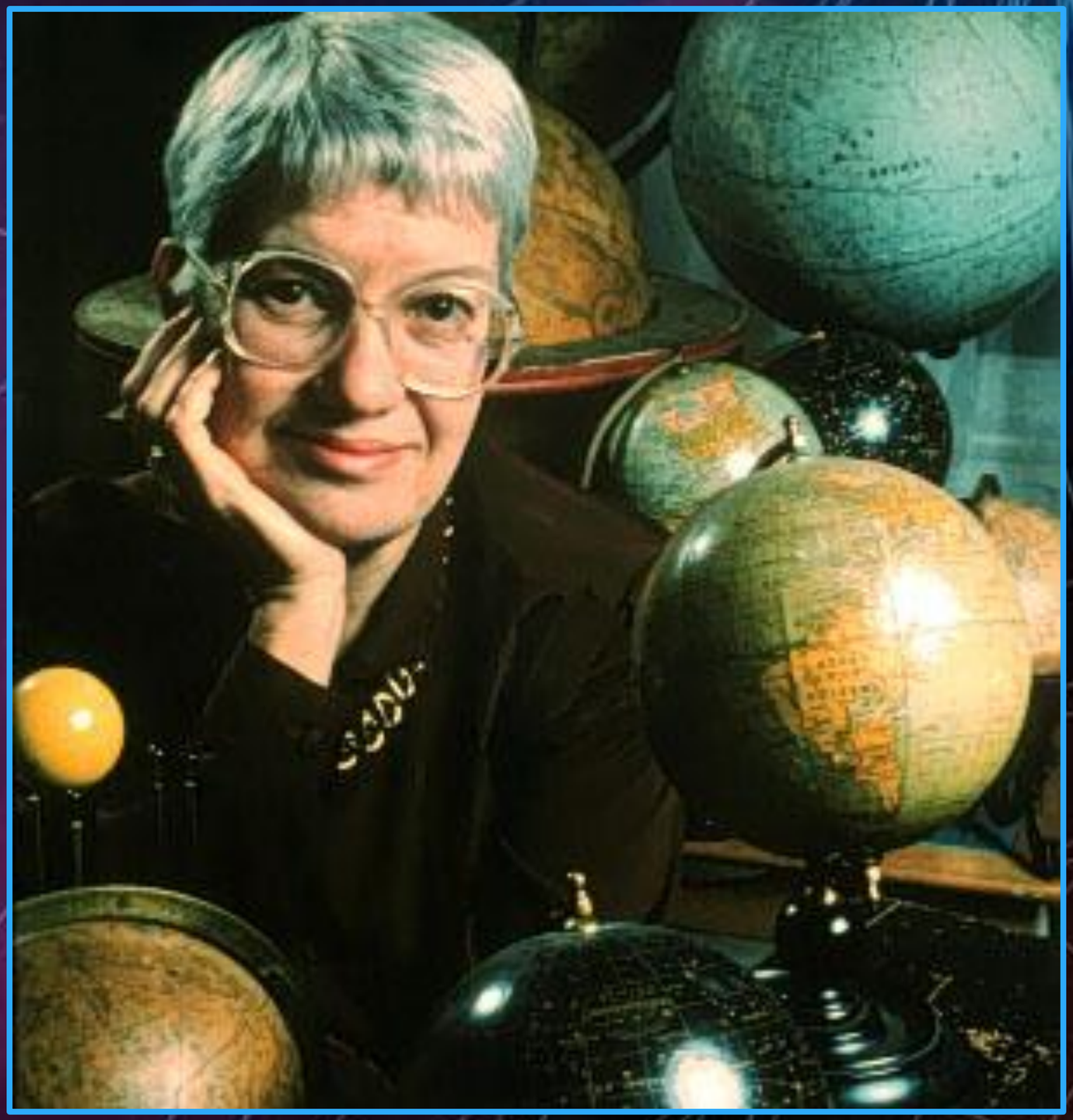
Fritz Zwicky

1933



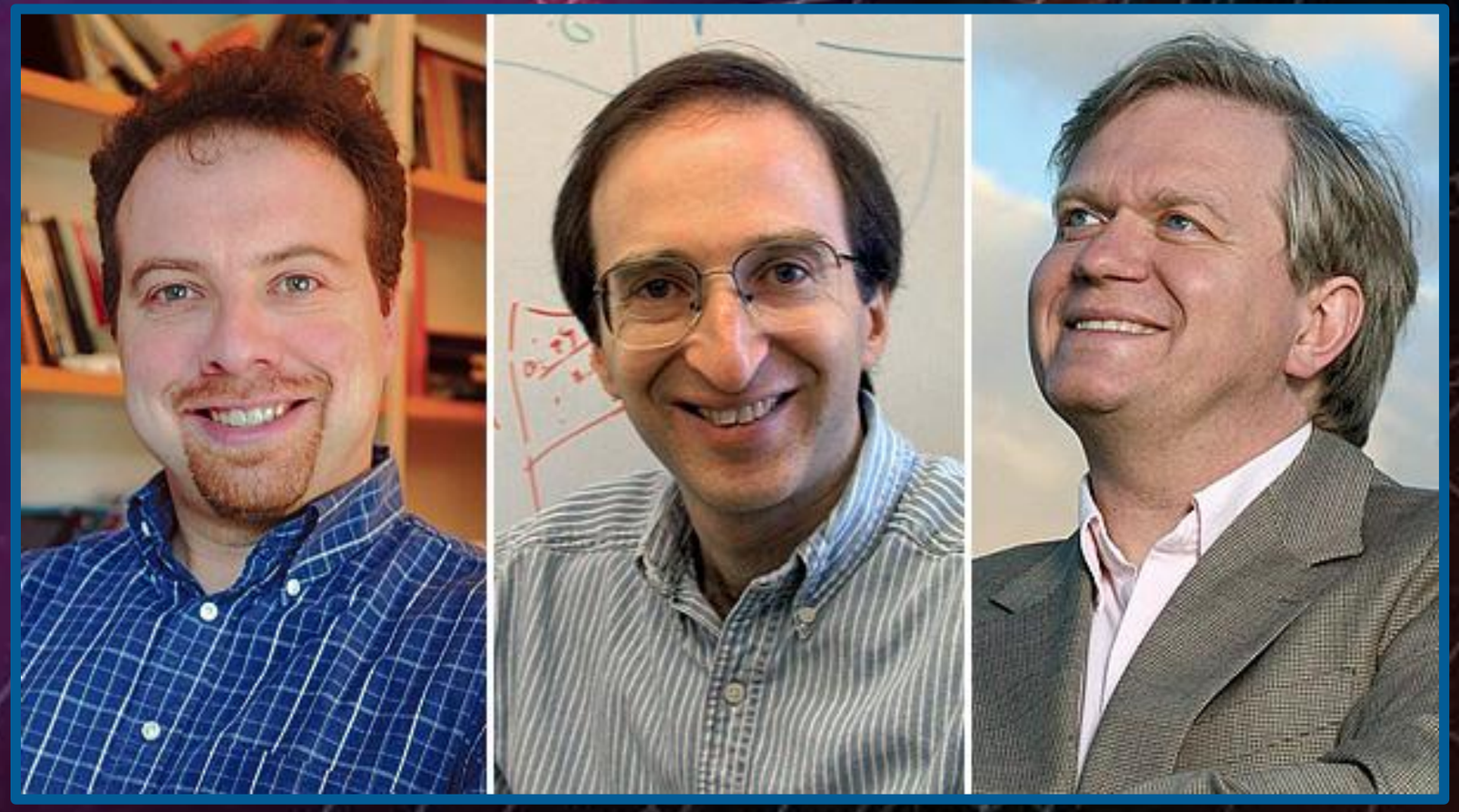
Vera Rubin

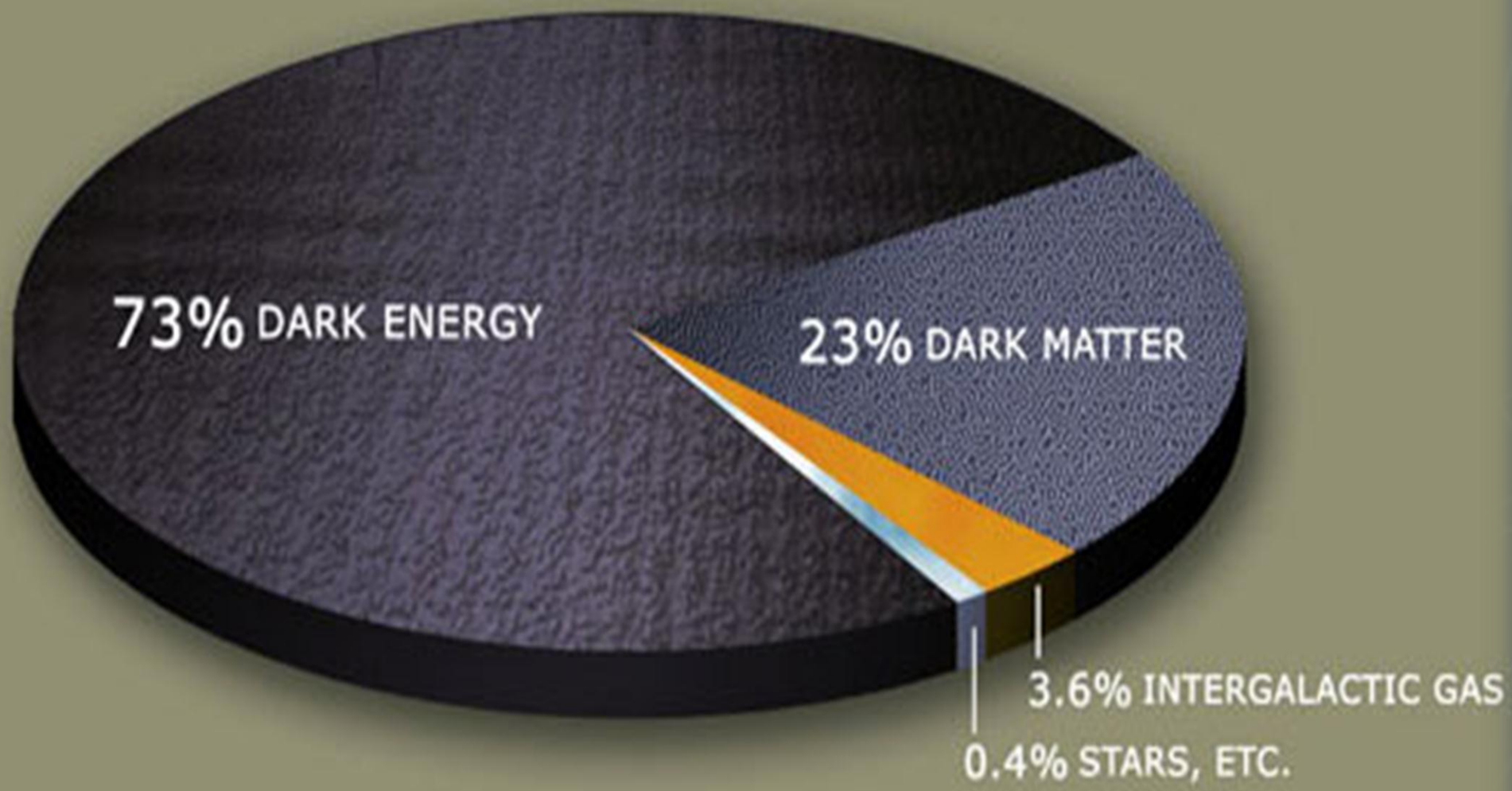
1970s

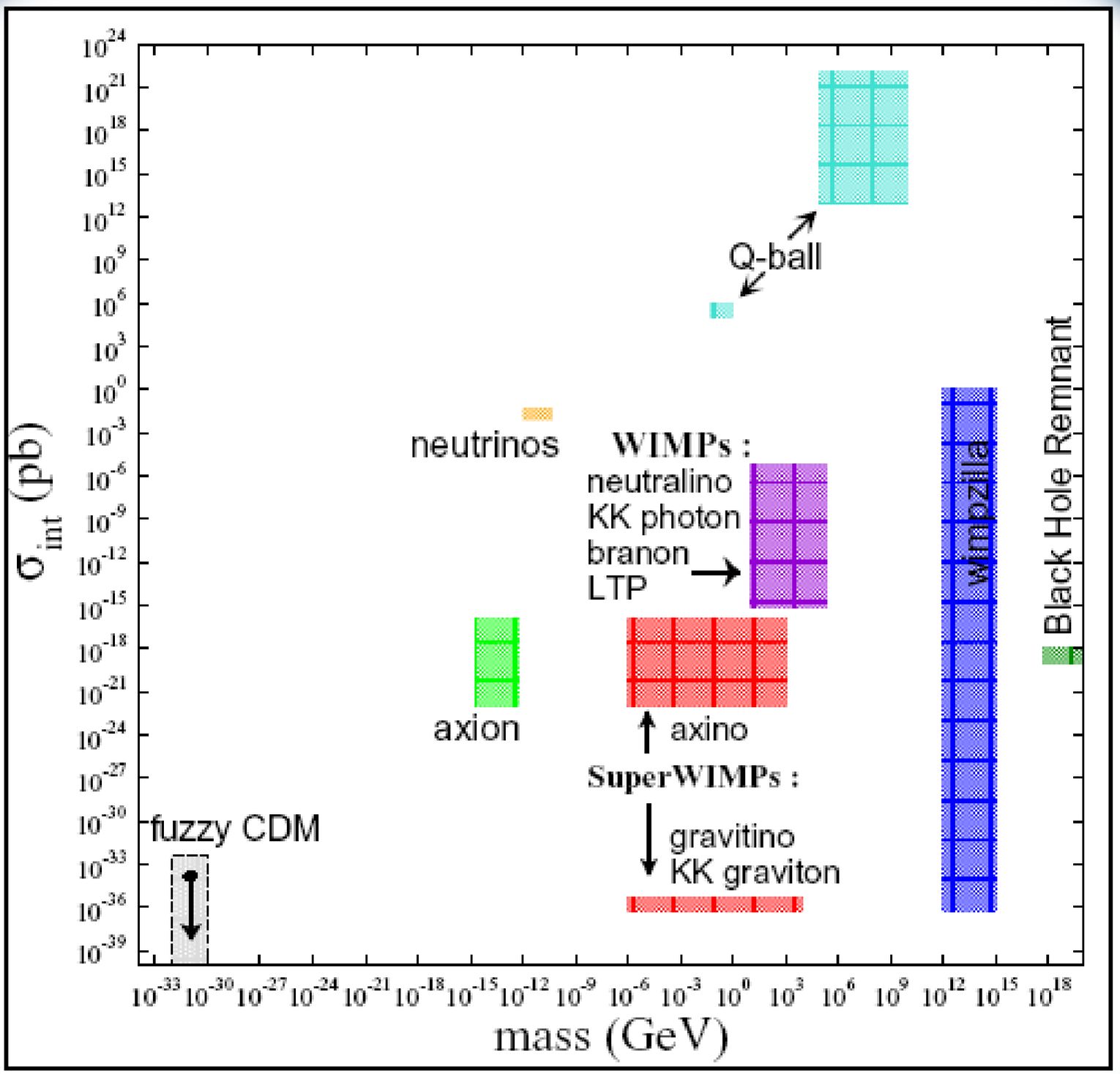


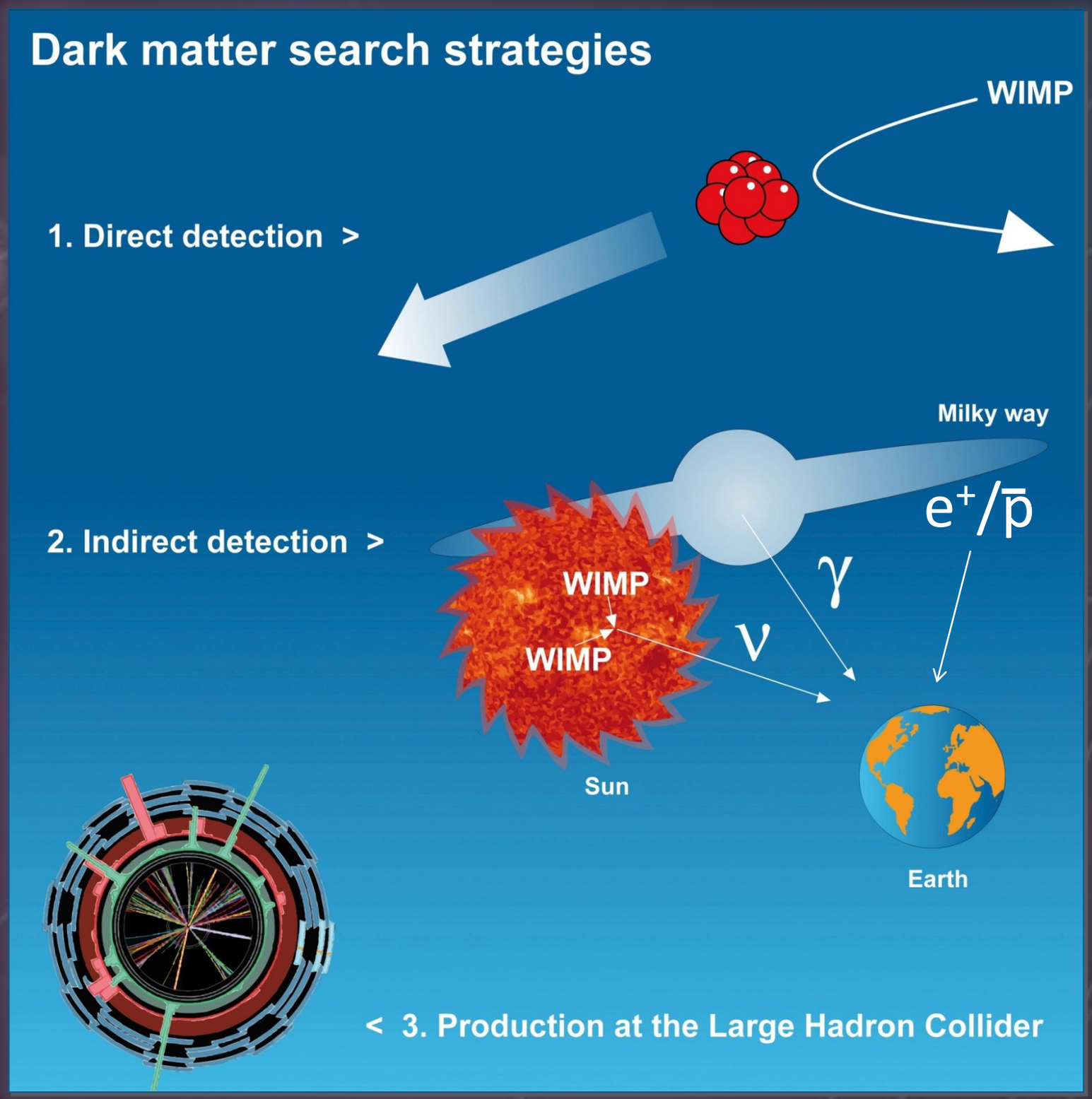
A. Riess, S. Perlmutter, B. Schmidt

1998



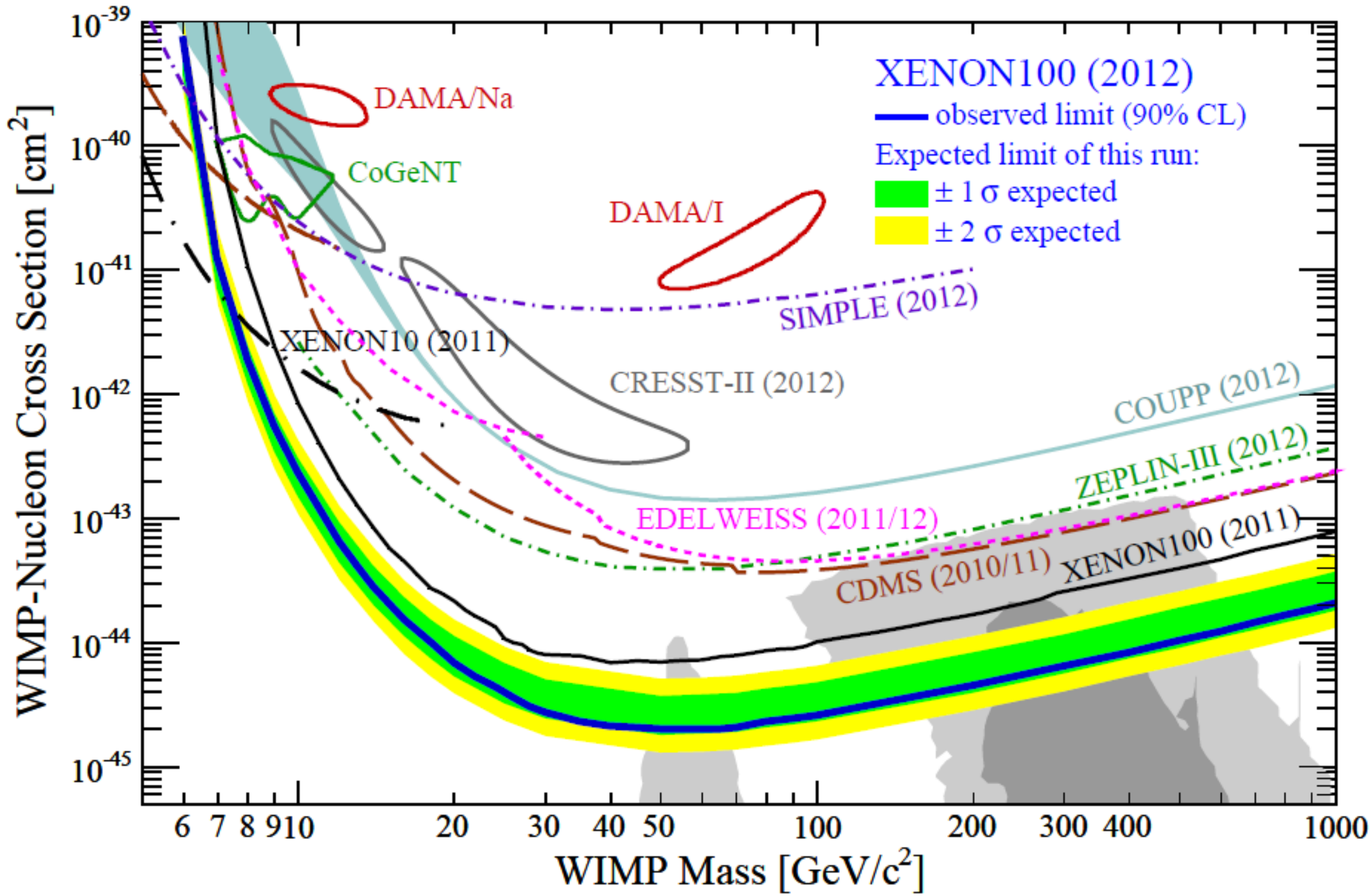

73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.


