Karlsruhe Institute of Technology

Perspectives and challenges in Astroparticle Physics

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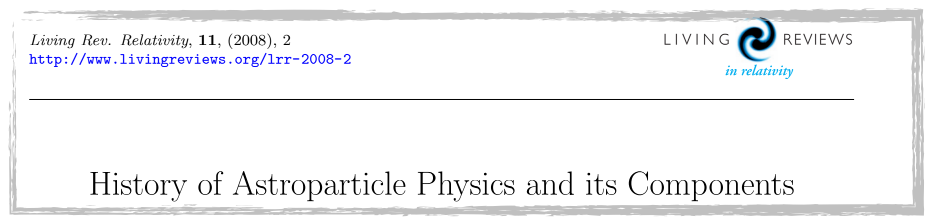
Perspectives and challenges in Astroparticle Physics

- What is Astroparticle Physics?
- The Grand View
- Selected pieces of success and challenge

When and how did it begin?

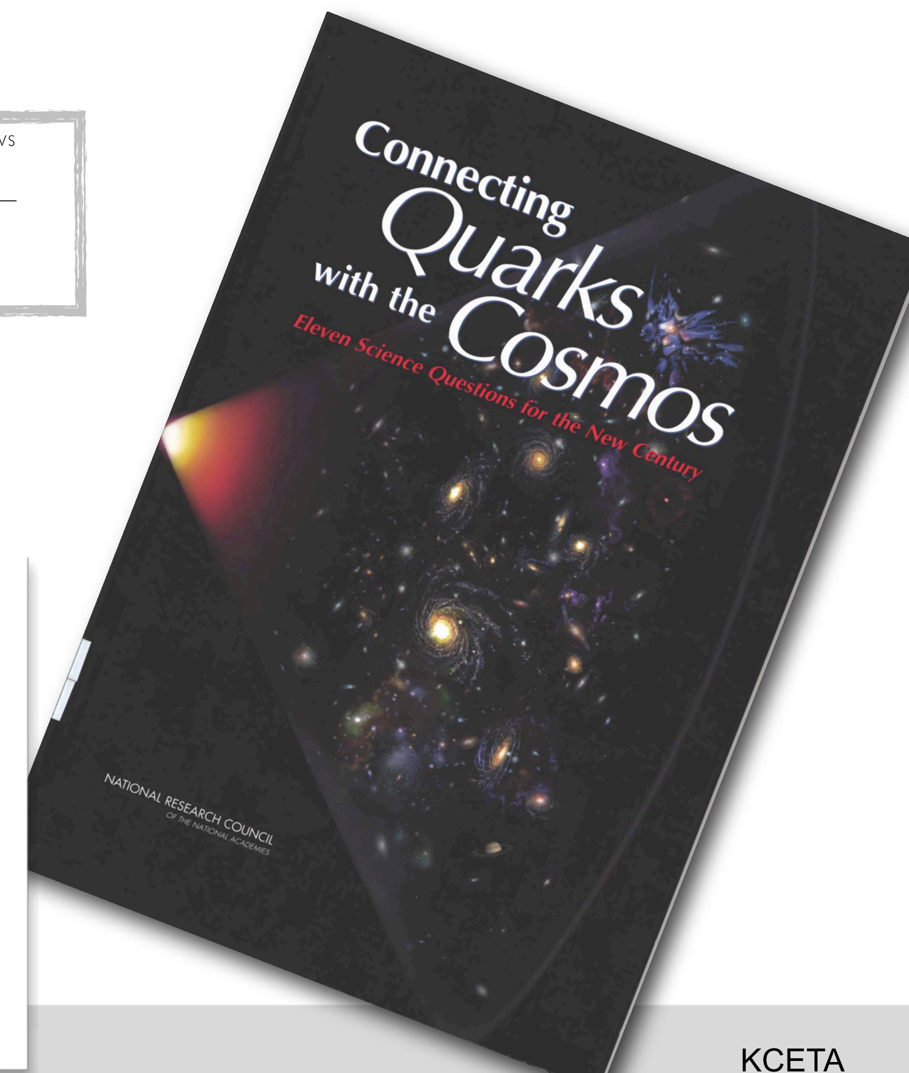
- **The historical approach**
  - The School of Athens
  - Hennfflin 1477 - Creation of the World

- **A recent scientific effort**
  - *History of Astroparticle Physics and its Components* by Vanessa Cirkel-Bartelt, Living Rev. Relativity, 11, (2008), 2

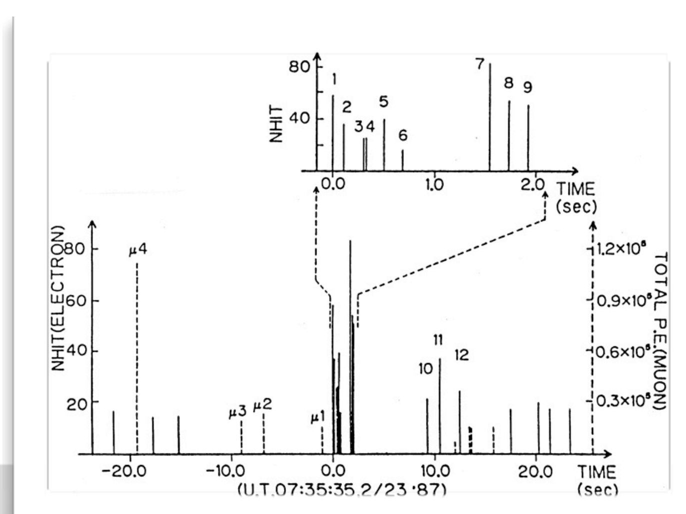

Living Rev. Relativity, 11, (2008), 2
http://www.livingreviews.org/lrr-2008-2
LIVING REVIEWS in relativity

History of Astroparticle Physics and its Components

- **Political definitions**
  - A stack of evaluations, roadmaps, brochures, recommendations, ...



- **My personal starting date:**
  - SN1987a



Vorred

werrt habent wyder sich harnach
die gezingt gezugnis von de xij
botten · Die latinische bücher sint
baß geluterrt dan die kriechische
vnd die kriechische baß dan die
hebreische vnd also hab ich dise
ding geredt wyder die nydische
Nu bit ich dich du aller liebester
merckere wan du mich gehaysse
hast das ich mich vnder wunde
han aines solichen werckes das sich
an hebt von de buch der schöpfung
das du mir behalffen syest in dine
gebette das ich niug vß gesprechen
dise buch in latinische sprach mit
de selben gaist mit de die selben
bücher sint geschribe ·I·


Vorred
wert habent wyder sich har nach
die gezingt gezugnis von de vij
botten. Die latinische bücher sint
bas geluteret dan die kriechische
und die kriechische bas dan die
hebreysche und also hab ich dise
ding geredt wyder die iudische
Nu bitt ich dich du aller liebester
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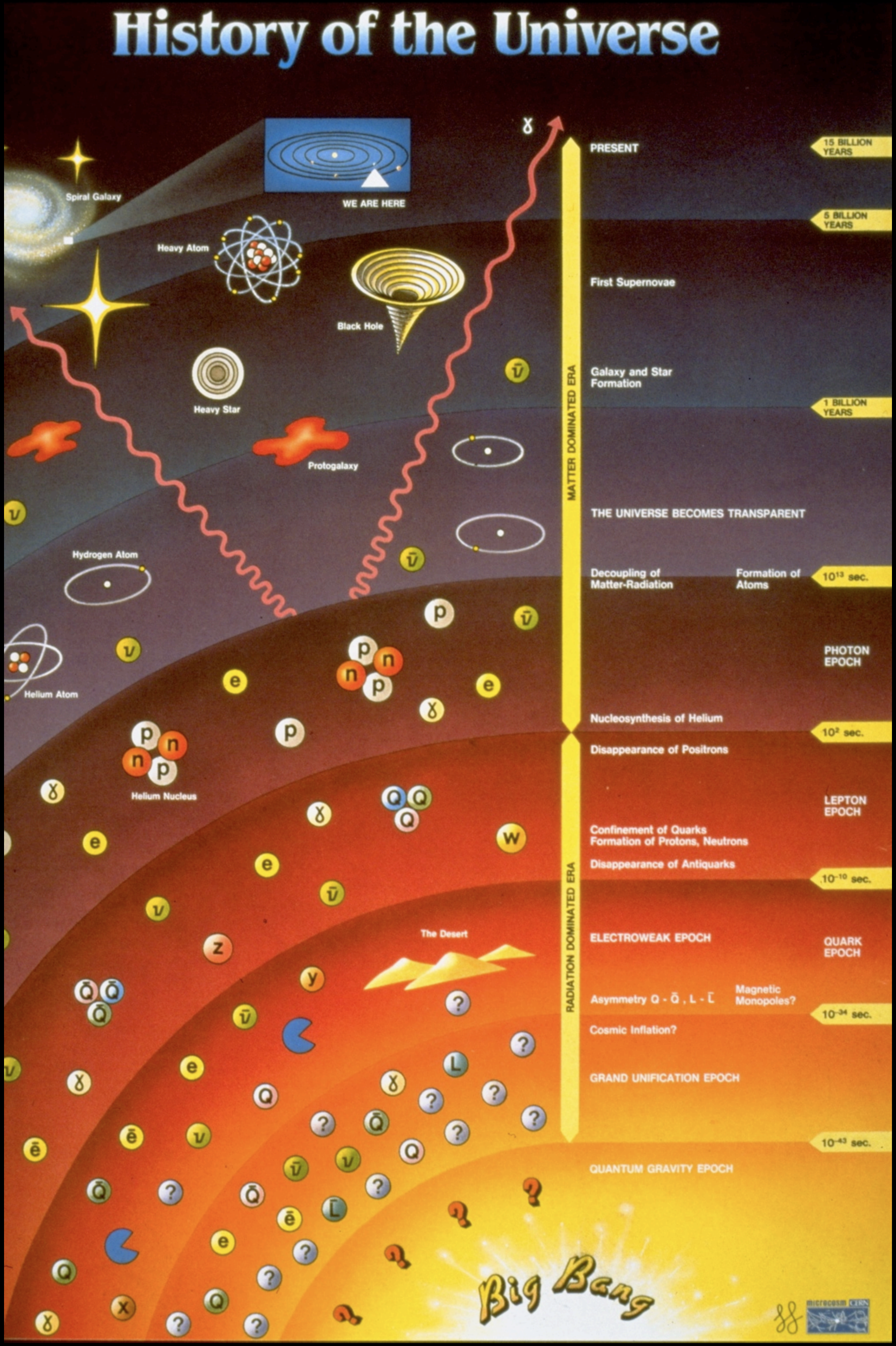
dise buch in latinische sprach mit
de selben gaist mit de die selben
bücher sint geschribe