Q-ball
neutrinos
WIMPs :
neutralino
KK photon
branon
LTP
wimpzilla
Black Hole Remnant
axion
axino
SuperWIMPs :
gravitino
KK graviton
fuzzy CDM
σ_{int} (pb)
mass (GeV)



ν	IceCube, Antares, Baikal , Super-K.
γ	HESS/MAGIC/VERITAS Agile, Fermi
e/p	balloon exp.s Pamela Fermi, AMS

Snapshot Summer 2012

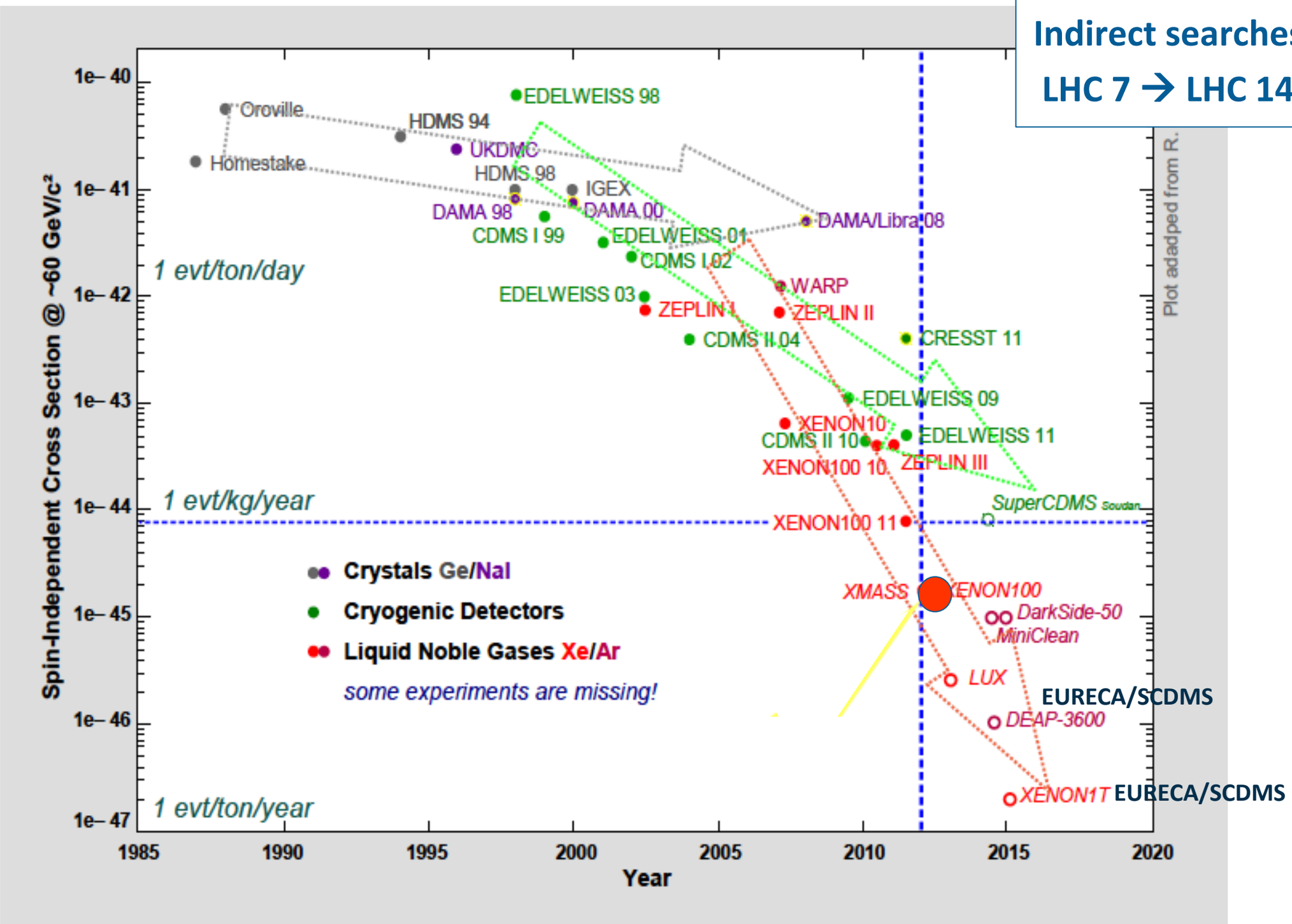


Perspectives 2017-20

Direct searches: factor of 100

Indirect searches: factor 10-30

LHC 7 → LHC 14: factor 300-1000



EURECA/SCDMS

EURECA/SCDMS

WIMP Dark Matter

- **SUSY -WIMP DM hypothesis will be proven/disproven within the next 5-10 years.**

- Stormy progress of LXe technology. XENON100 → XENON1T. XMASS. LUX.
- LAr technology: new interest using argon depleted in ^{39}Ar.
  Demonstration: DarkSide-50 (50 kt, LNGS).
- **DARWIN (target mass of noble liquids up to 10-20 tons)**

- Bolometric approach: EDELWEISS Ge), CRESST ($CaWO_4$). CDMS in US.
- **EURECA & SCDMS (~1 ton sensitive mass)**

- R&D on directional detection (confirmation of the galactic character of potential positive detection by high-density target detectors)
- DAMA/LIBRA: Need fully independent experiment of same/similar technology.

Neutrino Properties

m_ν → direct measurements

→ neutrinoless double beta decay, $0\nu\beta\beta$

Majorana vs. Dirac

→ neutrinoless double beta decay

Mixing parameters

→ oscillation experiments

Wolfgang Pauli

1930

Maria Göppert-Mayer

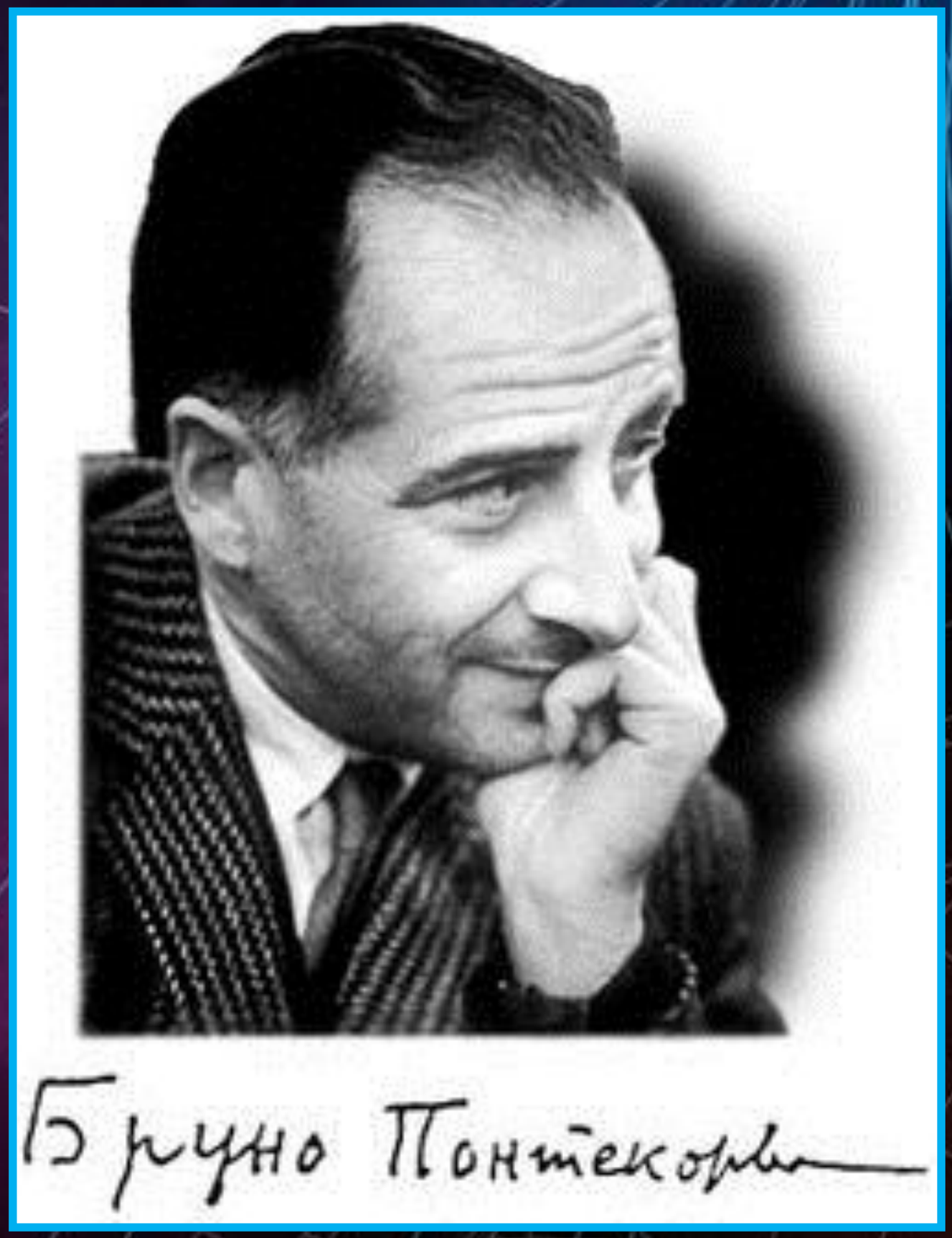
1935

Ettore Majorana

1937

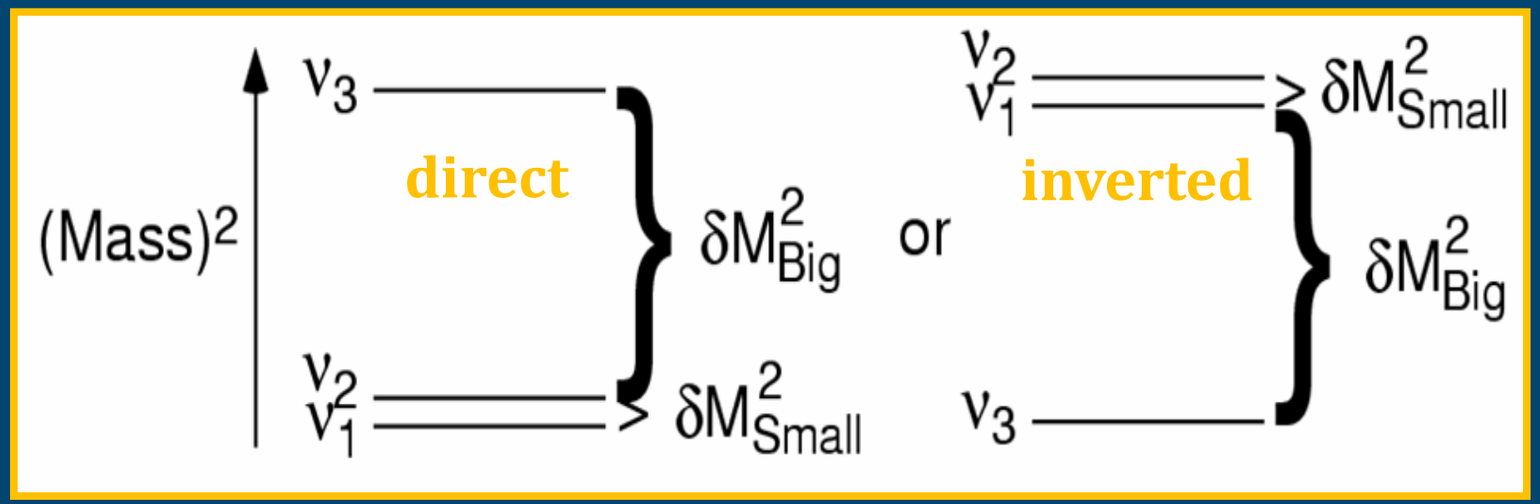
Bruno Pontecorvo

1957-67



We do not yet know:

- Absolute neutrino mass scale
- Mass hierarchy

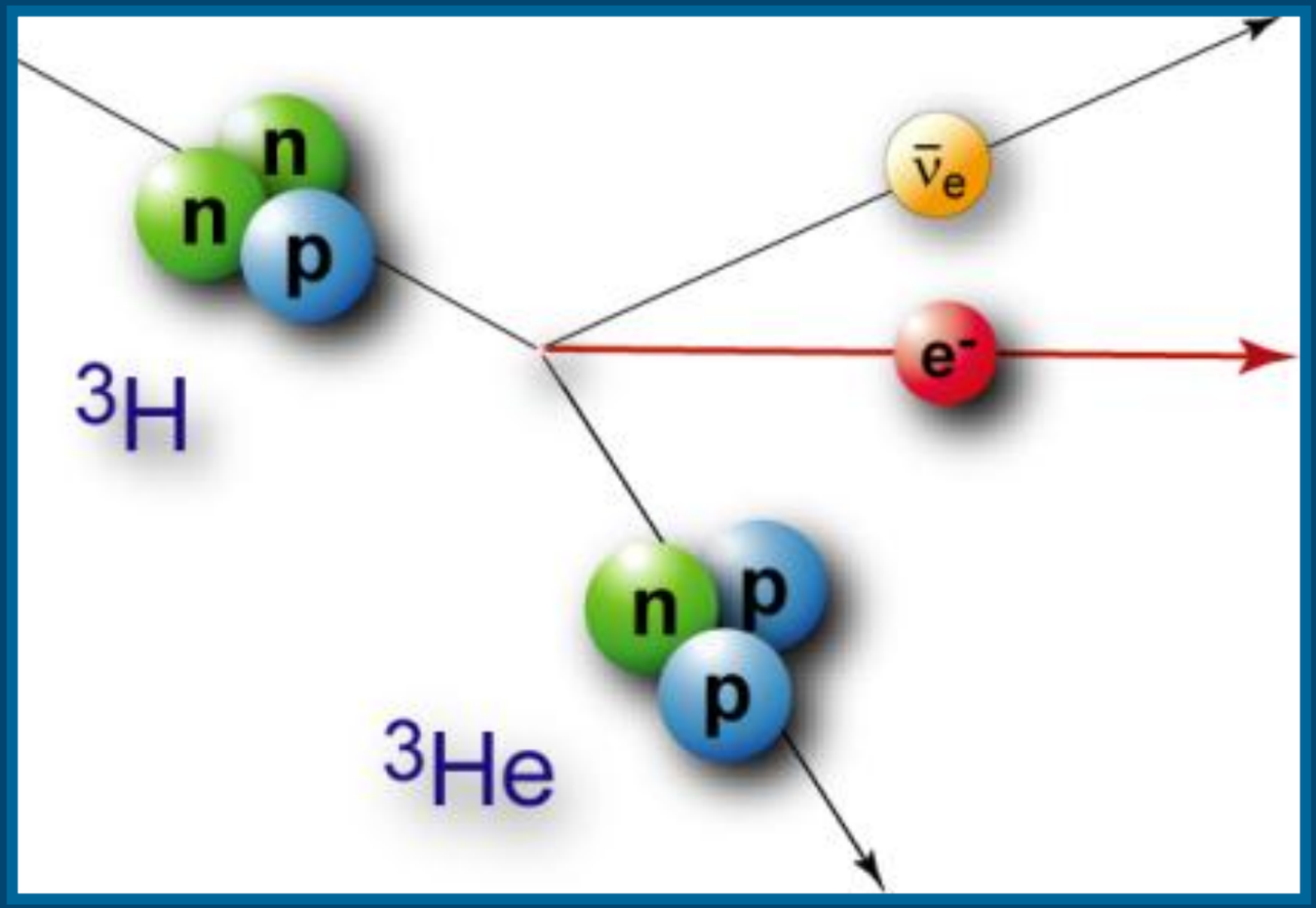


- Nature: Dirac or Majorana

$$\nu \neq \bar{\nu}$$

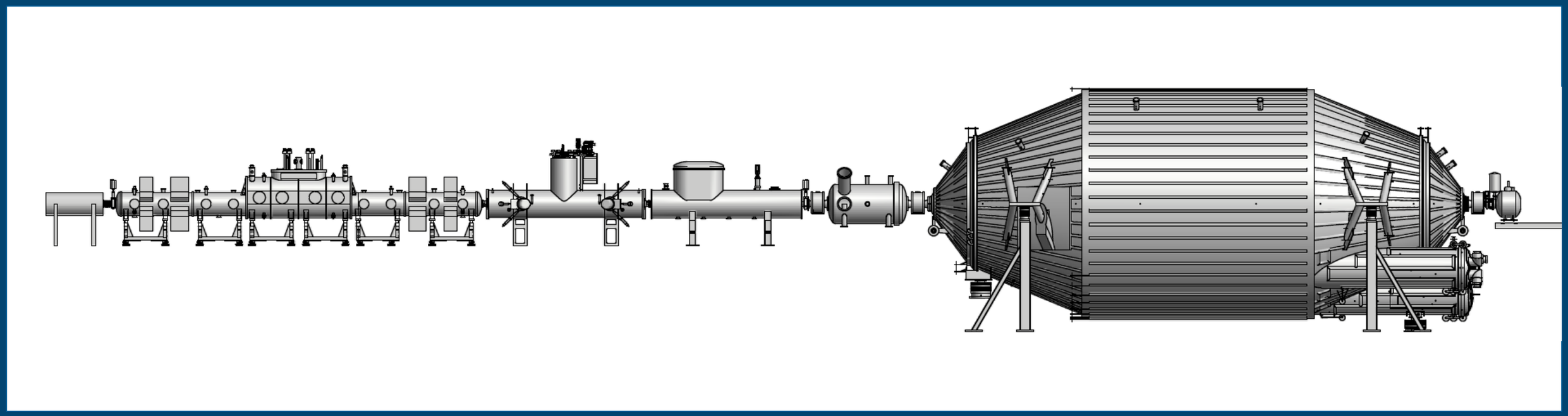
$$\nu \equiv \bar{\nu}$$

- CP violating phase
- Are there sterile neutrinos?



KATRIN

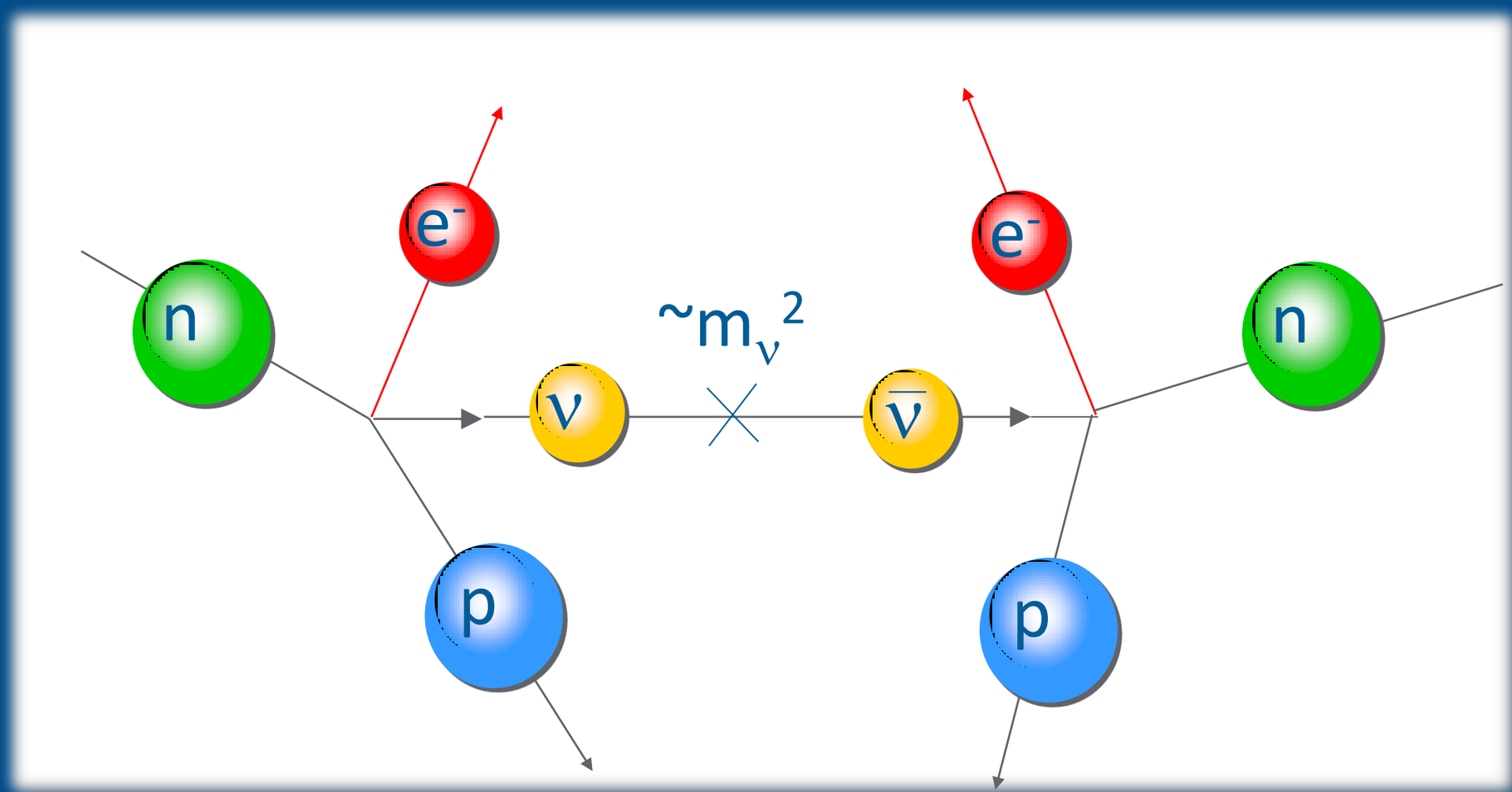
Karlsruhe Tritium Neutrino Experiment



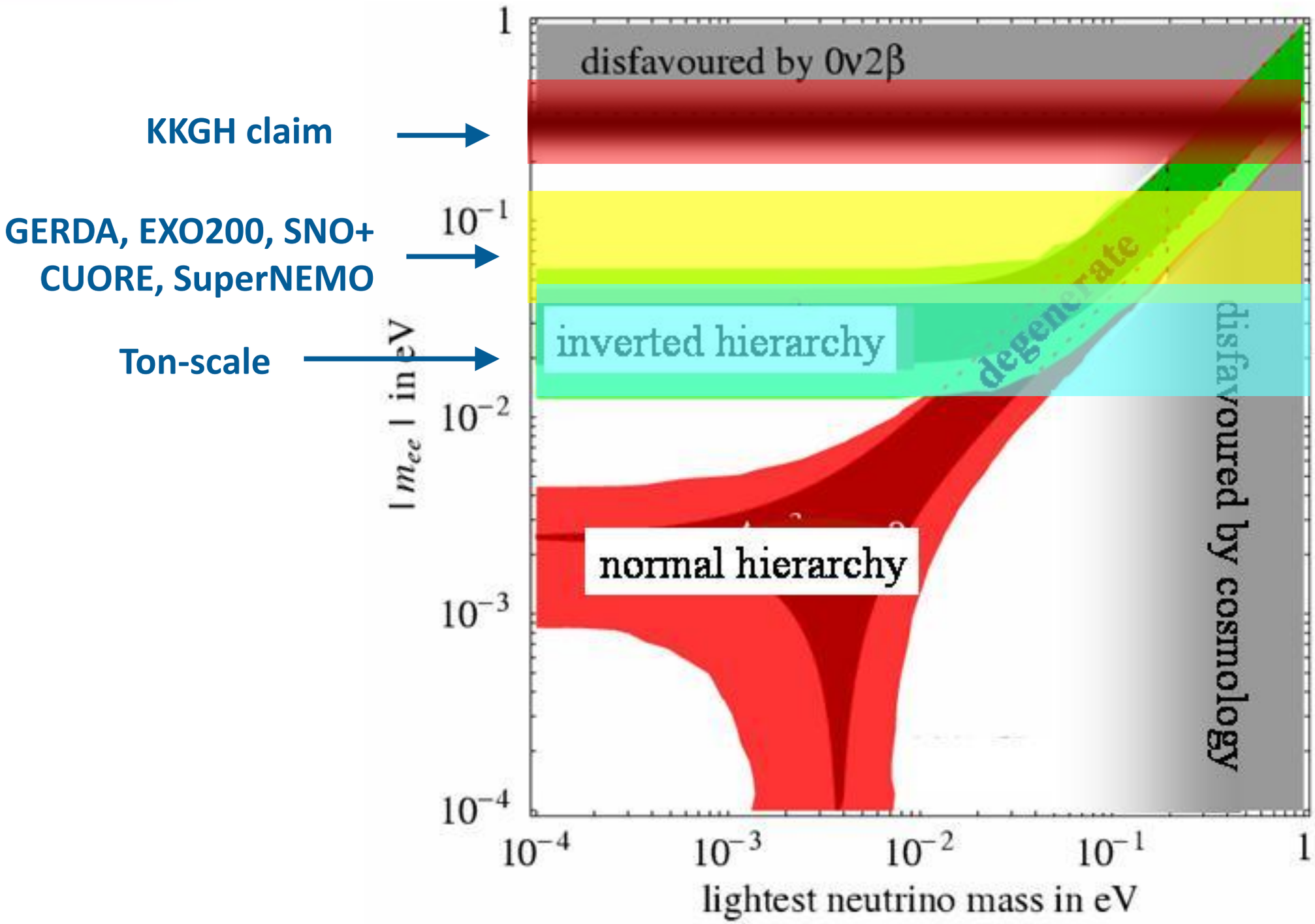
KATRIN main spectrometer electrode system installed

$0\nu\beta\beta$

Neutrinoless Double Beta Decay

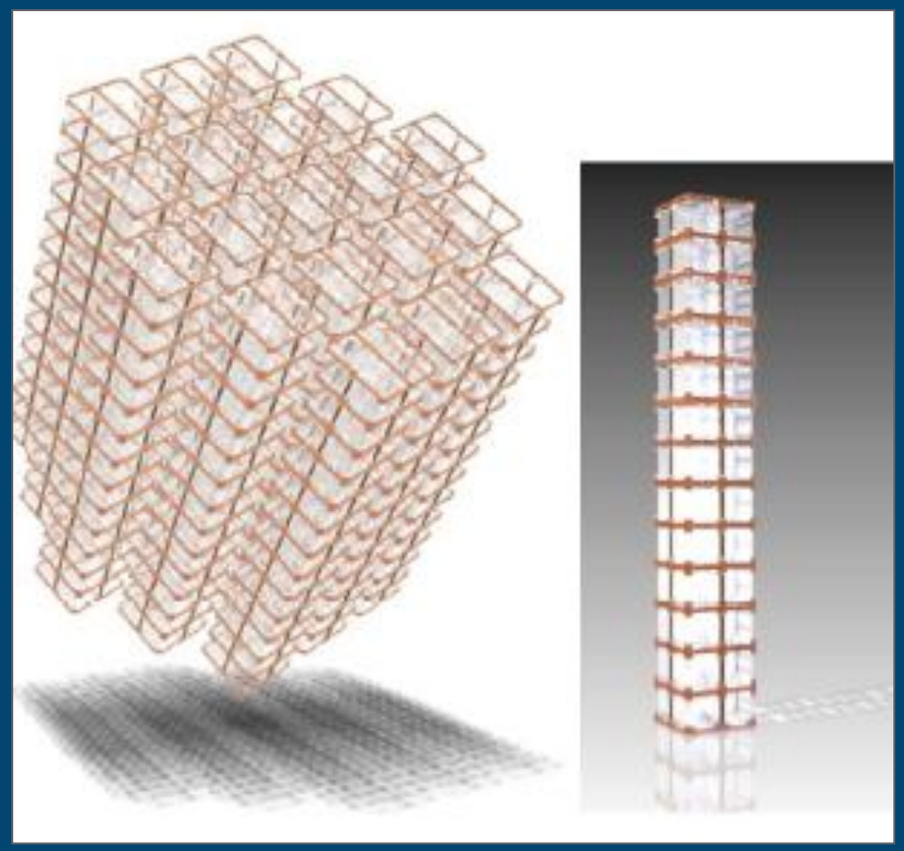


0νββ

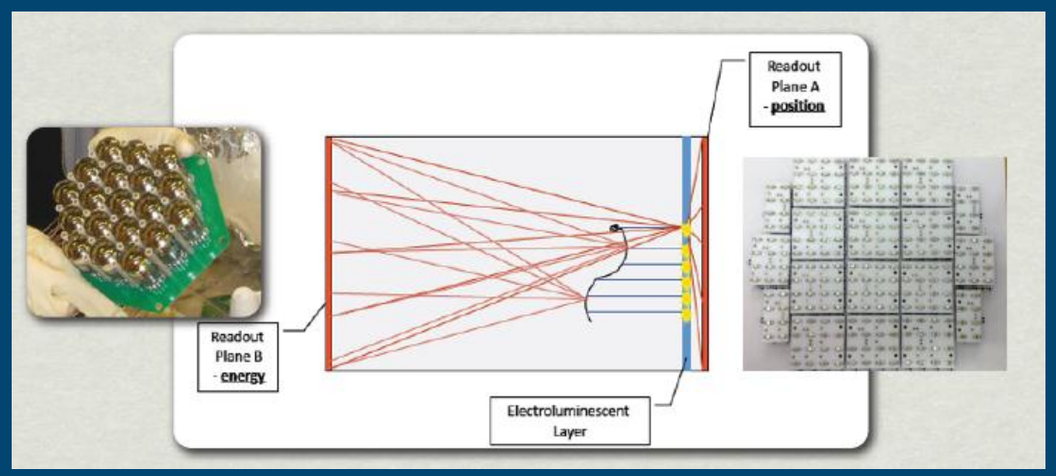

KKGH claim
GERDA, EXO200, SNO+
CUORE, SuperNEMO
Ton-scale
disfavoured by 0ν2β
inverted hierarchy
degenerate
normal hierarchy
disfavoured by cosmology
$|m_{ee}|$ in eV
lightest neutrino mass in eV
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1

0νββ in Europe

GERDA

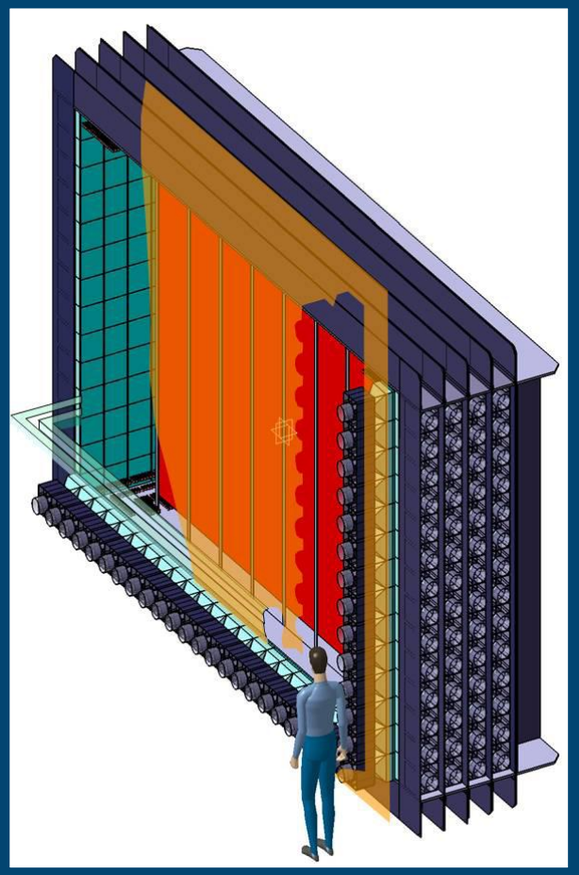


CUORE



NEXT

Super-NEMO



plus EXO-200, SNO+, COBRA, LUCIFER

GERDA – phase 1

GERDA Phase 2: 70 – 130 meV

GERDA Phase 3 (together with Majorana): 20- 40 meV

GERDA Inauguration Nov 2010

Now data taking. Unblinding spring 2013

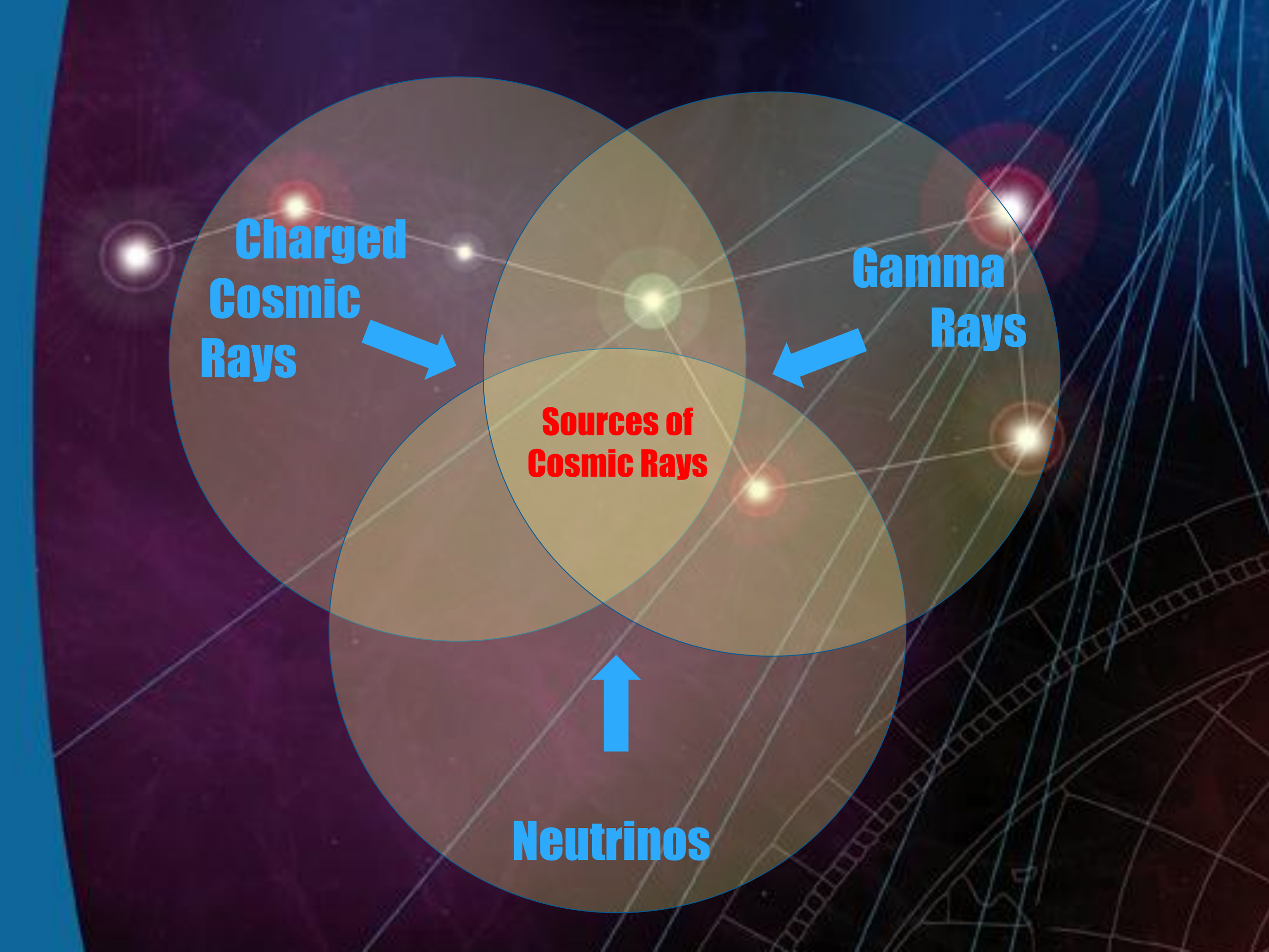
Summary $0\nu\beta\beta$ decay

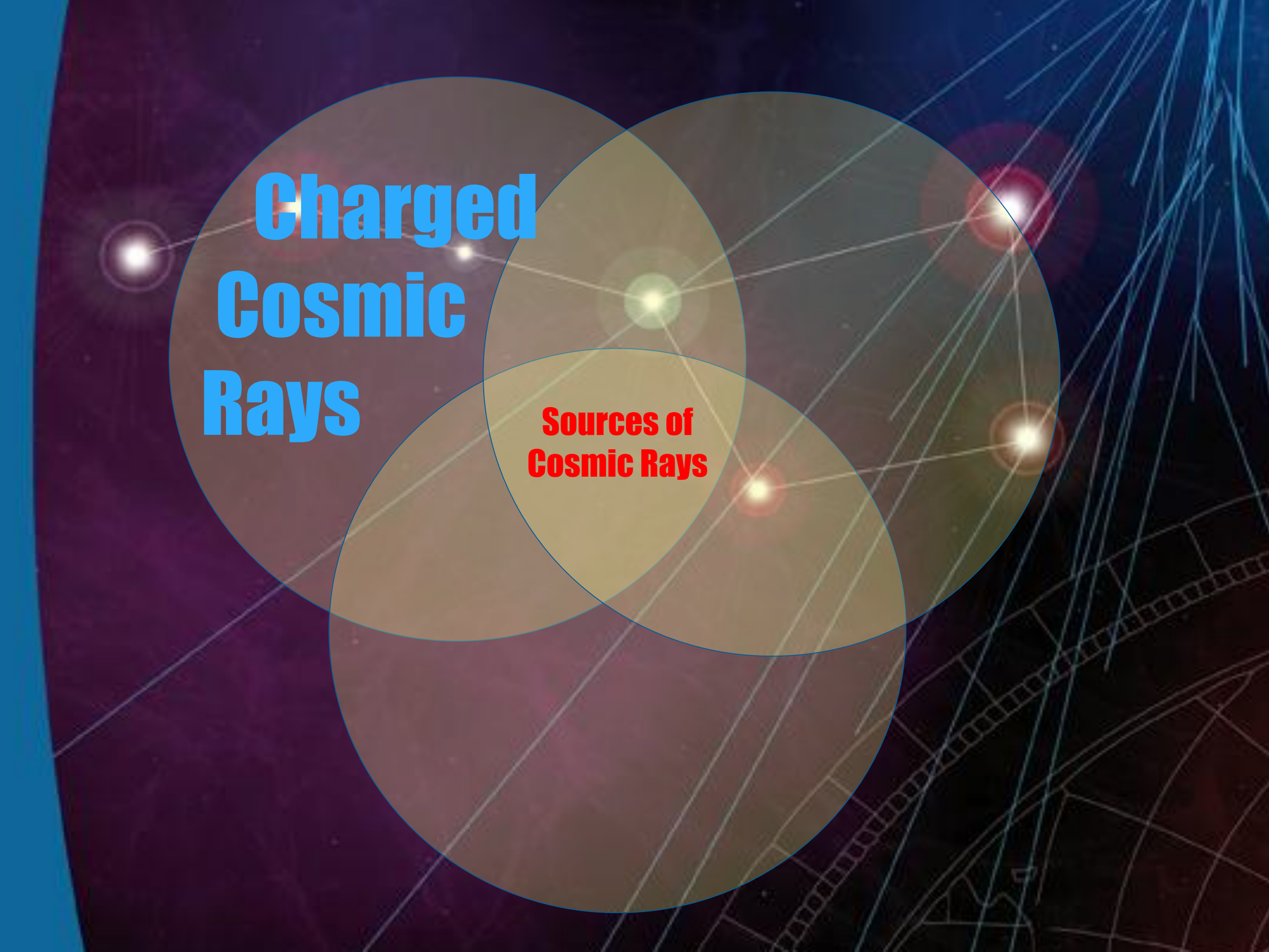
- **Phased experimental approach towards ton-scale masses with a sensitivity exploring fully the mass range predicted by oscillation experiments for the Inverted Hierarchy.**

- **R&D on new techniques for isotope separation.**

- **High cost of ton-scale → realisation within worldwide collaborations as e.g. pursued by GERDA and MAJORANA.**