History of the Universe
Spiral Galaxy
WE ARE HERE
Heavy Atom
Black Hole
Heavy Star
Protogalaxy
Hydrogen Atom
Helium Atom
Helium Nucleus
The Desert
Big Bang
PRESENT
15 BILLION YEARS
5 BILLION YEARS
First Supernovae
Galaxy and Star Formation
1 BILLION YEARS
MATTER DOMINATED ERA
THE UNIVERSE BECOMES TRANSPARENT
Decoupling of Matter-Radiation
Formation of Atoms
10¹³ sec.
PHOTON EPOCH
Nucleosynthesis of Helium
10² sec.
Disappearance of Positrons
LEPTON EPOCH
Confinement of Quarks Formation of Protons, Neutrons
Disappearance of Antiquarks
10⁻¹⁰ sec.
RADIATION DOMINATED ERA
ELECTROWEAK EPOCH
QUARK EPOCH
Magnetic Monopoles?
Cosmic Inflation?
10⁻³⁴ sec.
GRAND UNIFICATION EPOCH
10⁻⁴³ sec.
QUANTUM GRAVITY EPOCH

Living Rev. Relativity, **11**, (2008), 2
http://www.livingreviews.org/lrr-2008-2

LIVING REVIEWS *in relativity*

History of Astroparticle Physics and its Components

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Abstract

This article gives an outline of the historical events that led to the formation of contemporary astroparticle physics. As a starting point for analyzing the history of astroparticle physics this article will review the various, yet scattered pieces of historical work that have been done so far. To make the picture more complete it will then give a brief survey of the most important fields that have played a role in the development of astroparticle physics as we know it today. It will conclude with an overview of the historical questions that are still open and the rich philosophical implications that lie behind those questions.

(...) It is generally held that Hess "discovered" cosmic rays in 1911 and 1912 and thus laid the foundation for modern astroparticle physics. But neither did he happen to stumble upon the phenomenon by mere coincidence, nor did he invest only one year of work into it. Quite on the contrary, his famous article about the "penetrating rays" is the result of a rather long period of research, as will be shown in the following paragraphs. Besides, even after the publication of his famous balloon experiments, his evidence for the cosmic origin of "penetrating rays" was far from being generally accepted.

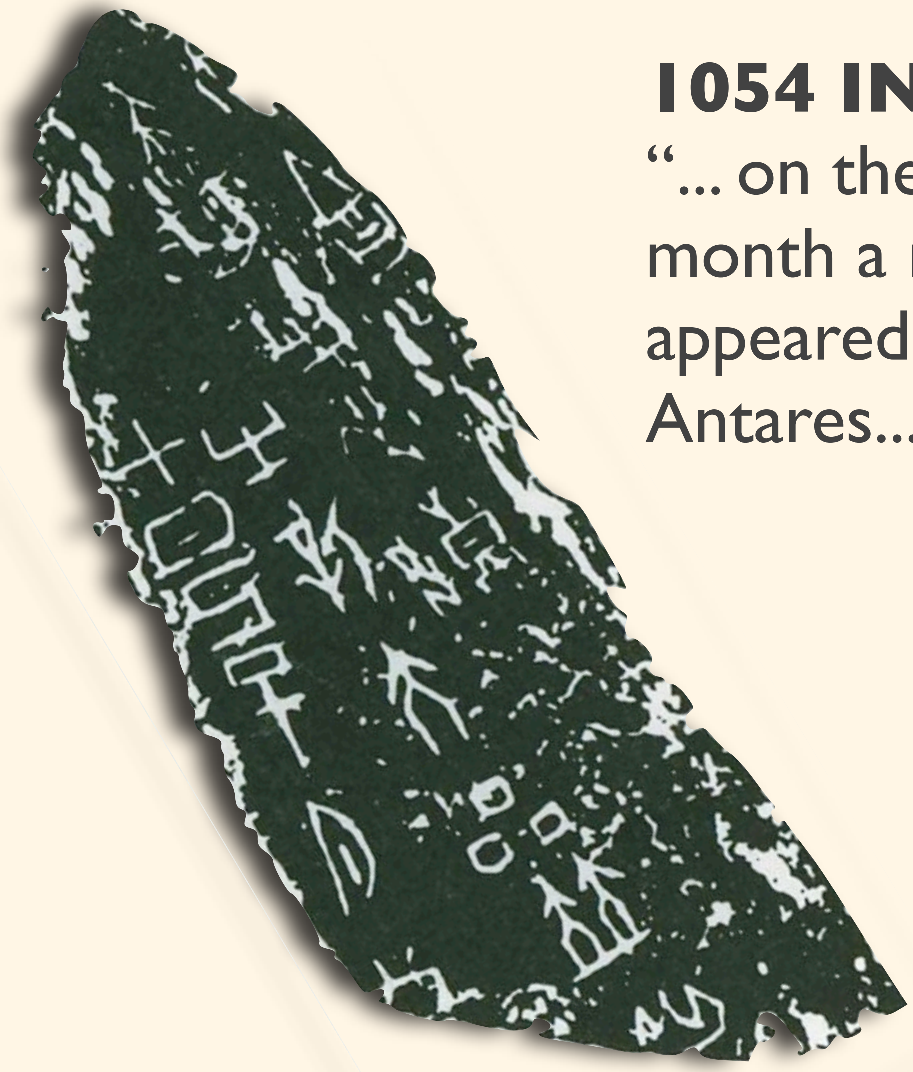

Connecting Quarks with the Cosmos
Eleven Science Questions for the New Century
Joint Study on the Future of Neutrino Physics
The Neutrino Matrix
Elementary-Particle Physics
Revealing the Secrets of Energy and Matter
NATIONAL RESEARCH COUNCIL
REVEALING THE HIDDEN NATURE OF SPACE AND TIME
Charting the Course for Elementary Particle Physics
Teilchenphysik in Deutschland
Status und Perspektiven
NATIONAL RESEARCH COUNCIL
QUANTUM UNIVERSE
NEUTRINOS AND BEYOND
New Windows on Nature
NATIONAL RESEARCH COUNCIL
MEGASCIENCE: THE OECD FORUM
ASTRONOMY
MEGASCIENCE: THE OECD FORUM
MEGASCIENCE AND ITS BACKGROUND
MEGASCIENCE: THE OECD FORUM
PARTICLE PHYSICS
OECD
Linking of existing infrastructures report
ASTROPARTICLE PHYSICS
the European strategy
Kosmische Spurensuche
Astroteilchenphysik in Deutschland
Ein Forschungsgebiet im Aufbruch
1 . Messengers from the early Universe
2 . Messengers from the violent Universe
3 . Messengers from the invisible Universe
The European strategy
for particle physics

German Committee for Astroparticle Physics 2003:

- Dark Matter
- Charged Cosmic Radiation
- Gamma-Ray Astronomy
- High-Energy Neutrino Astrophysics
- Low-Energy Neutrino Astrophysics
- Neutrino Properties
- Gravitational Waves
- Theoretical Astroparticle Physics
- Nuclear Astrophysics