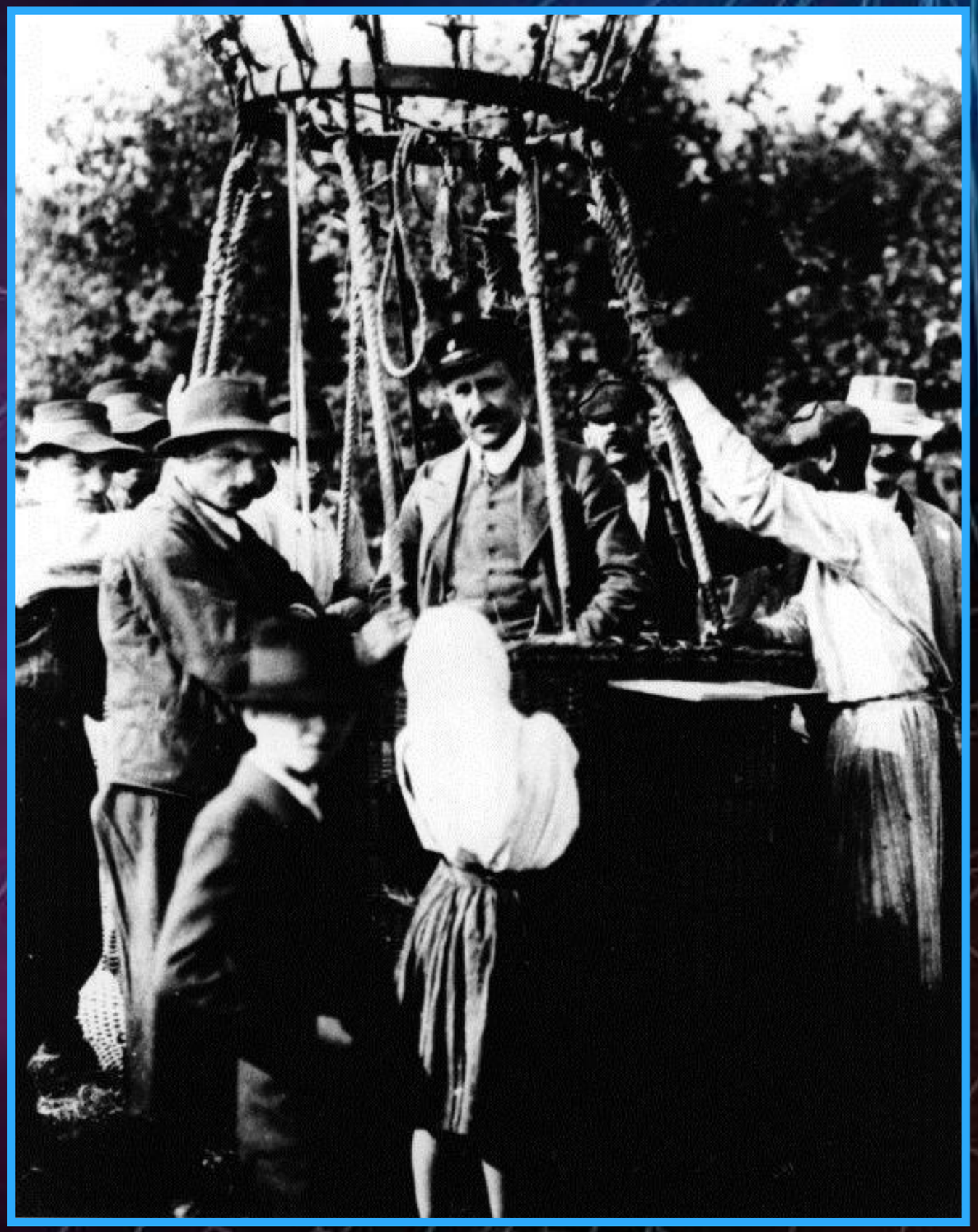
The High-Energy Universe


Charged Cosmic Rays
Gamma Rays
Sources of Cosmic Rays
Neutrinos


Charged Cosmic Rays
Sources of Cosmic Rays

Viktor Hess

1912



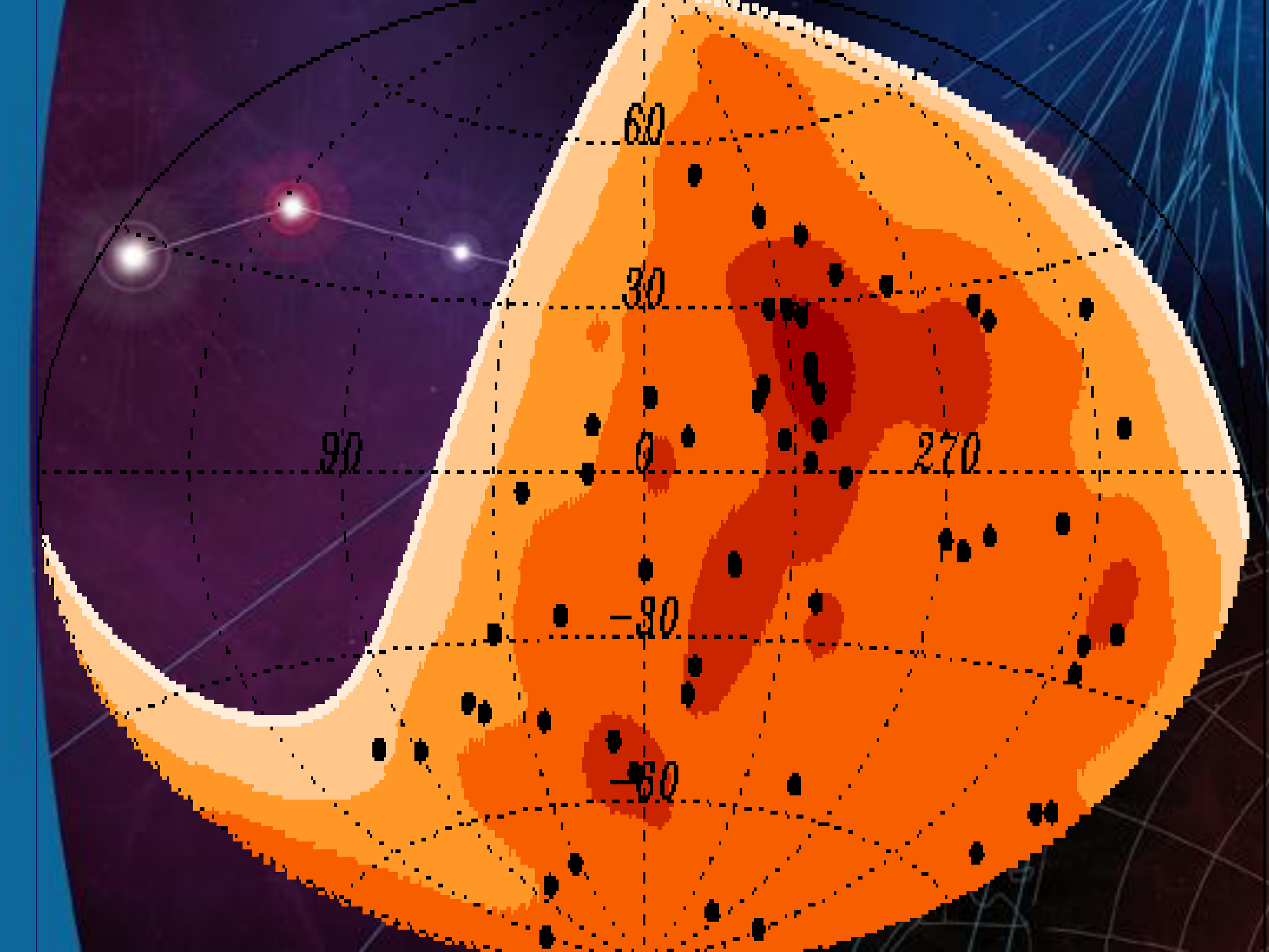
Pierre Auger

1939

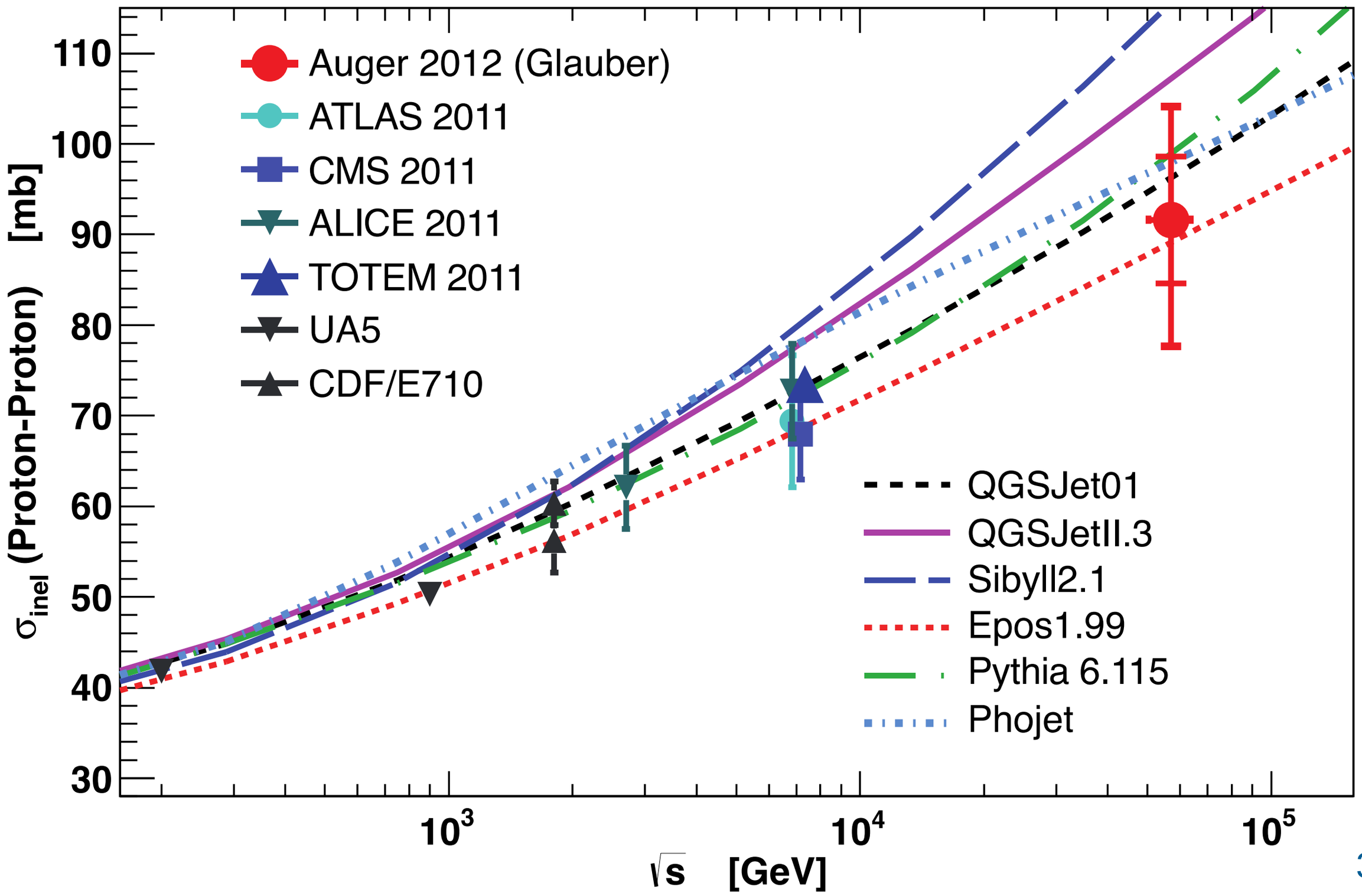
John Linsley

1961

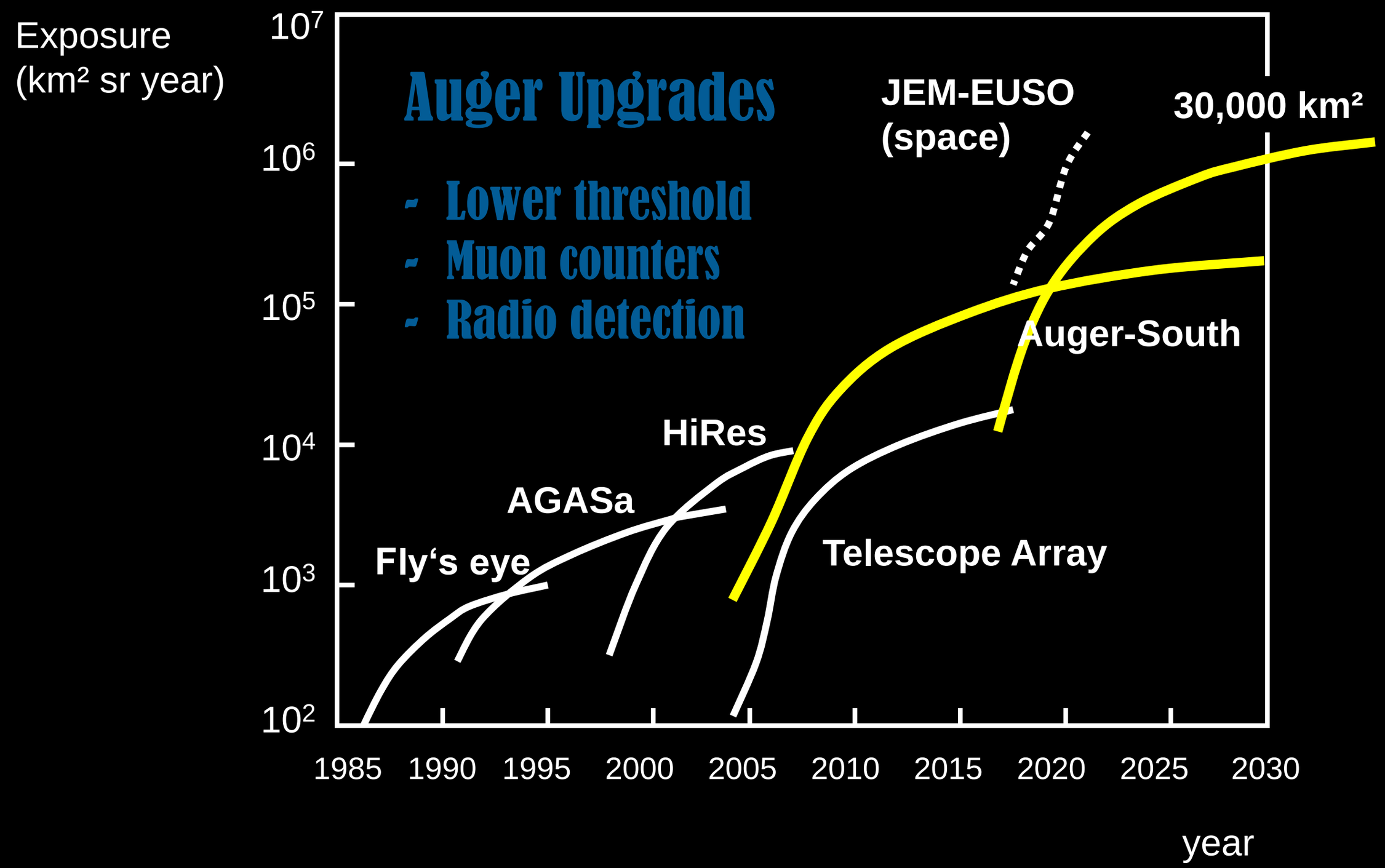
The Pierre Auger Observatory

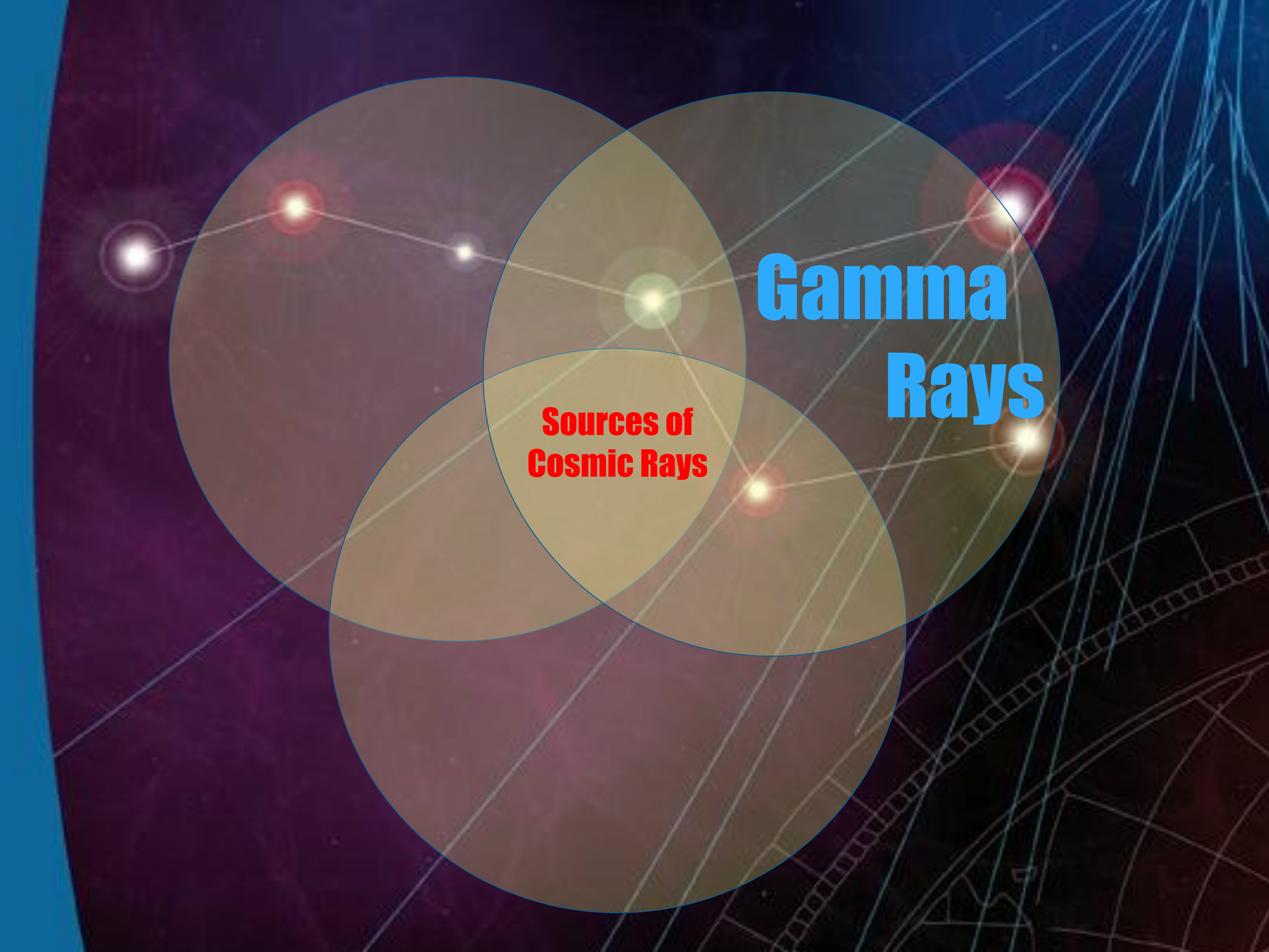

60
30
90
0
270
−30
−60

Cosmic Rays and LHC



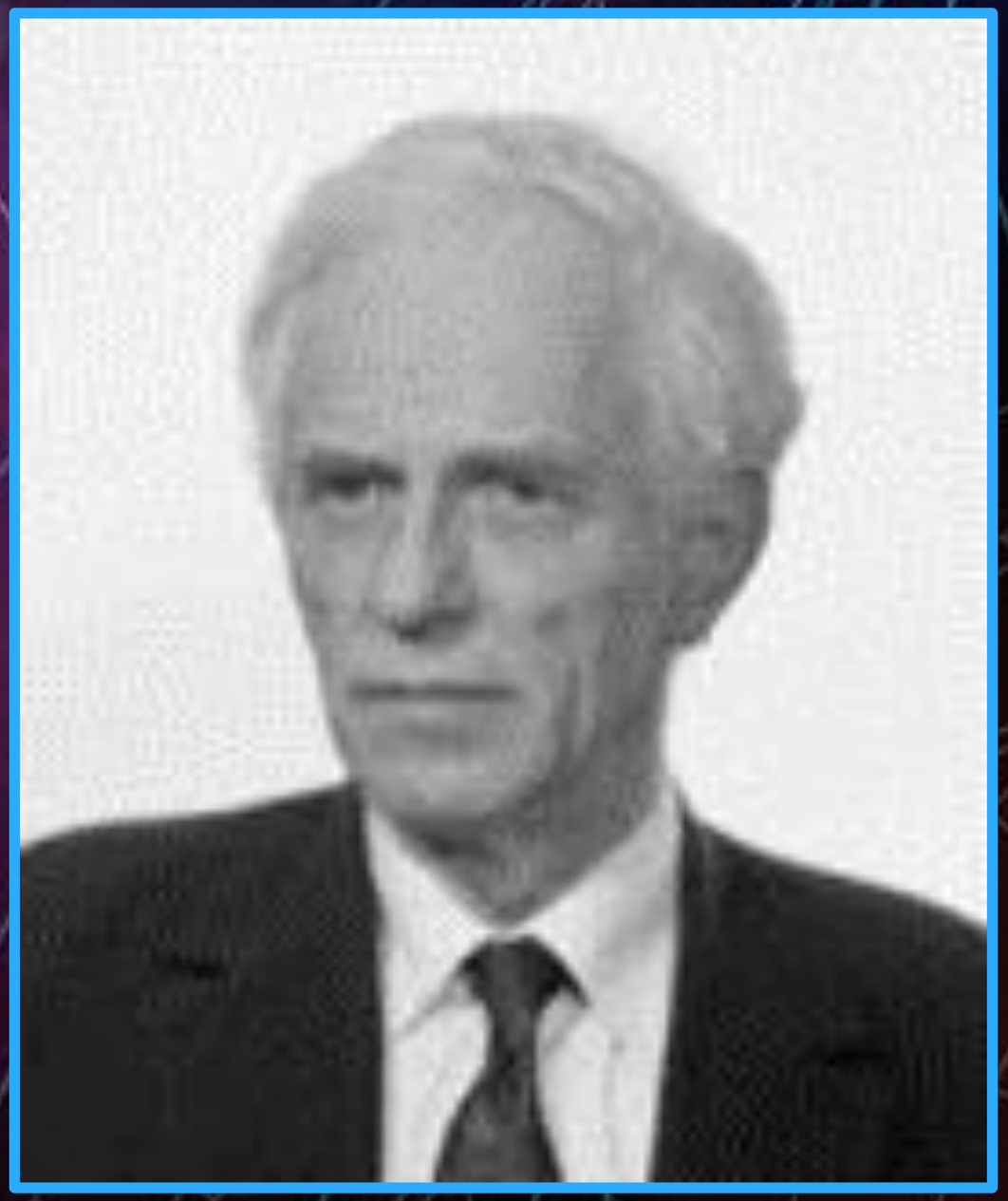
Perspective for cosmic rays at highest Energies



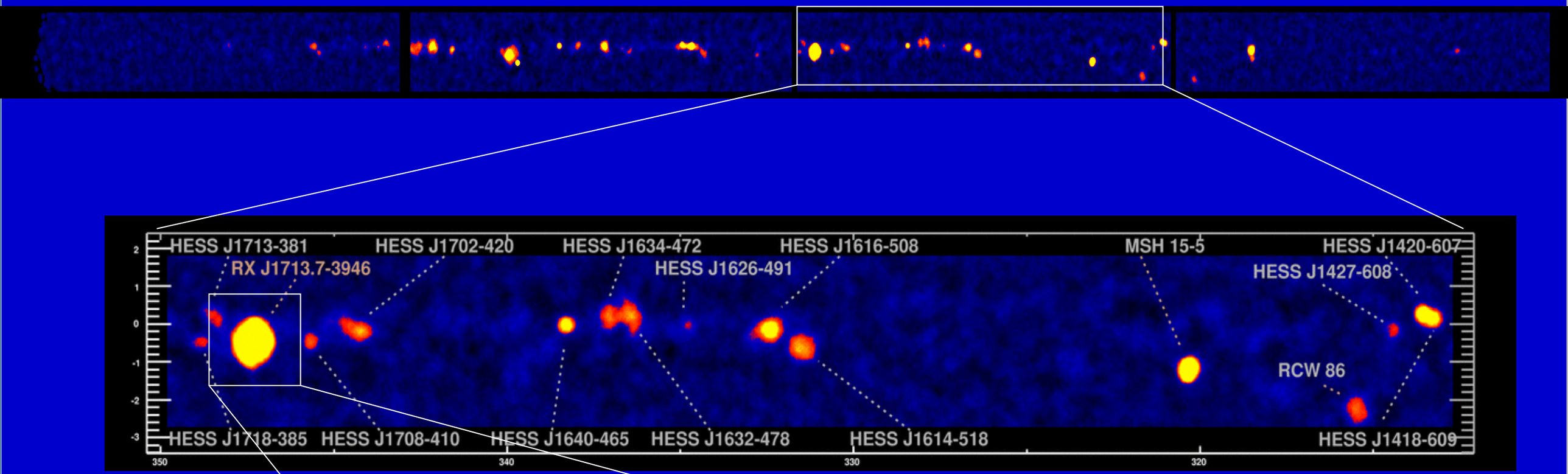

Gamma Rays
Sources of Cosmic Rays

Alexander Chudakov

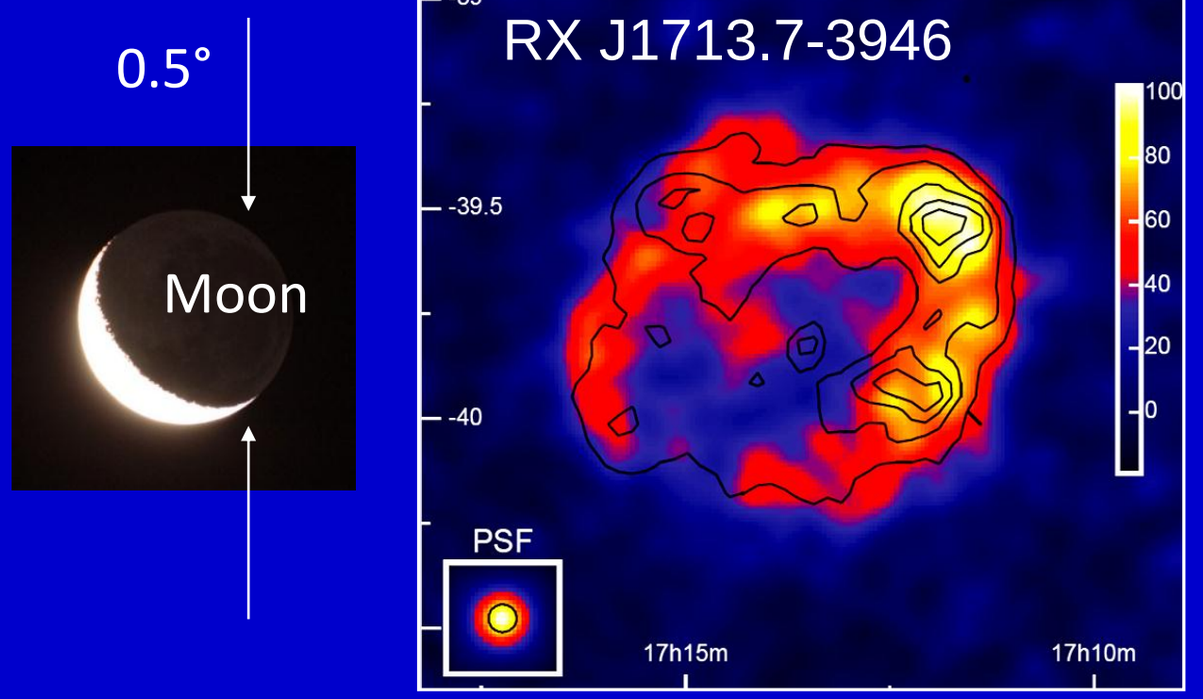
1965



The Sky at TeV-Energies

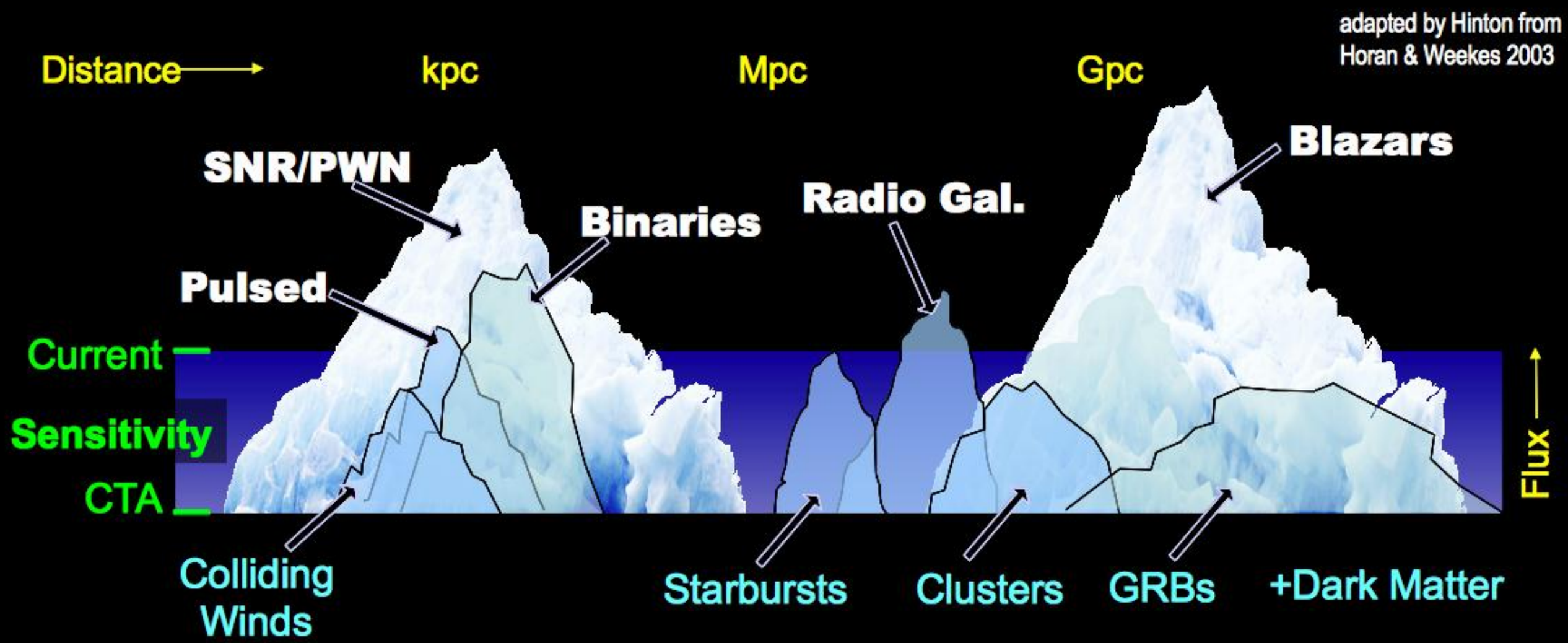


H.E.S.S.-Scan of the galactic plane



1989:	1 Source
1996:	3 Sources
2005:	80 Sources
2012:	150 Sources

Science Potential



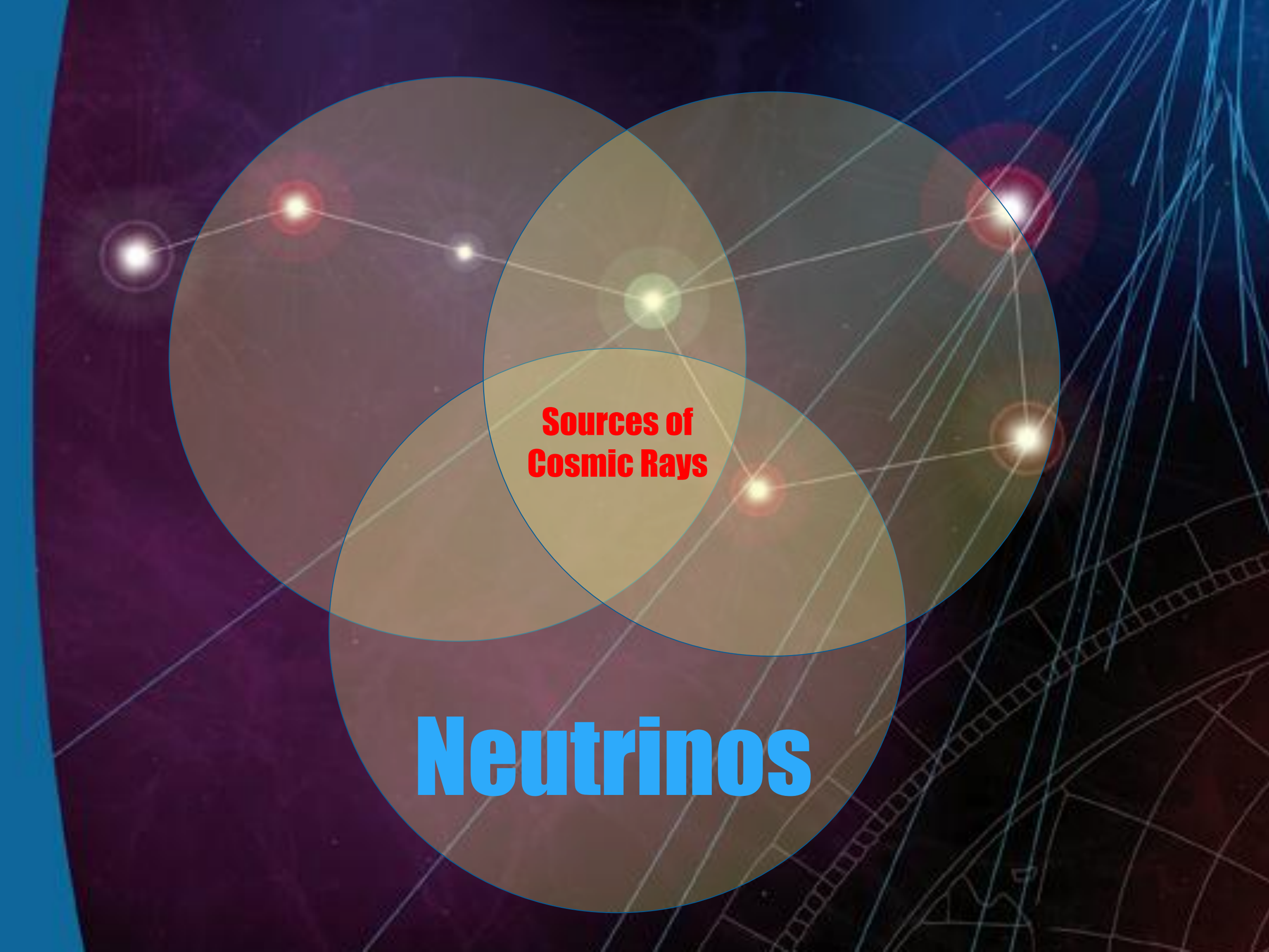
- **Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg**


cta
cherenkov telescope array


Prototyp of Mid-Size Telescope CTA, Berlin
(photoshop version)