OECD 2010

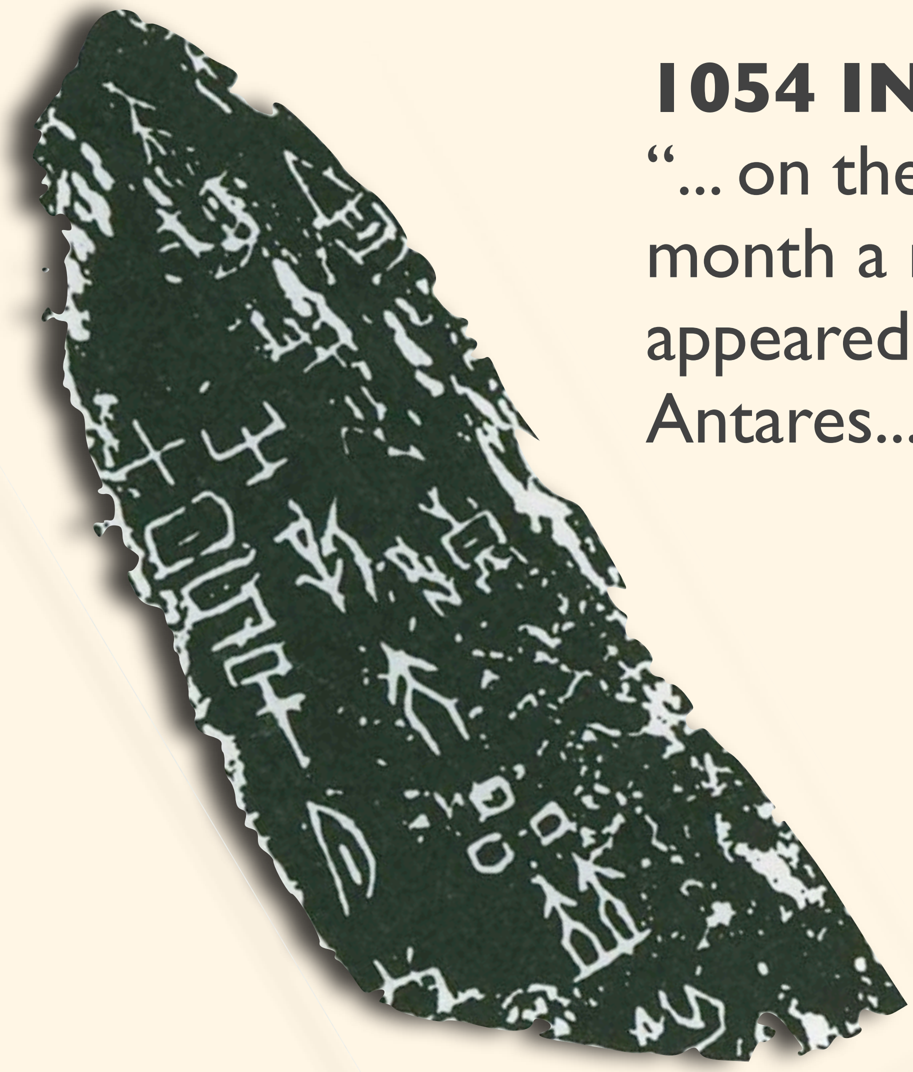
- What is the Universe made of?
  - Nature of dark matter
  - Nature of dark energy
- What is the role of high energy phenomena in the Universe ?
  - Generalised cosmic ray studies (charged particles, photons, neutrinos)
  - Detection of gravitational waves
- What is the form of matter and interaction at the highest energies?
  - Proton decay and neutrino properties
  - Neutrino mass and nature



1054 IN CHINA:

"... on the 11th of the month a new star appeared near Antares..."

Today: the famous Crab nebulus



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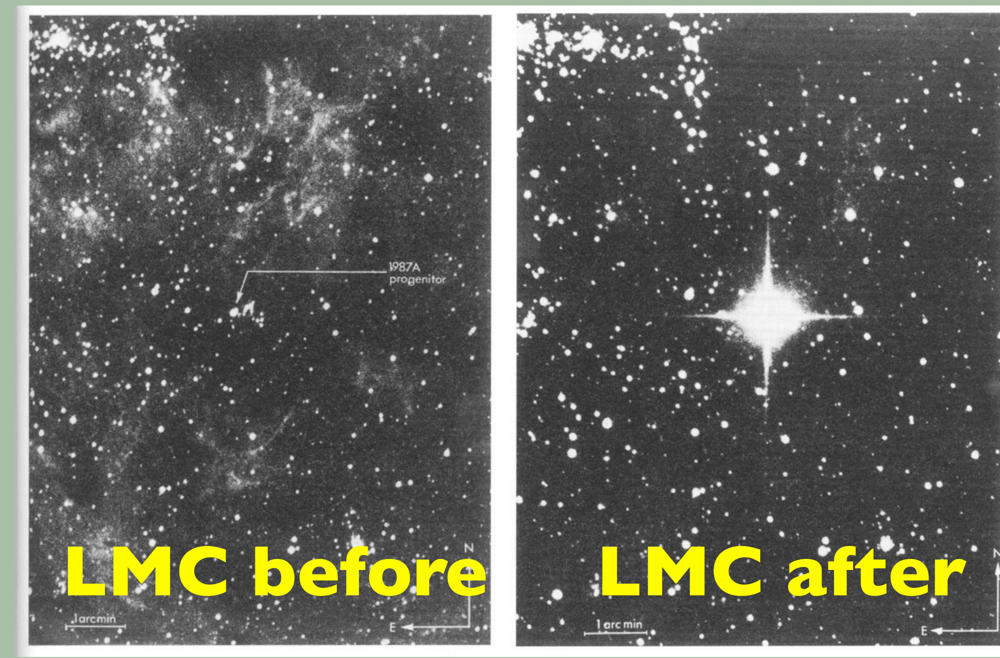