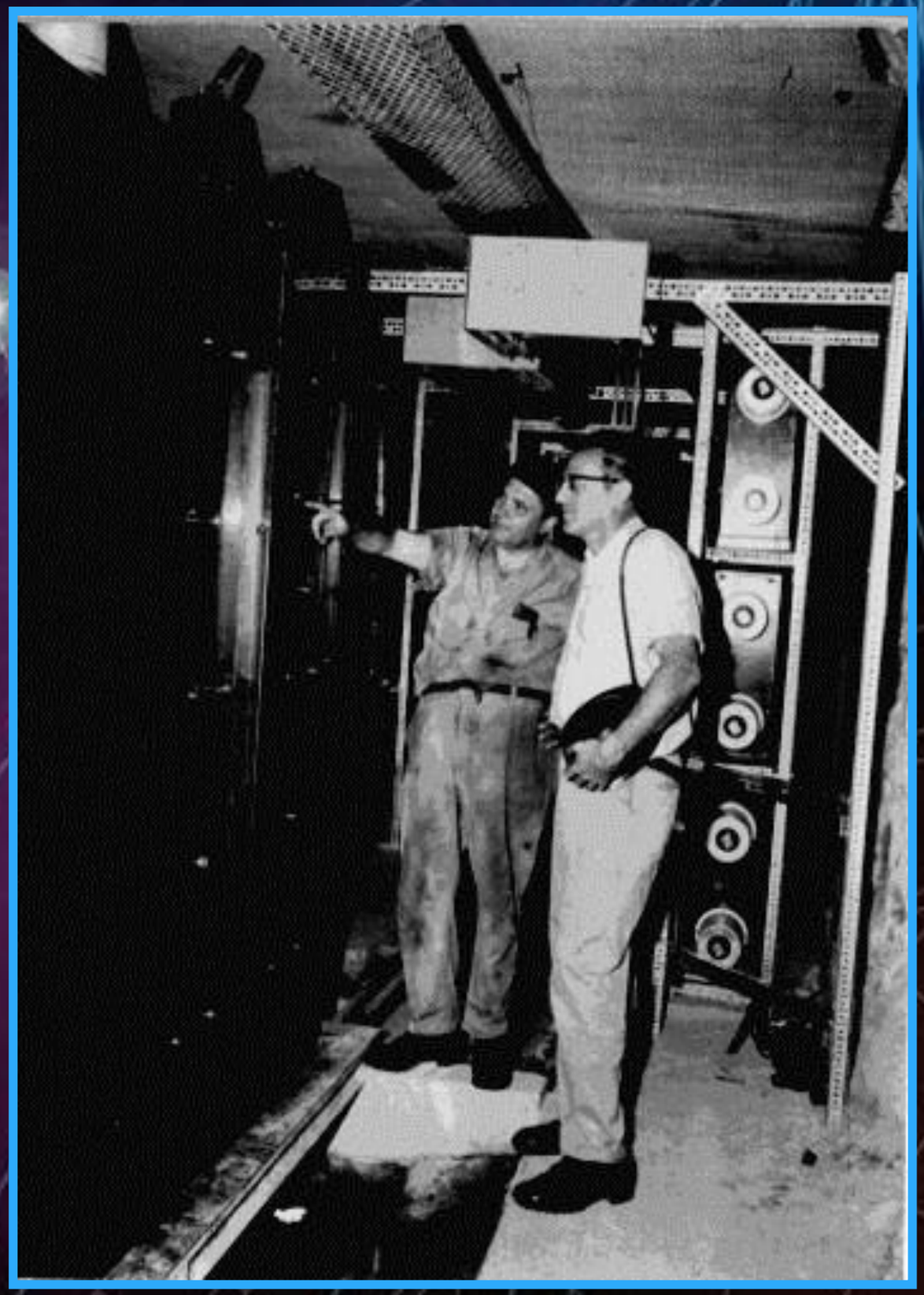
Plus:

- MACE (India)
- HAWC (Mexico)
- HiSCORE (Siberia)
- LHAASO (Tibet)
- Fermi (space, USA-led)
- GAMMA-400 (space, Russia-led)


Sources of
Cosmic Rays
Neutrinos

Fred Reines

1965

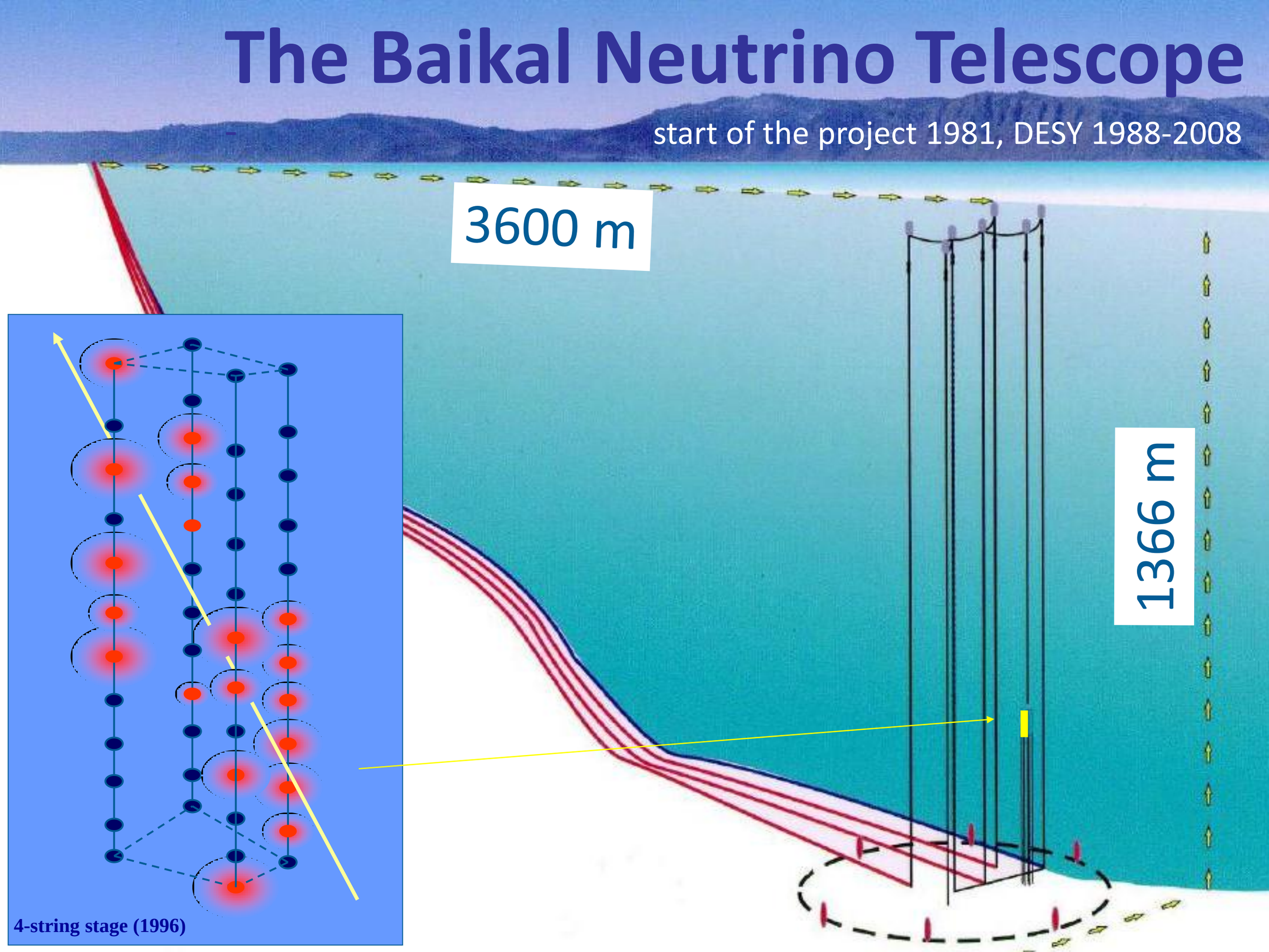


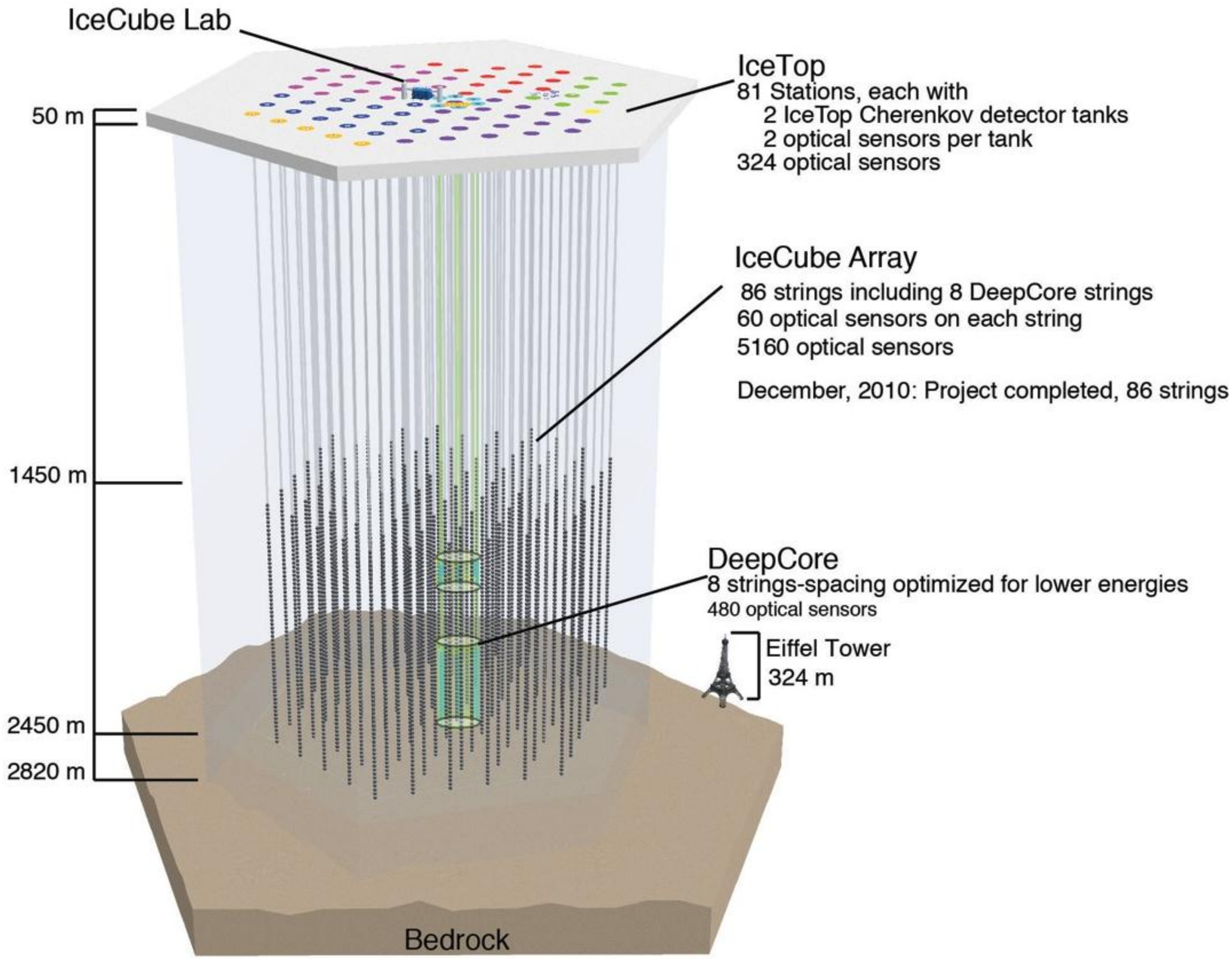
Moisej Markov

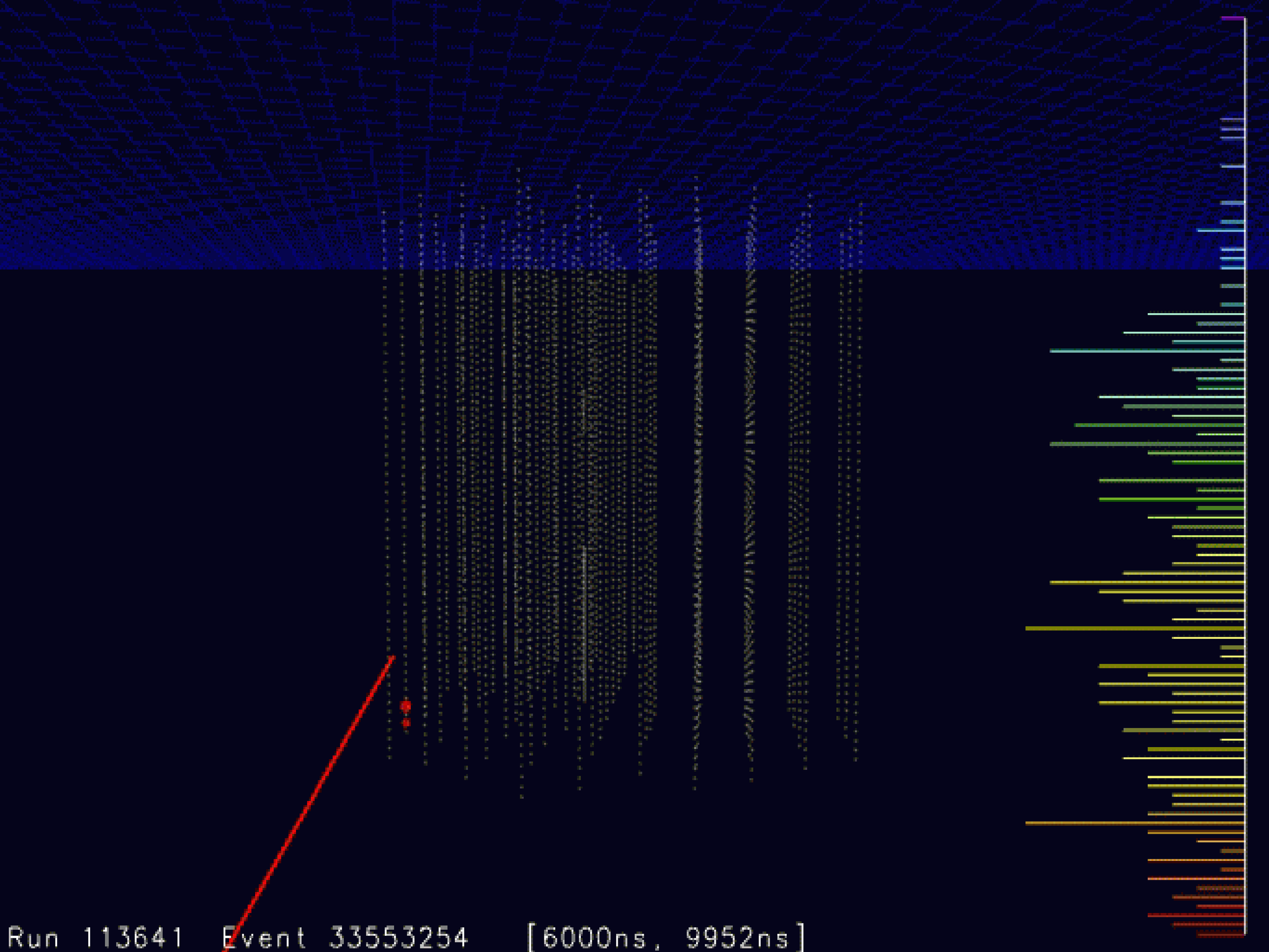
1960

The Baikal Neutrino Telescope

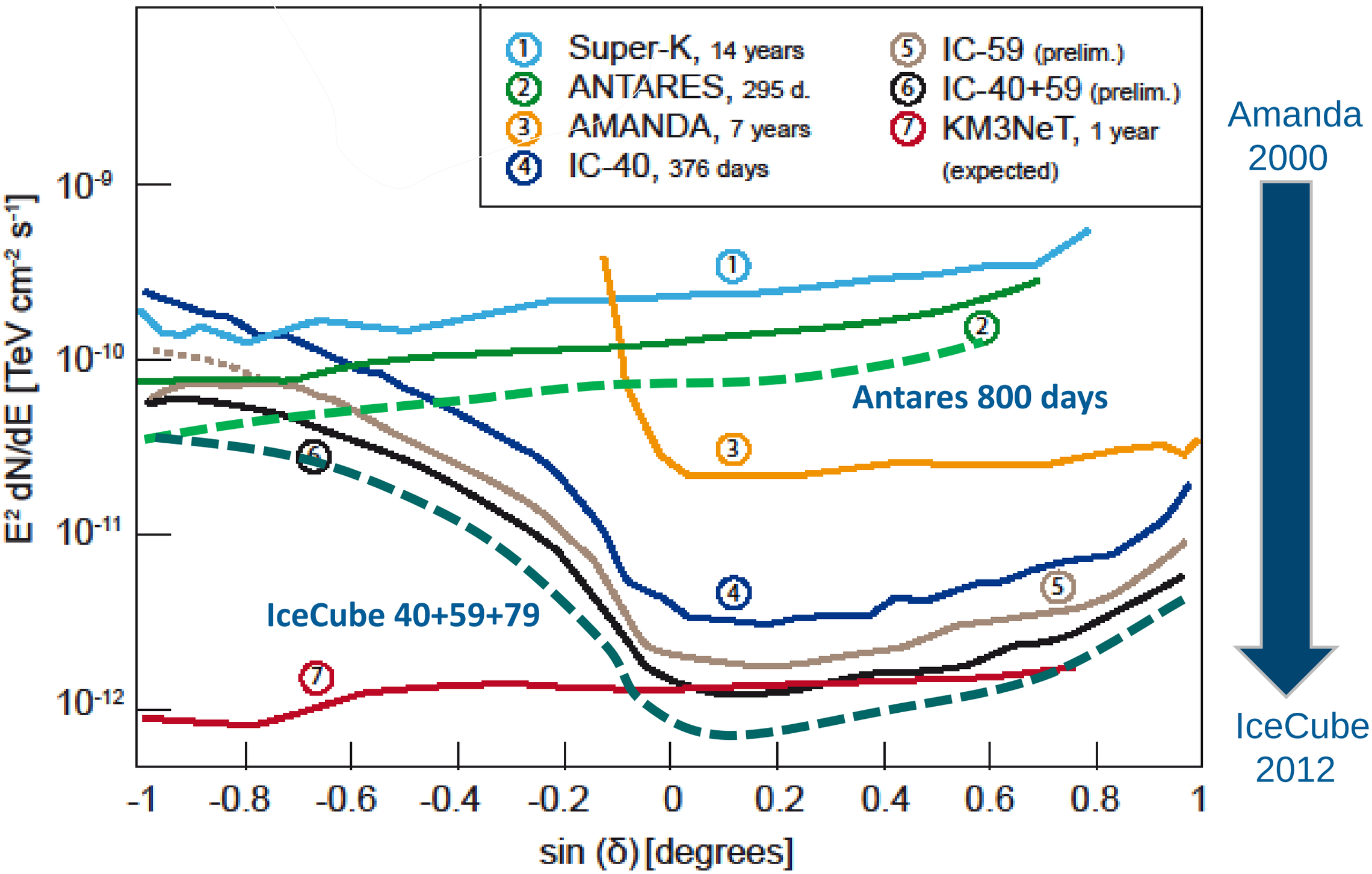
start of the project 1981, DESY 1988-2008

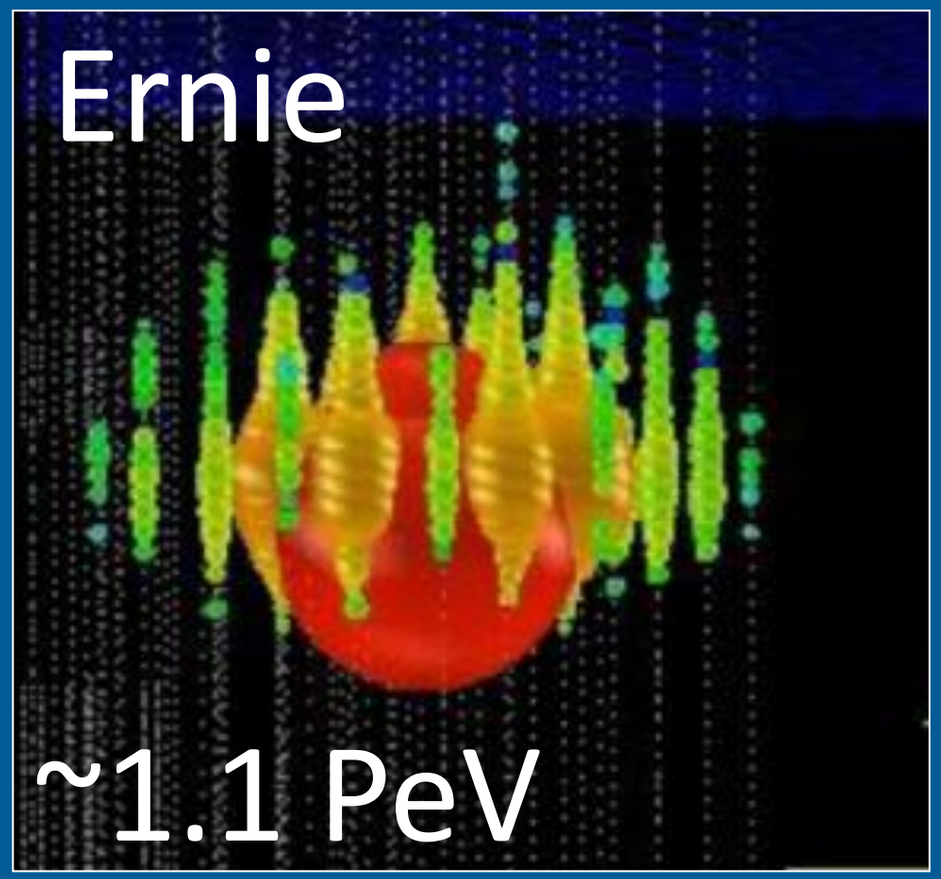


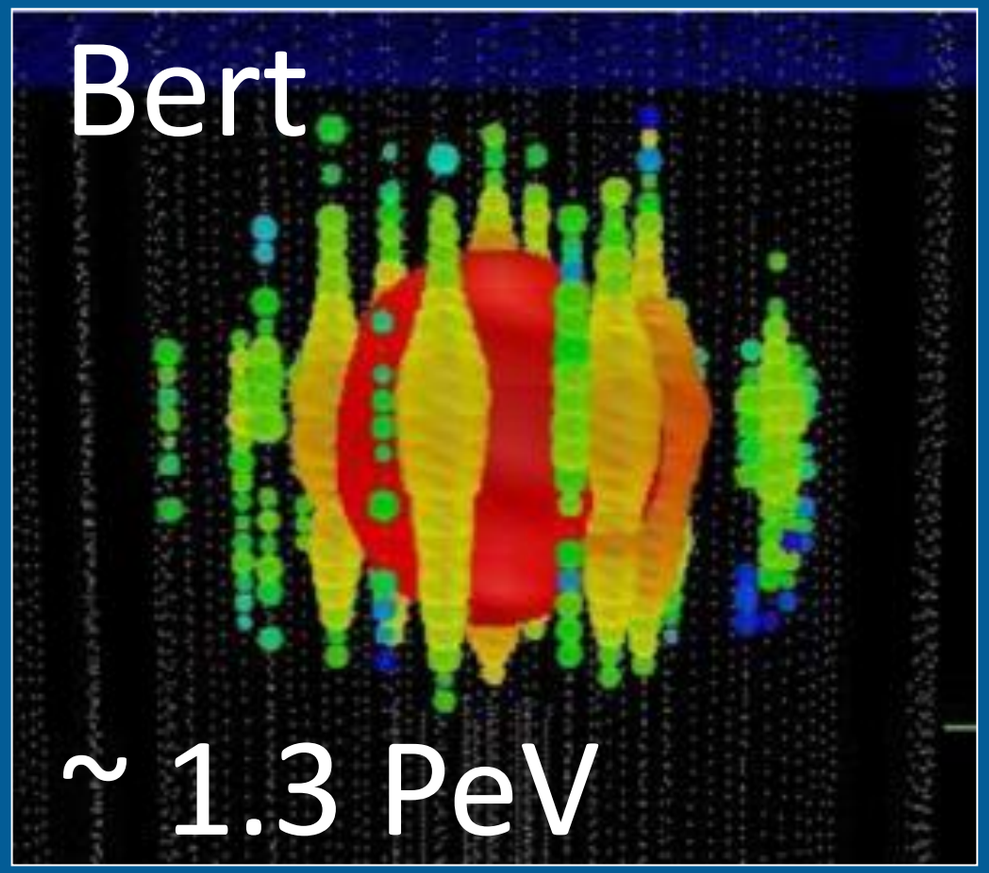

IceCube Lab
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
50 m
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
1450 m
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
2450 m
2820 m
Bedrock


Run 113641 Event 33553254 [6000ns, 9952ns]

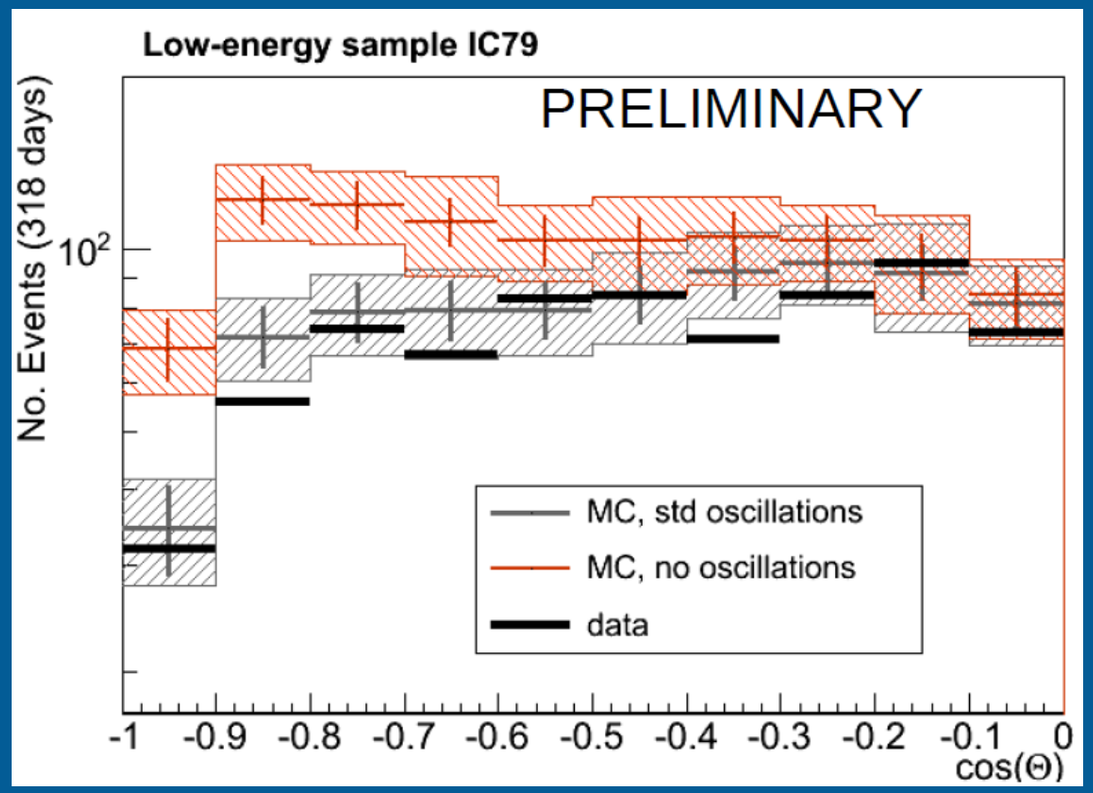
Last 12 years: a factor of 1000 !







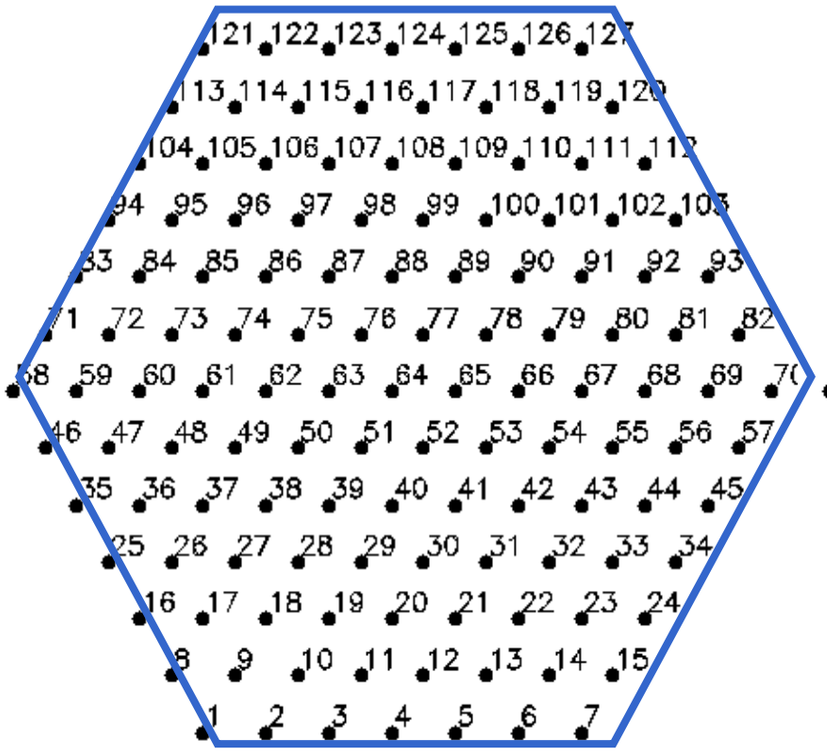
excess at high energies ?

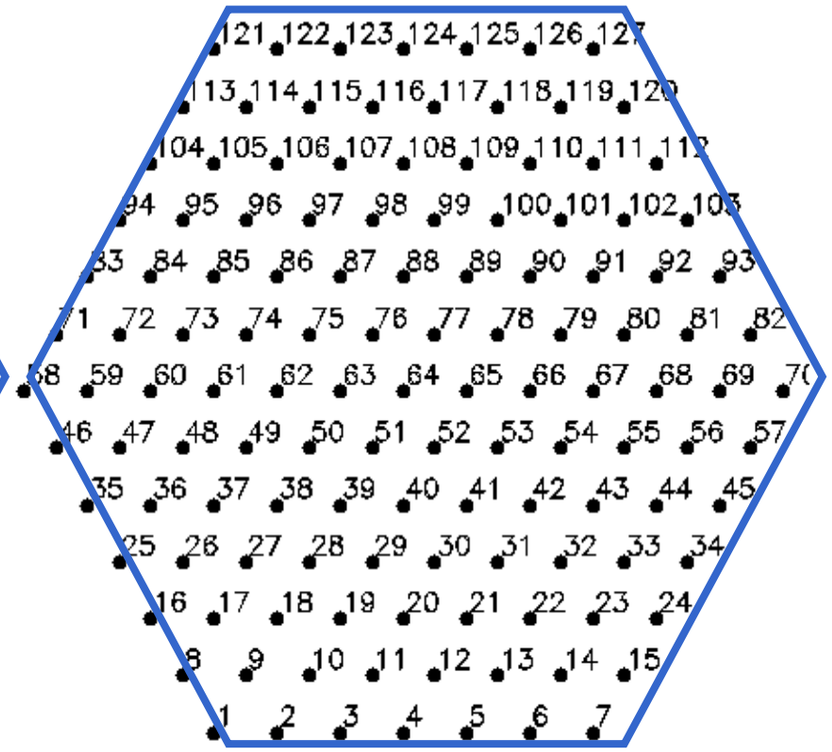


neutrino oscillations in DeepCore

→ PINGU (mass hierarchy)?

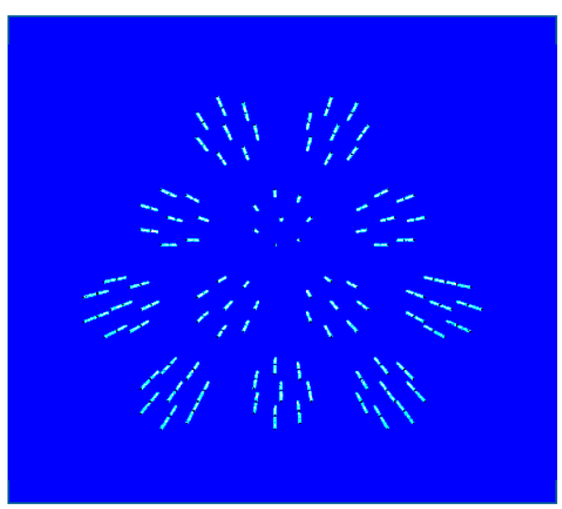
H.E. Neutrino Telescopes: The Future



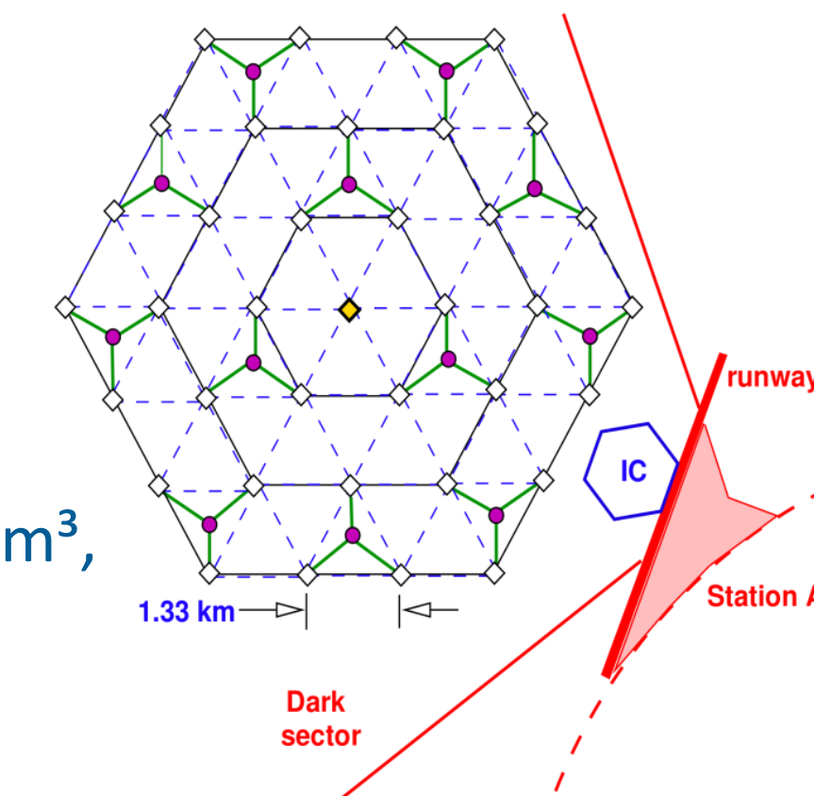


KM3NeT,
Mediterranean Sea,
2 x 3 km³,
sensitive above 1 TeV

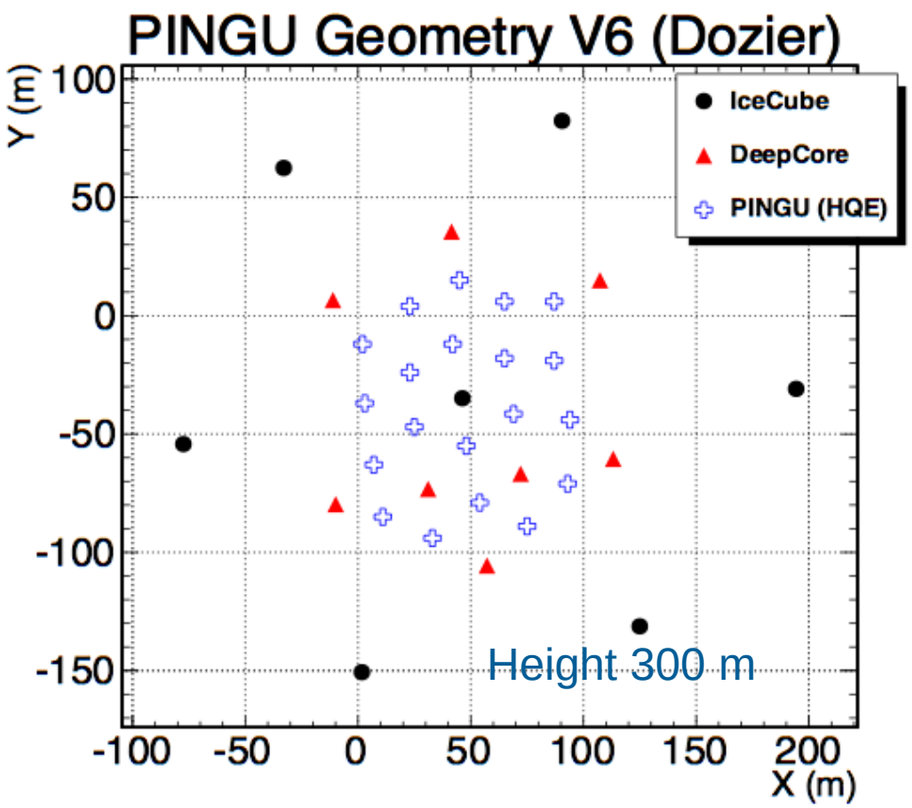
GVD, Lake Baikal, 0.5 km³,
sensitive above 3 TeV



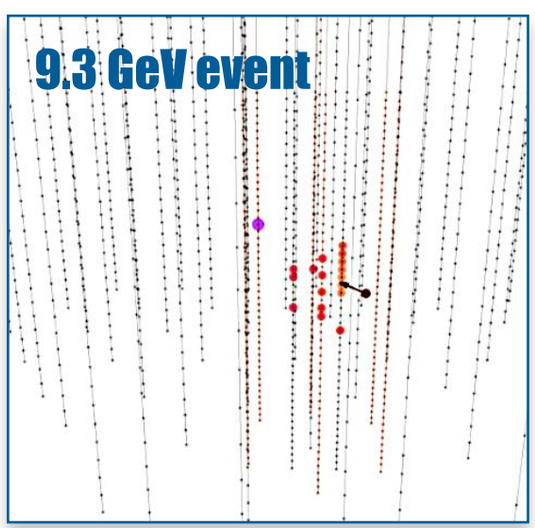
ARA, South Pole
radio array, 160 km³,
sensitive
above 100 PeV



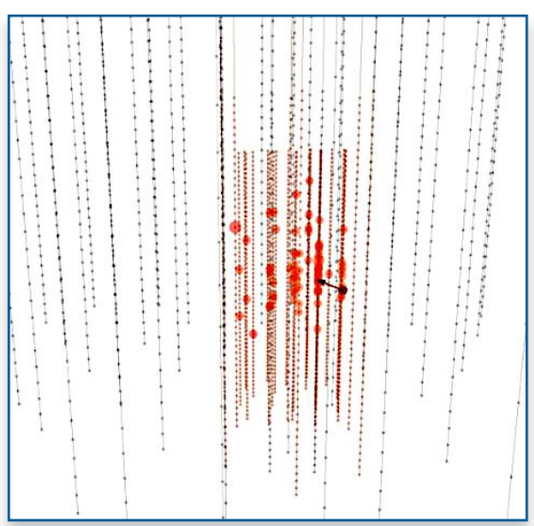
Options for IceCube Extensions

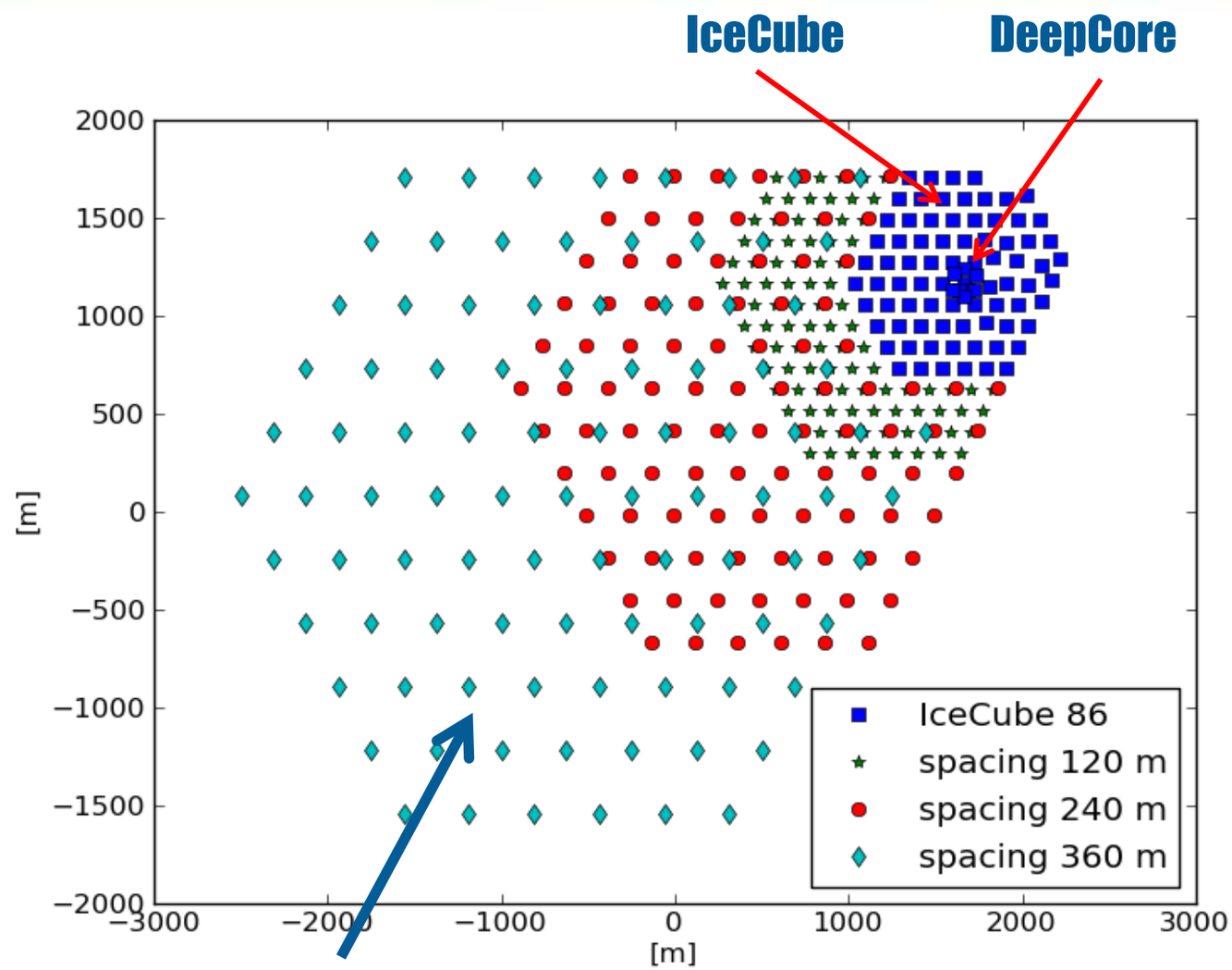


DeepCore



DeepCore + PINGU





12,6 km^3

Threshold for muons ~ 50 TeV,
gain eff. area for muons ~ factor 4,
gain for cascades ~ factor 10

Detectors for low-energy neutrinos and proton decay

- SAGE, BNT (Baksan)
- LVD, Borexino (Italy)
- Super-K, KamLAND (Japan)
- soon: SNO+ (Canada)