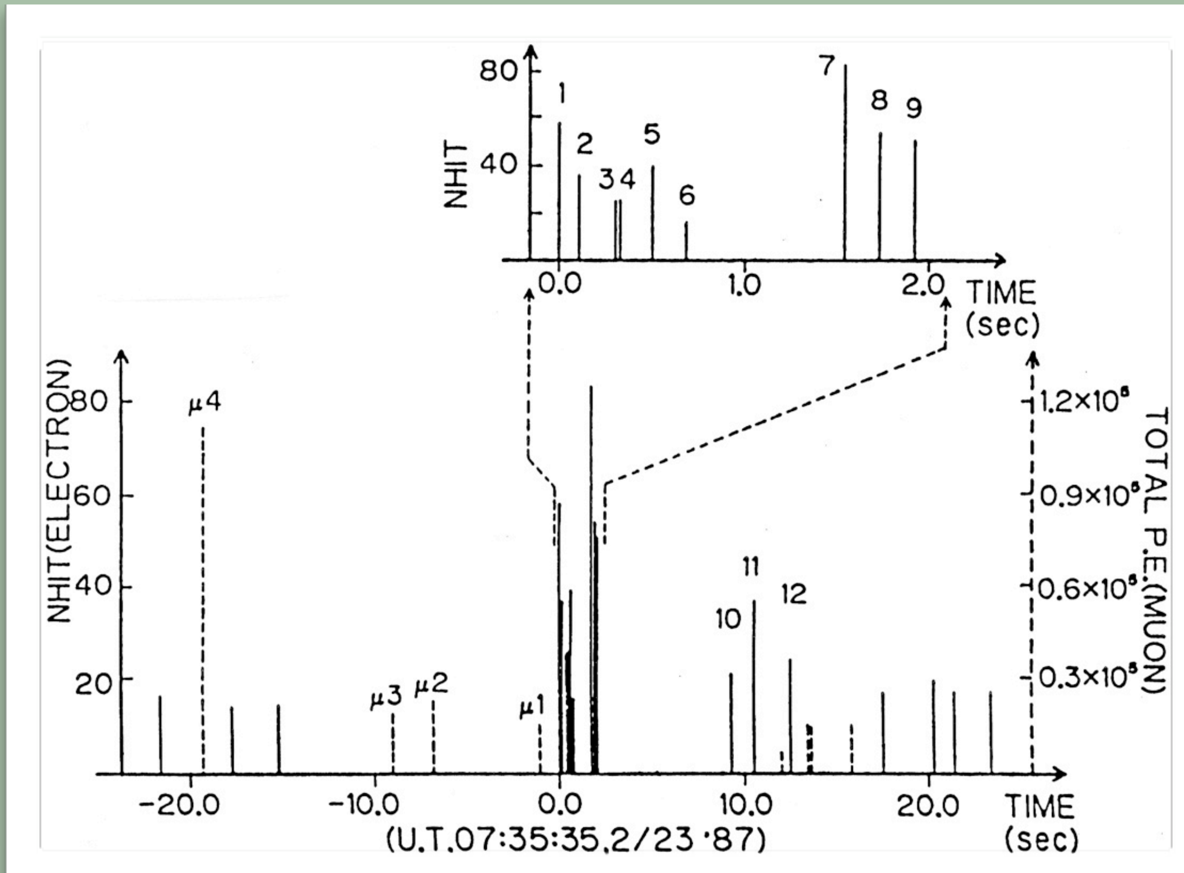
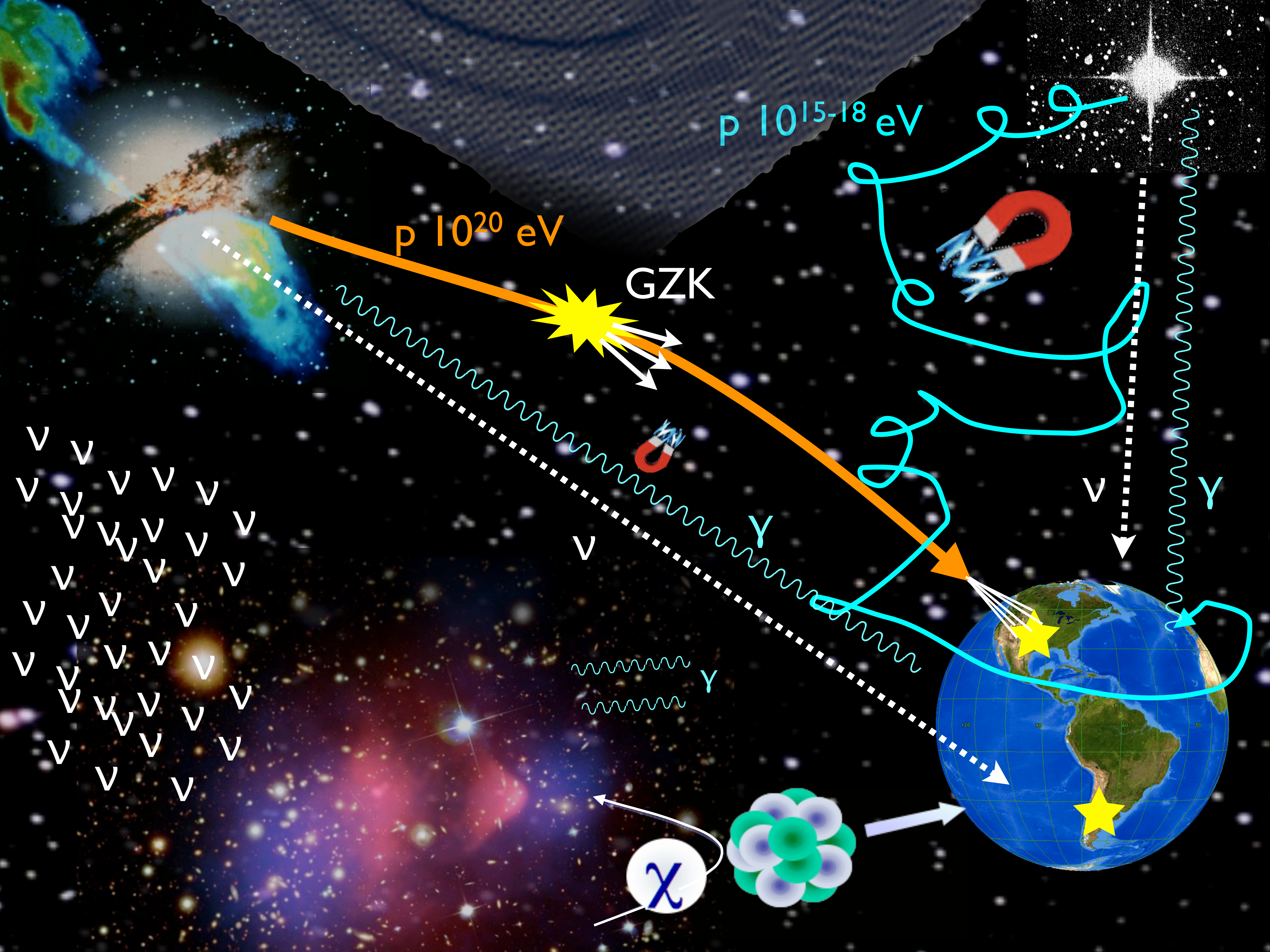
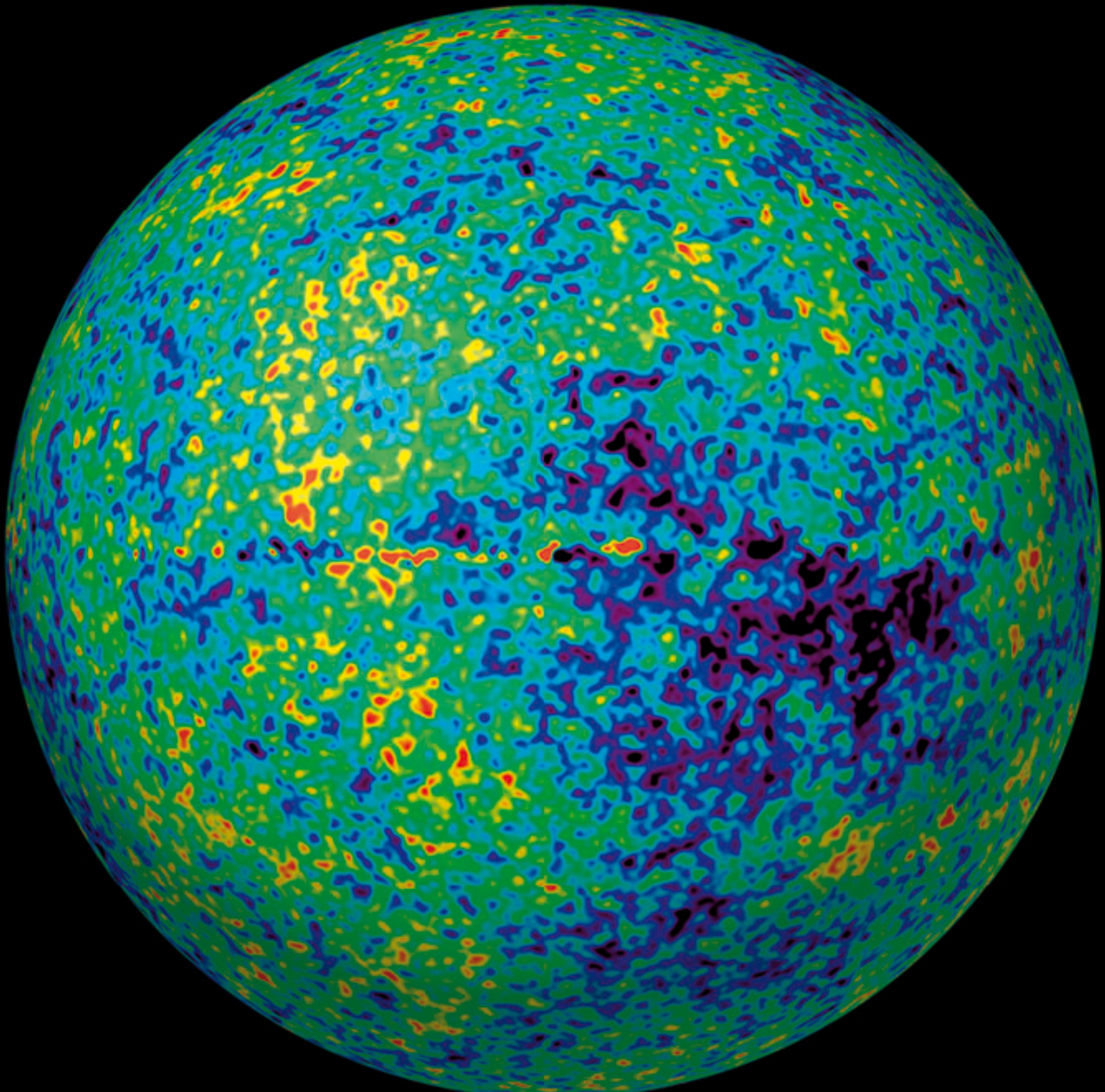