Hans Bethe

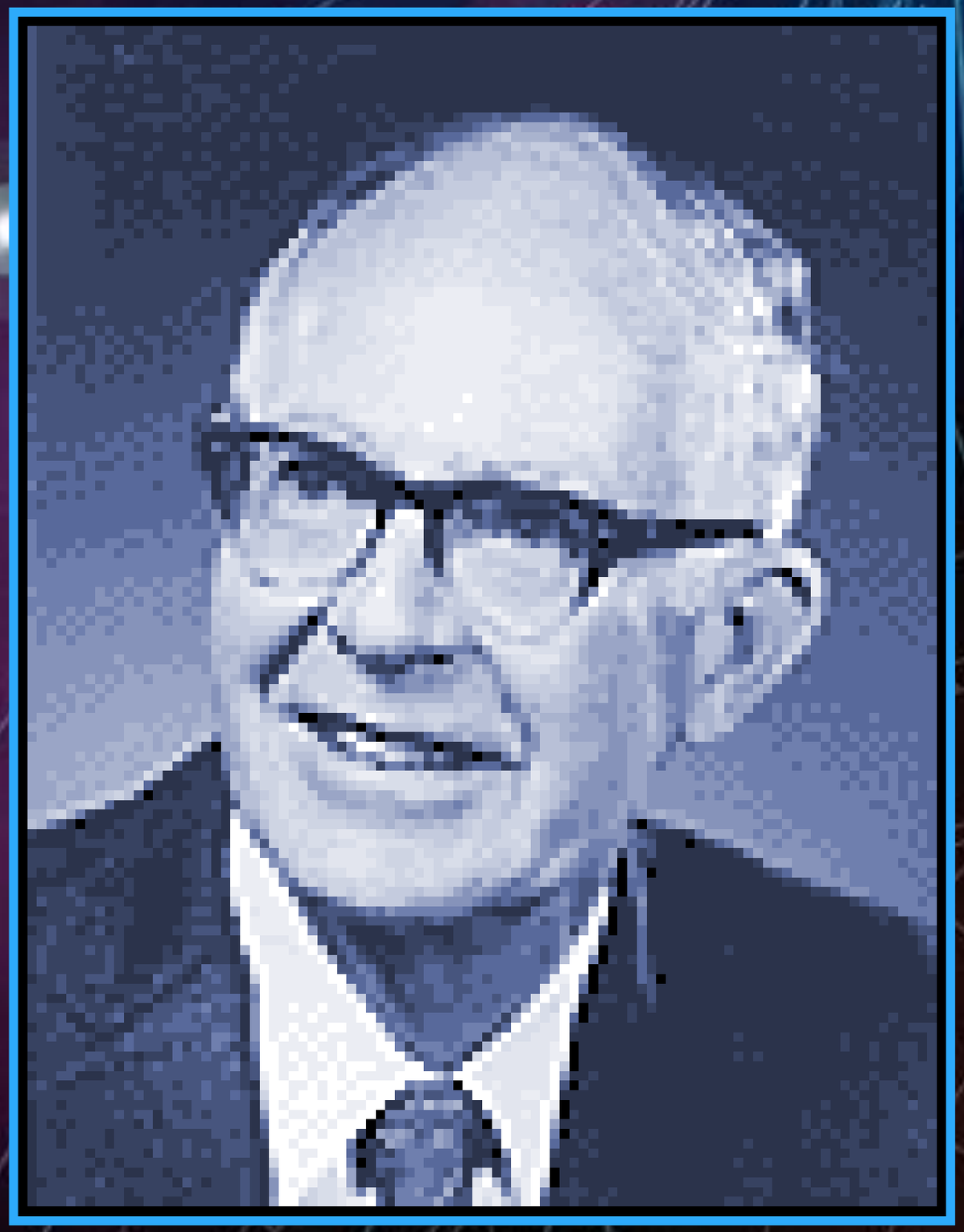
1939

John Bahcall

1960s

Raymond Davis

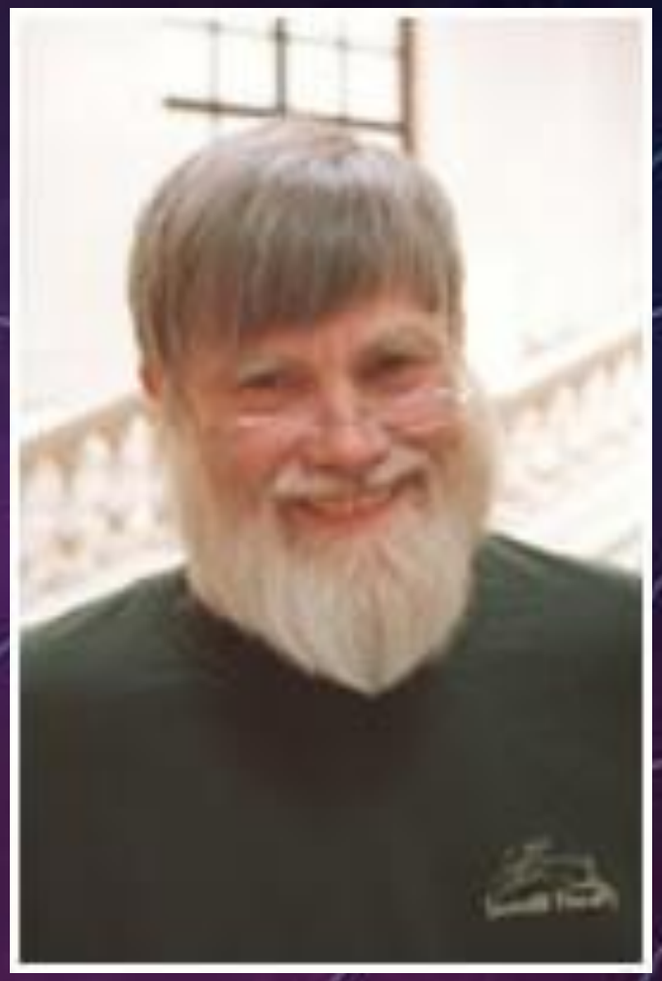
~1970



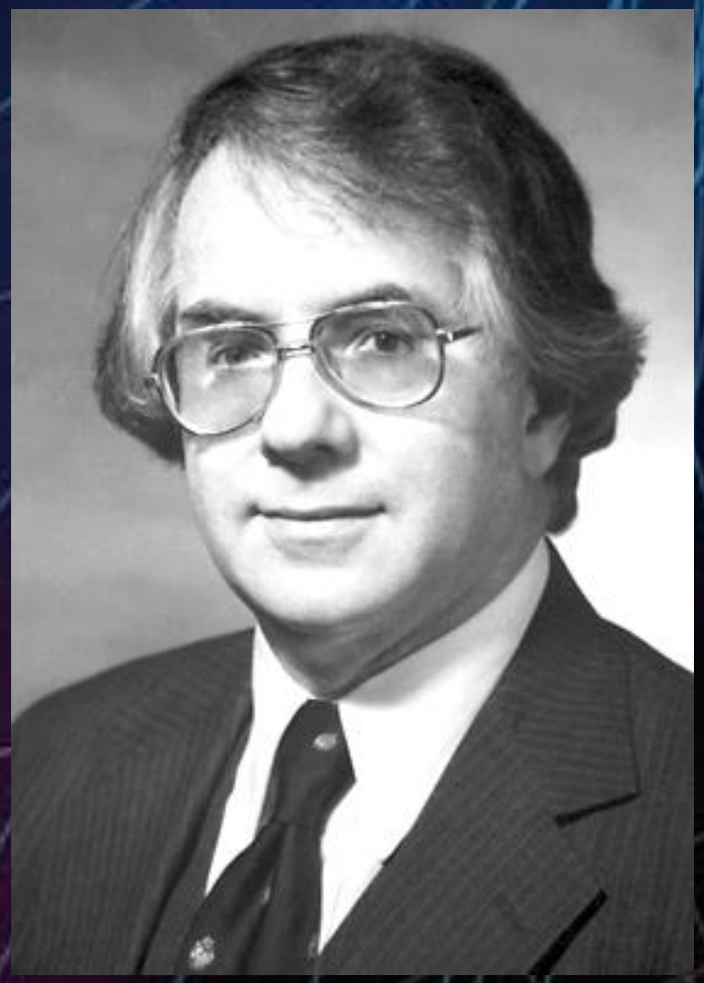
Masatoshi Koshiba

1987

Andrei Sacharow



Howard Georgi

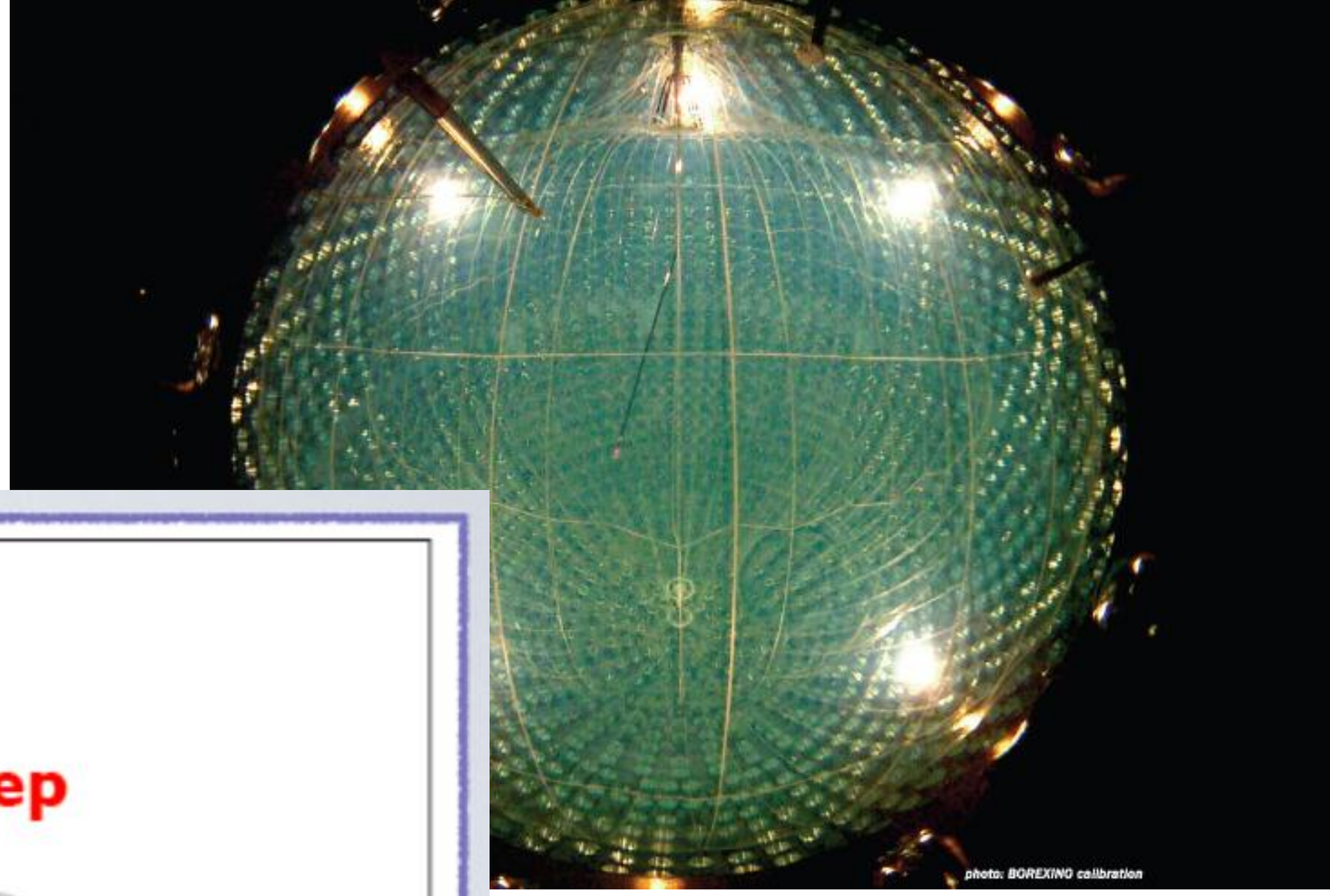


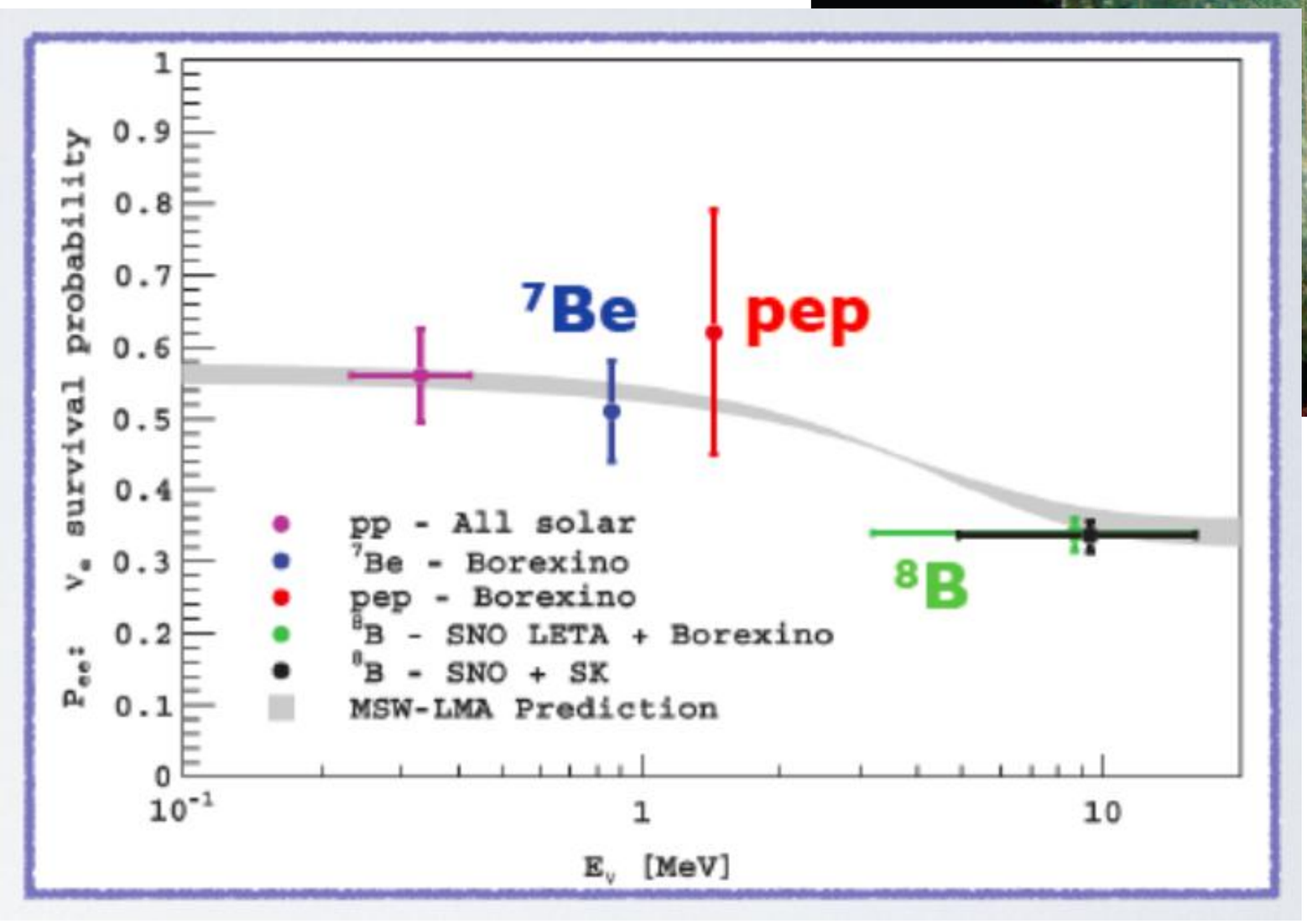
Sheldon Glashow

1965

1974

Borexino





solar ν: ^{7}Be, pep

geoneutrinos

Science on the Megaton scale

- **Proton decay:** improve sensitivity by > factor 10 and test a new class of Supersymmetry models
- **Galactic Supernova:** 10^4- 10^5 events
  Incredibly detailed information on the early SN phase
- **Diffuse flux from past SN:** probe cosmological star formation rate
- **Solar neutrinos:** details of the Standard Solar Model determined with percent accuracy. CNO cycle. Time variations.
- **Atmospheric neutrinos:** high statistics would improve knowledge neutrino mixing and provide information on the neutrino mass hierarchy
- **Geo-neutrinos:** improve understanding of the Earth interior
- **Indirect WIMP search**
- **Neutrinos from accelerators:** neutrino properties !

Projects on the Megaton scale

Europe: Laguna-LBNO

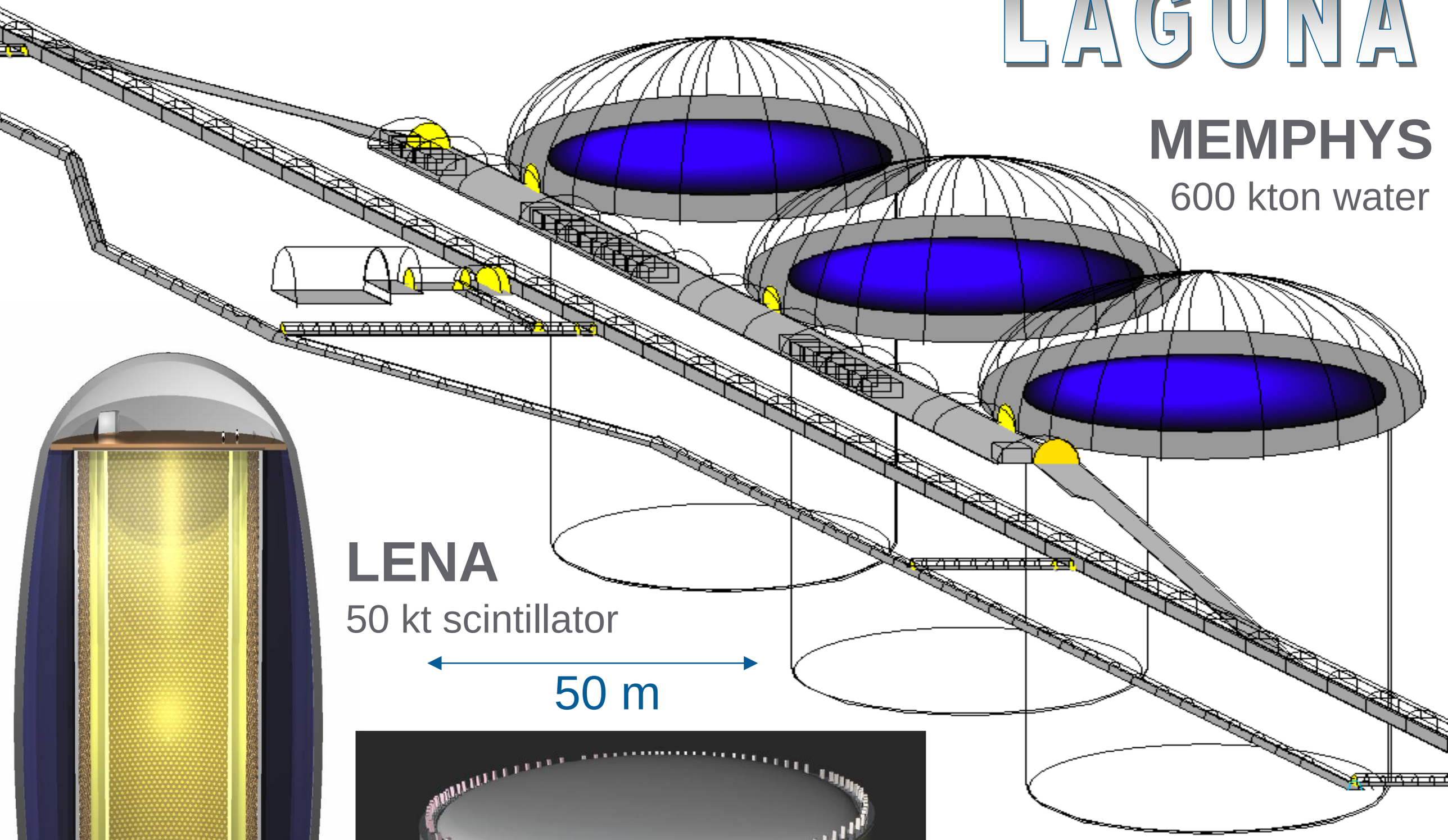
Japan: Hyper-K

USA: LBNE

LAGUNA

MEMPHYS

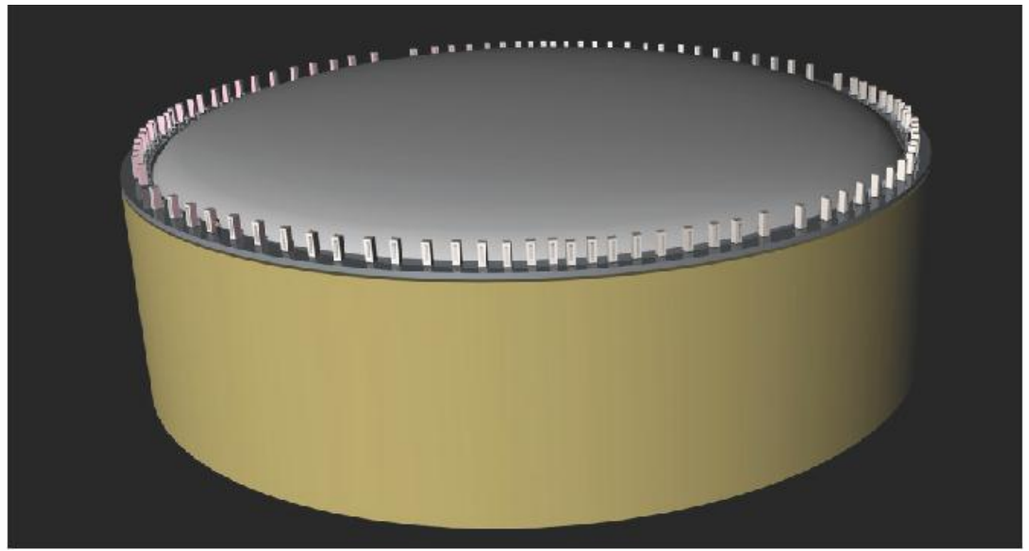
600 kton water



LENA

50 kt scintillator

50 m



GLACIER

100 kton liquid argon

Science on the Megaton scale

- **Proton decay:** improve sensitivity by > factor 10 and test a new class of Supersymmetry models
- **Galactic Supernova:** 10^4- 10^5 events
  Incredibly detailed information on the early SN phase
- **Diffuse flux from past SN:** probe cosmological star formation rate **LSc**
- **Solar neutrinos:** details of the Standard Solar Model determined with percent accuracy. Time variations. CNO cycle **LSc**
- **Atmospheric neutrinos:** high statistics would improve knowledge neutrino mixing and provide unique information on the neutrino mass hierarchy
- **Geo-neutrinos:** improve understanding of the Earth interior **LSc**
- **Indirect WIMP search**
- **Neutrinos from accelerators:** neutrino properties ! **LAr, $H_2$0**

Summary on large underground detectors

- **Exciting symbiosis of**
  - ***tackling fundamental questions of particle physics,***
  - ***accessing new cosmic landscapes,***
  - ***high-precision measurement of known cosmic phenomena.***

- **Common program on**
  - ***accelerator based neutrino physics***
  - ***astroparticle physics***

  will have more impact than the sum of its parts.

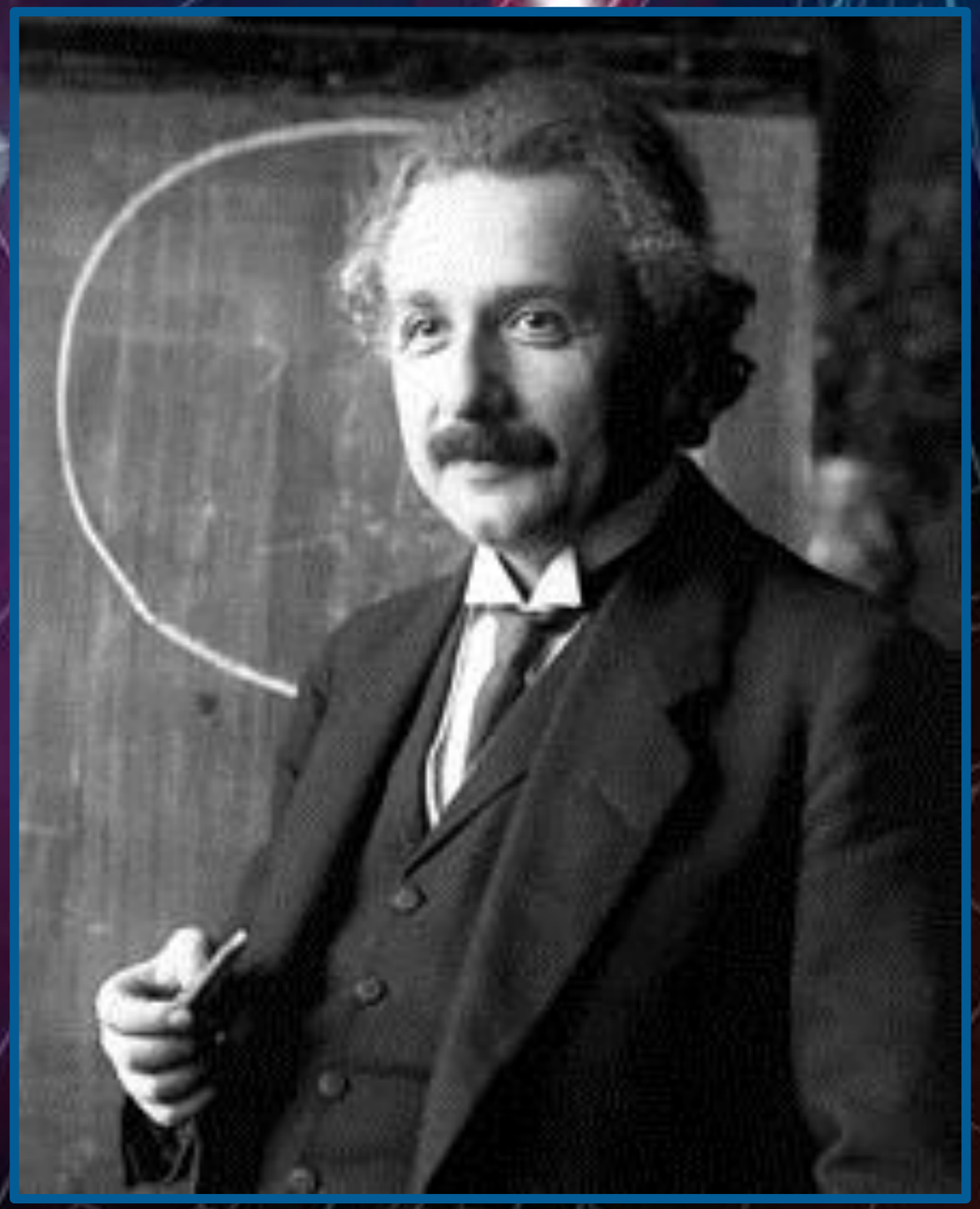
- **Impact of PINGU?**

- **Needs coherent international strategy**

Gravitational Waves

Albert Einstein

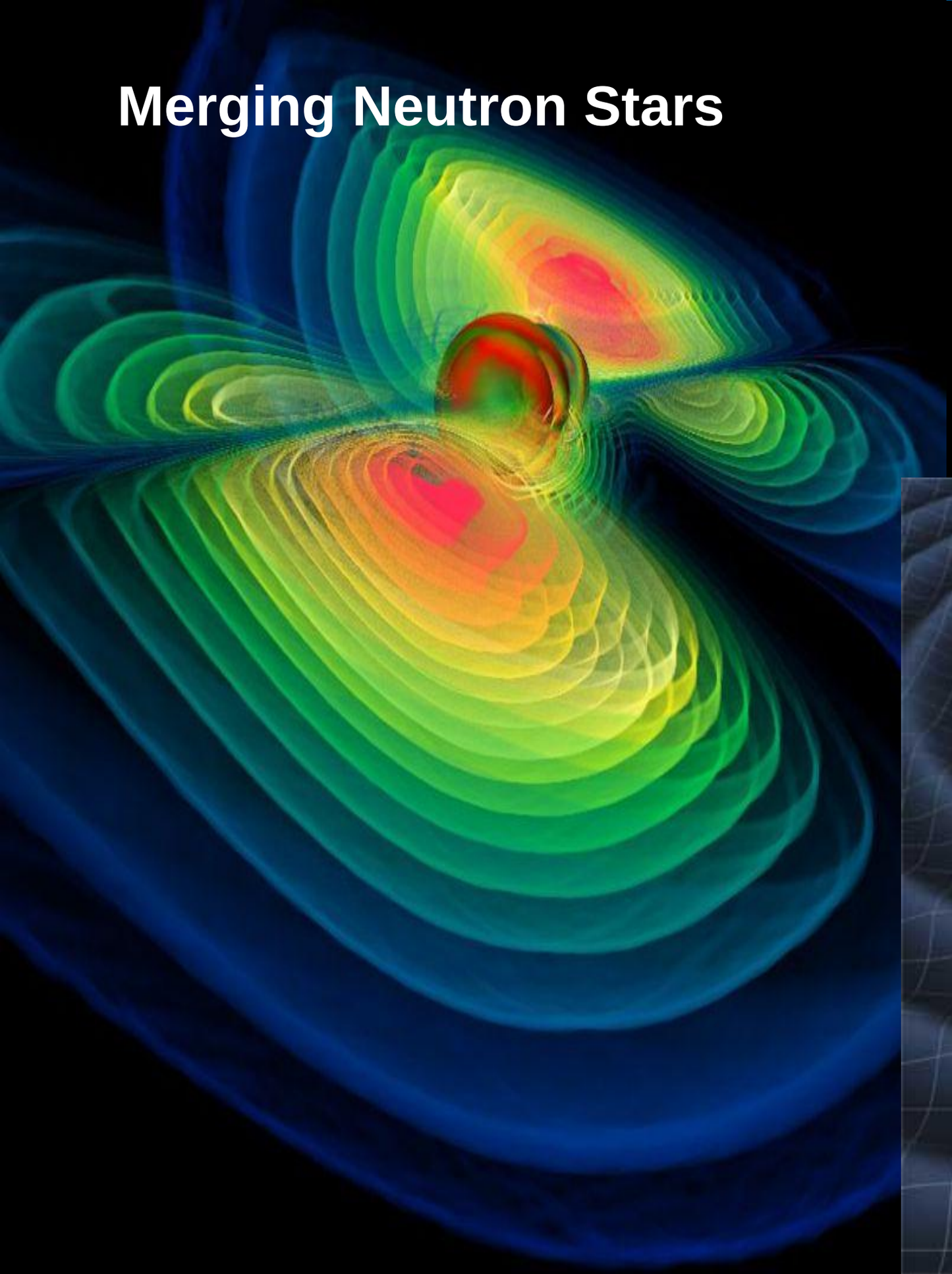
1918

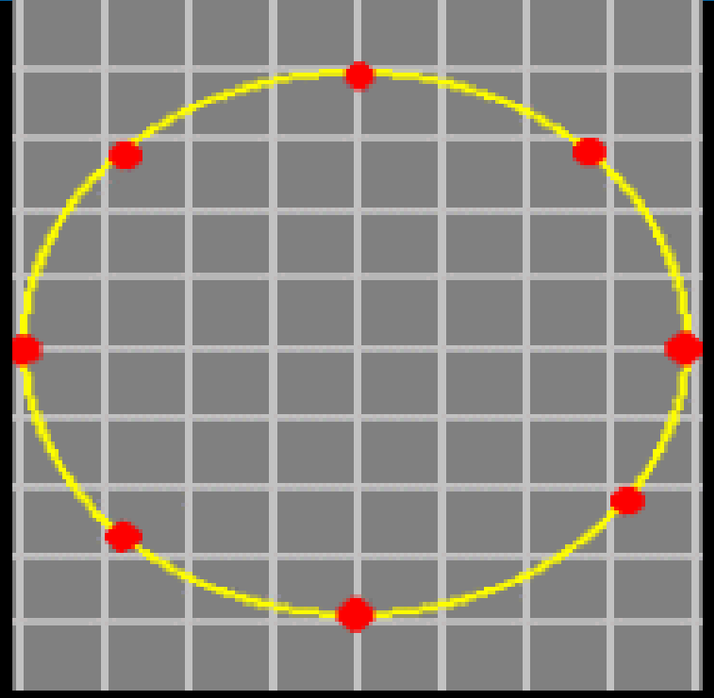


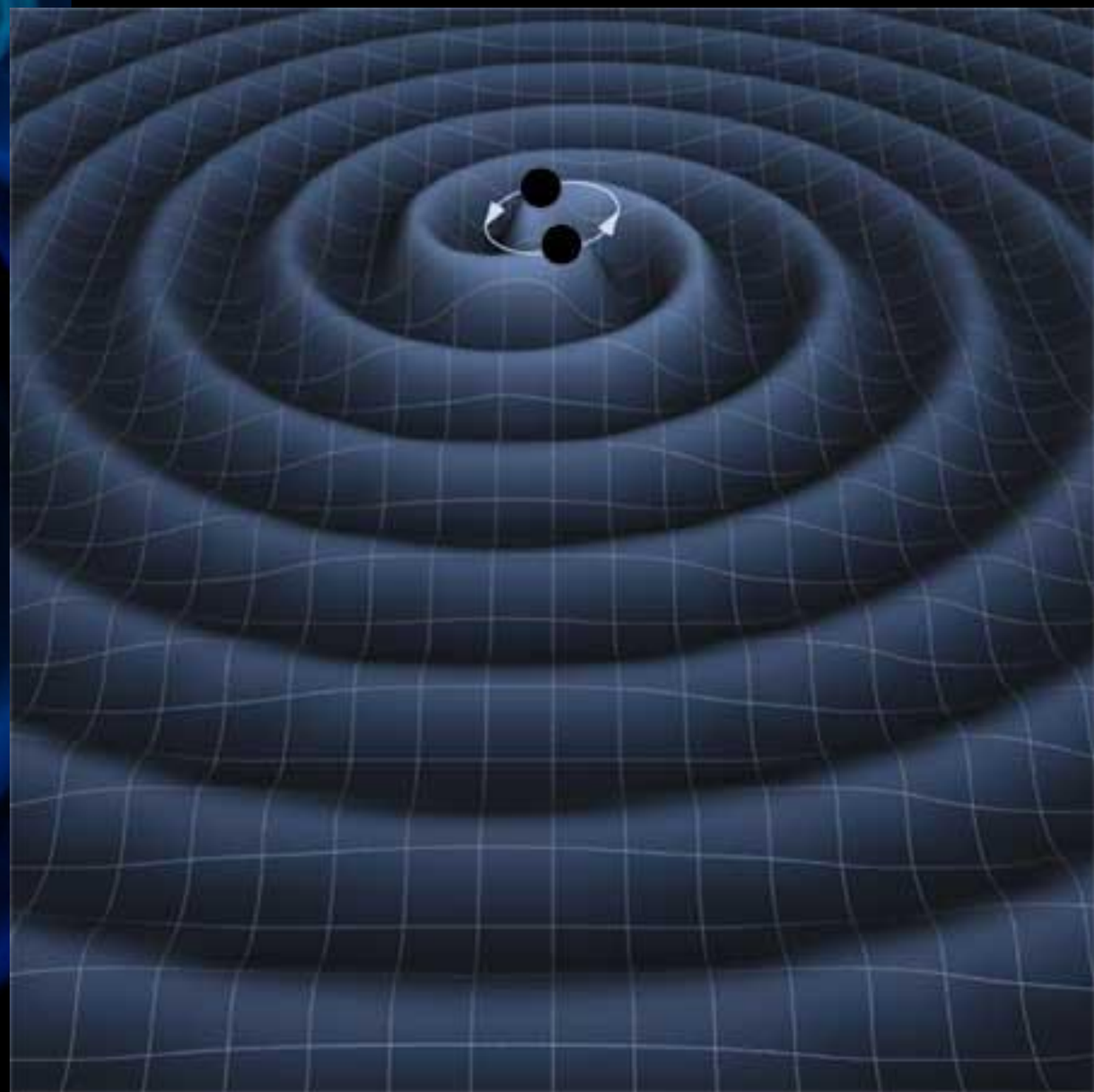
Joseph Weber

1958

Merging Neutron Stars







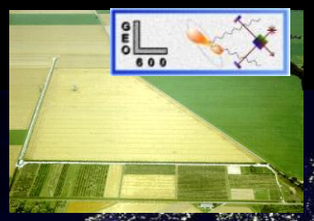
GEO-600

Hannover/Germany

The current GW Network

LIGO Hanford, 4 km: 2 ITF on the same site!

GEO, Hannover, 600 m



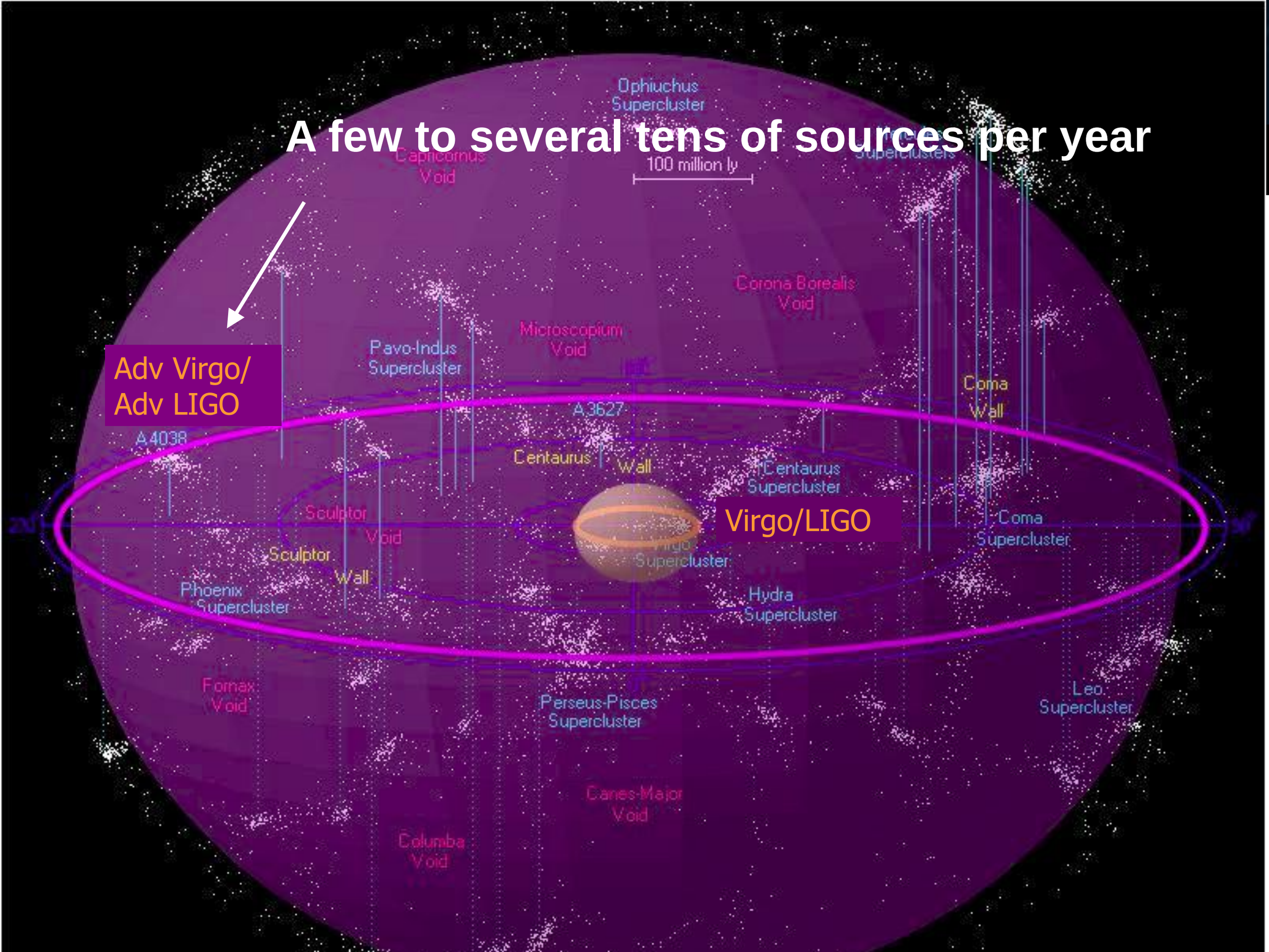
LIGO Livingston, 4 km

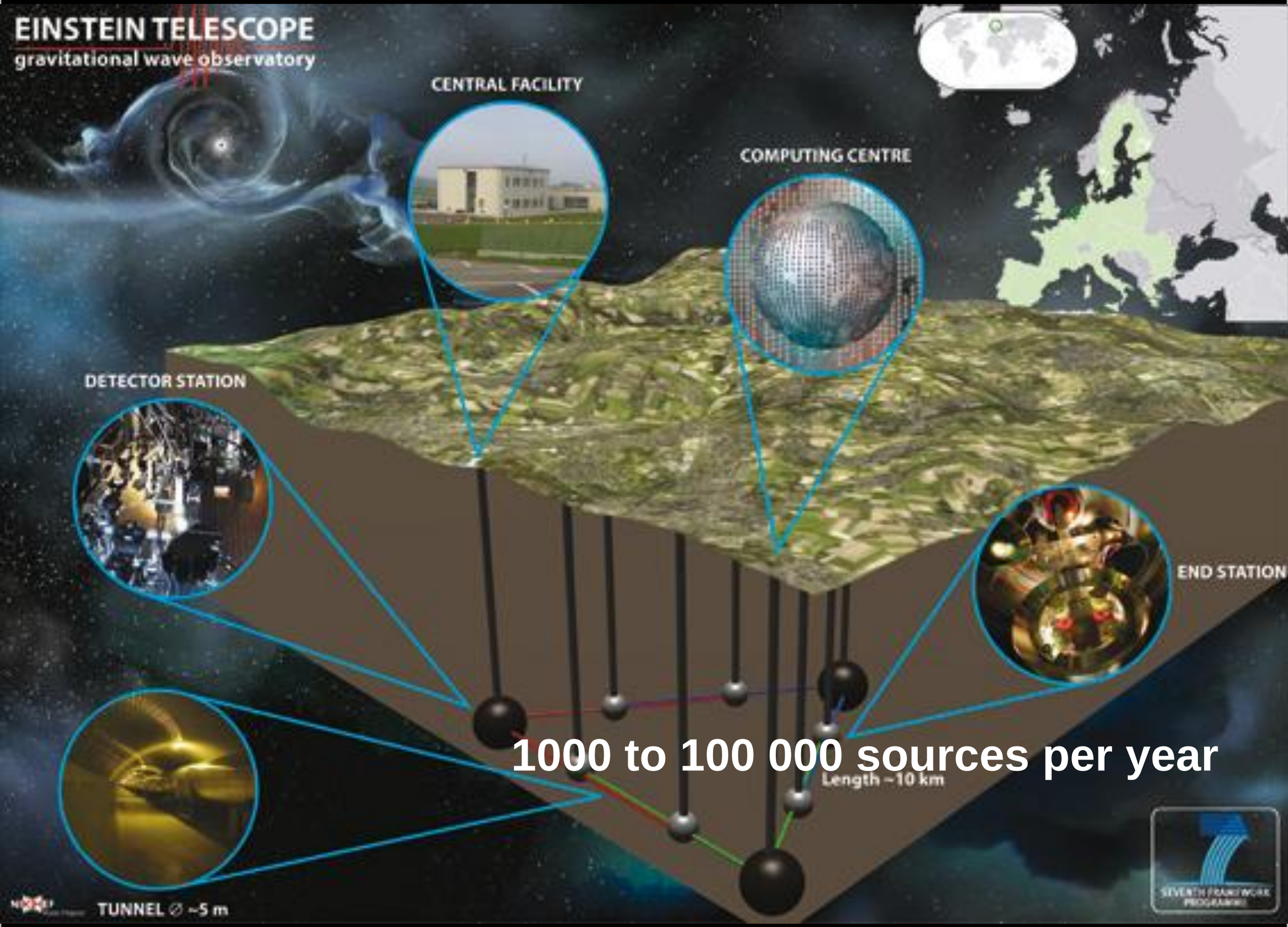
Virgo, Cascina, 3 km

INDIGO

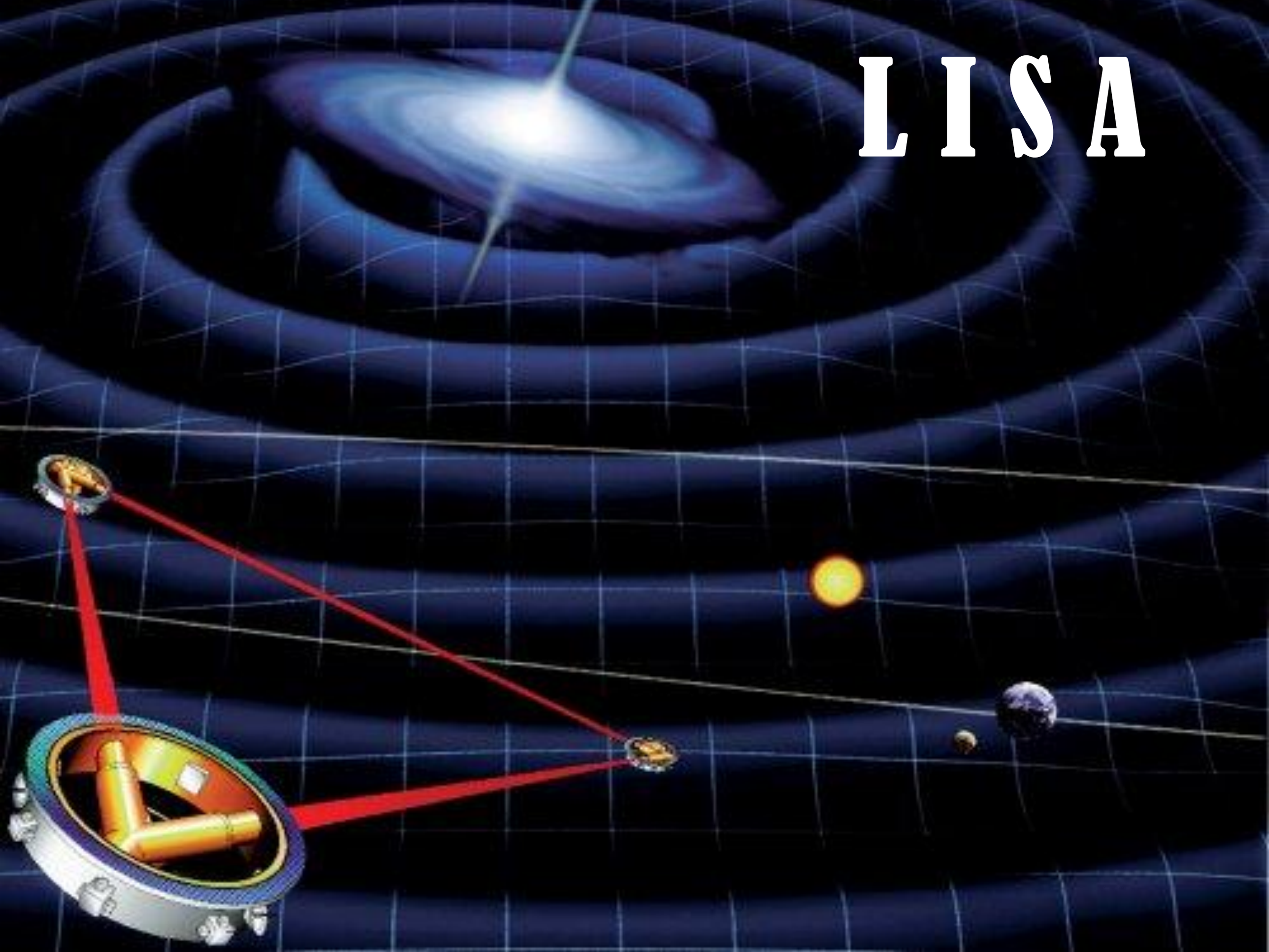
TAMA, Tokyo, 300 m (LCGT 3km being started)

A few to several tens of sources per year



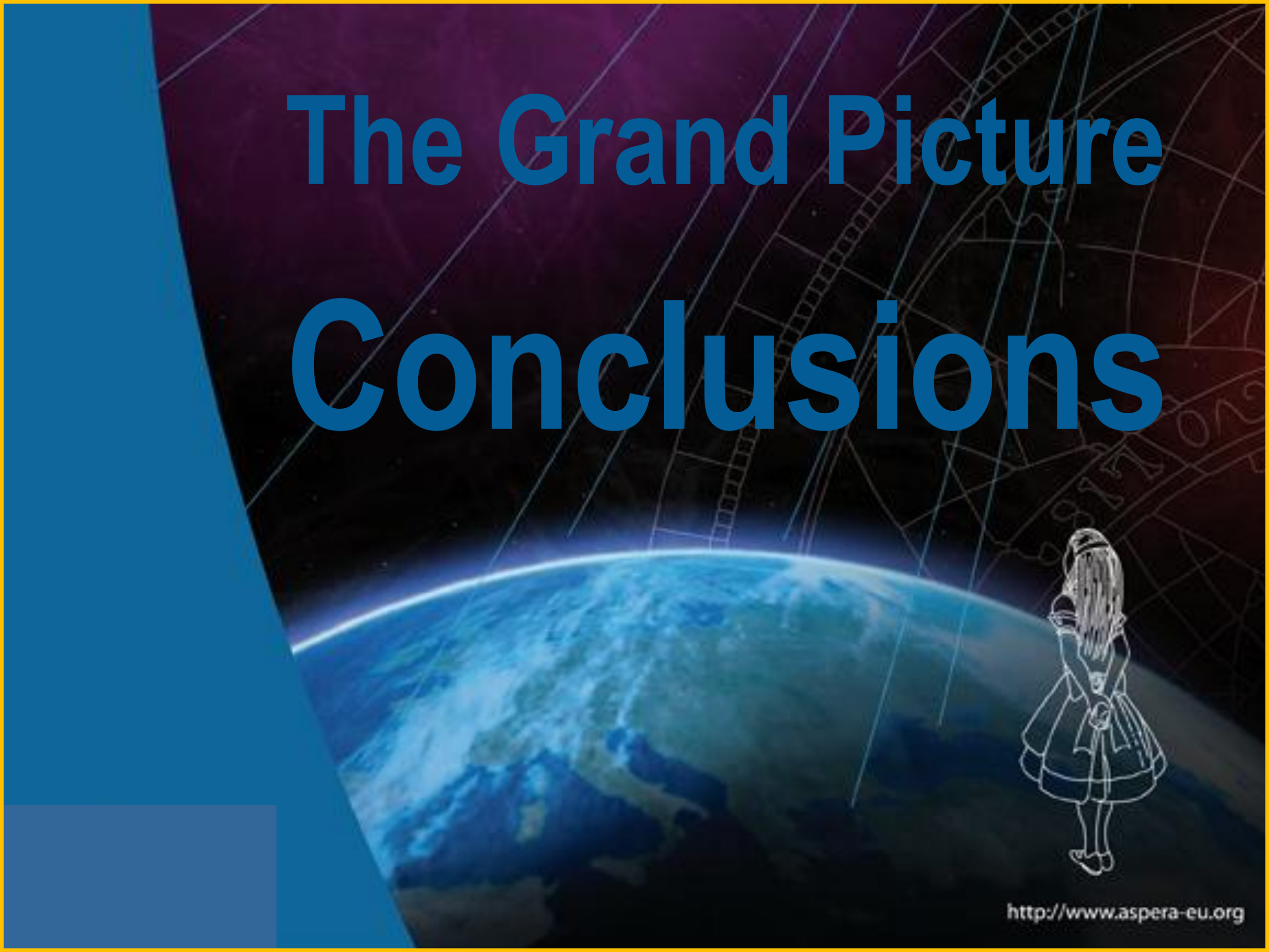


1000 to 100 000 sources per year


LISA

The Grand Picture

Conclusions



- Rapidly growing, dynamical field
- Break-throughs:
  - neutrinos from Sun and Supernova
  - neutrino oscillations
  - gamma-ray astronomy
- Many fields approaching sensitivity with high discovery potential for fundamental questions:
  - gravitational waves
  - dark matter
  - neutrino mass & double beta decay
- Tantalizing hints:
  - UHE cosmic rays
  - high energy neutrinos
  - sterile neutrinos ???

http://www.aspera-eu.org

We‘ve got a lot of work to do !

http://www.aspera-eu.org

The best is yet to come !

http://www.aspera-eu.org


cta
cherenkov telescope array
http://www.aspera-eu.org


http://www.aspera-eu.org

*Physics potential of the 3 types of detectors for proton decay and neutrino astrophysics **

Topics	**GLACIER** (50 kt)	**LENA** (50 kt)	**MEMPHYS** (500 kt)
proton decay, sensitivity(10 years) $e^+\pi^0$ anti-ν K^+ (**)	2.5×10^{34} 5×10^{34}	- 4×10^{34}	15×10^{34} 2.5×10^{34}
SN at 10 kpc, # events CC NC ES Elastic scatt. P	~ 19,500 0.8×10^4 (ν_e) 1.1×10^4 0.4×10^3 (e) -	~16,000 1.3×10^4 (anti-ν_e) 1.0×10^3 6.2×10^2 (e) 2.6×10^3 (p)	~250,000 2.5×10^5 (anti-ν_e) - 1.3×10^3 (e) -
Diffuse SN #Signal/Background events (10 years)	~50/30	~60/10	~120/100 (1 module with Gd)
Solar neutrinos # events, 1 year	^{8}B ES : 1.5×10^4 Abs: 0.5×10^5 (dependent on the achievable threshold)	^{7}Be: 3.6×10^6 pep: 1.0×10^5 ^{8}B: 2.9×10^4 CNO: 7×10^4	^{8}B ES: 1.2×10^5
Atmospheric ν # events, 1 year	5×10^3	5×10^3	5×10^4
Geo-neutrinos # events, 1 year	Below threshold	1.5×10^3	Below threshold

* some numbers strongly depend on model assumptions and give a qualitative rather than an exact quantitative comparison.
** this channel is particularly prominent in SUSY theories. Indications for SUSY at the LHC would boost its importance.

*Physics potential of the 3 types of detectors for proton decay and neutrino astrophysics **

Topics	GLACIER (50 kt)	LENA (50 kt)	MEMPHYS (500 kt)
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$e^+\pi^0$	2.5×10^{34}	-	15×10^{34}
anti-ν K^+ (**)	5×10^{34}	4×10^{34}	2.5×10^{34}
SN at 10 kpc, # events	~19,500	~16,000	~250,000
CC	0.8×10^4 (ν_e)	1.3×10^4 (anti-ν_e)	2.5×10^5 (anti-ν_e)
NC	1.1×10^4	1.0×10^3	-
ES	0.4×10^3 (e)	6.2×10^2 (e)	1.3×10^3 (e)
Elastic scatt. P	-	2.6×10^3 (p)	-
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Low energy!

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