Today: the famous Crab nebulus

Feb 23, 1987: "A neutrino burst was observed in the Kamiokande II detector on 23 February, 7:35:35 UT (±1 min) during a time interval of 13 sec."

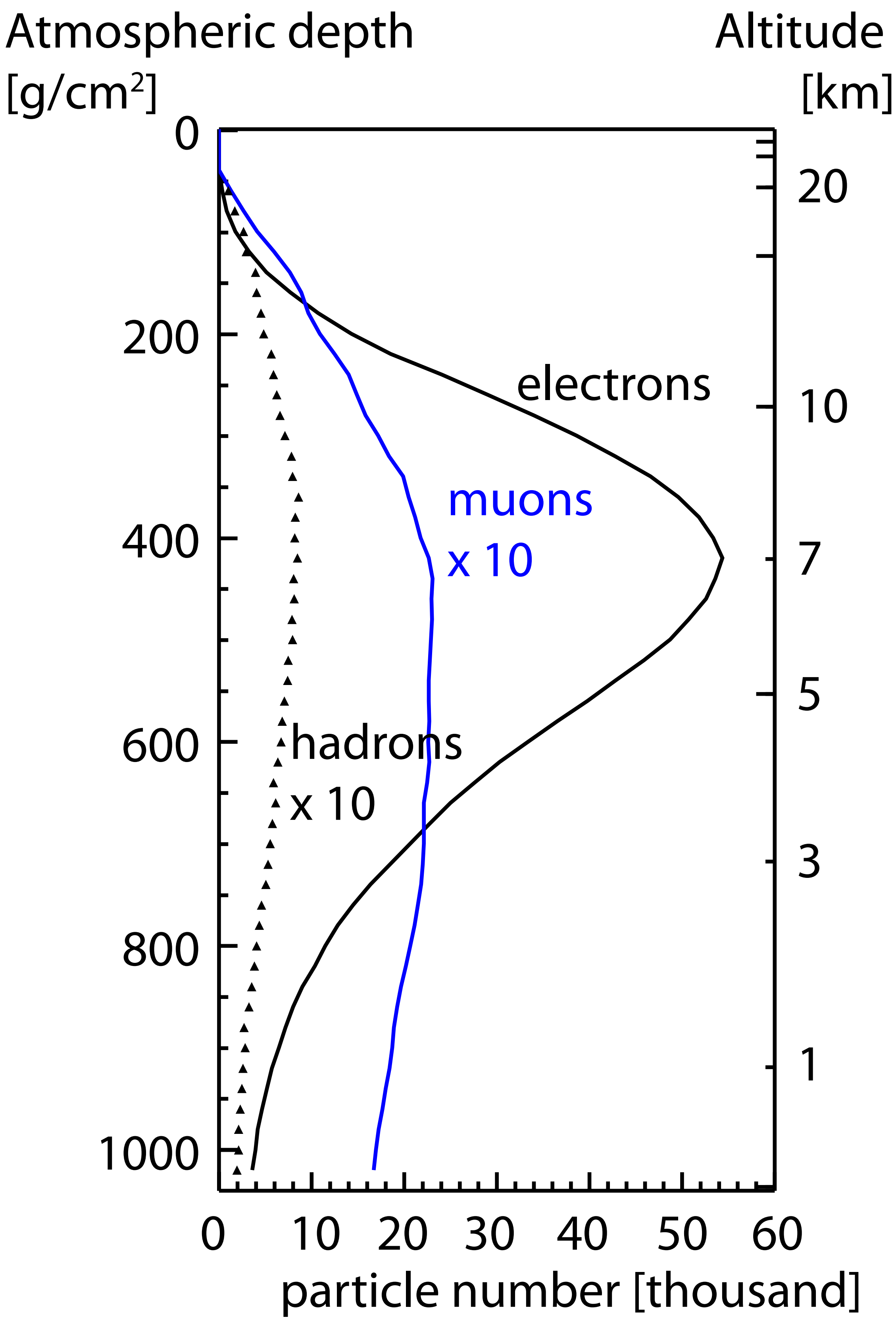

p $10^{15\text{-}18}$ eV
p 10^{20} eV
GZK
ν
γ
ν
γ
ν
γ
χ



CMB temperature fluctuations: one of the most influential discoveries

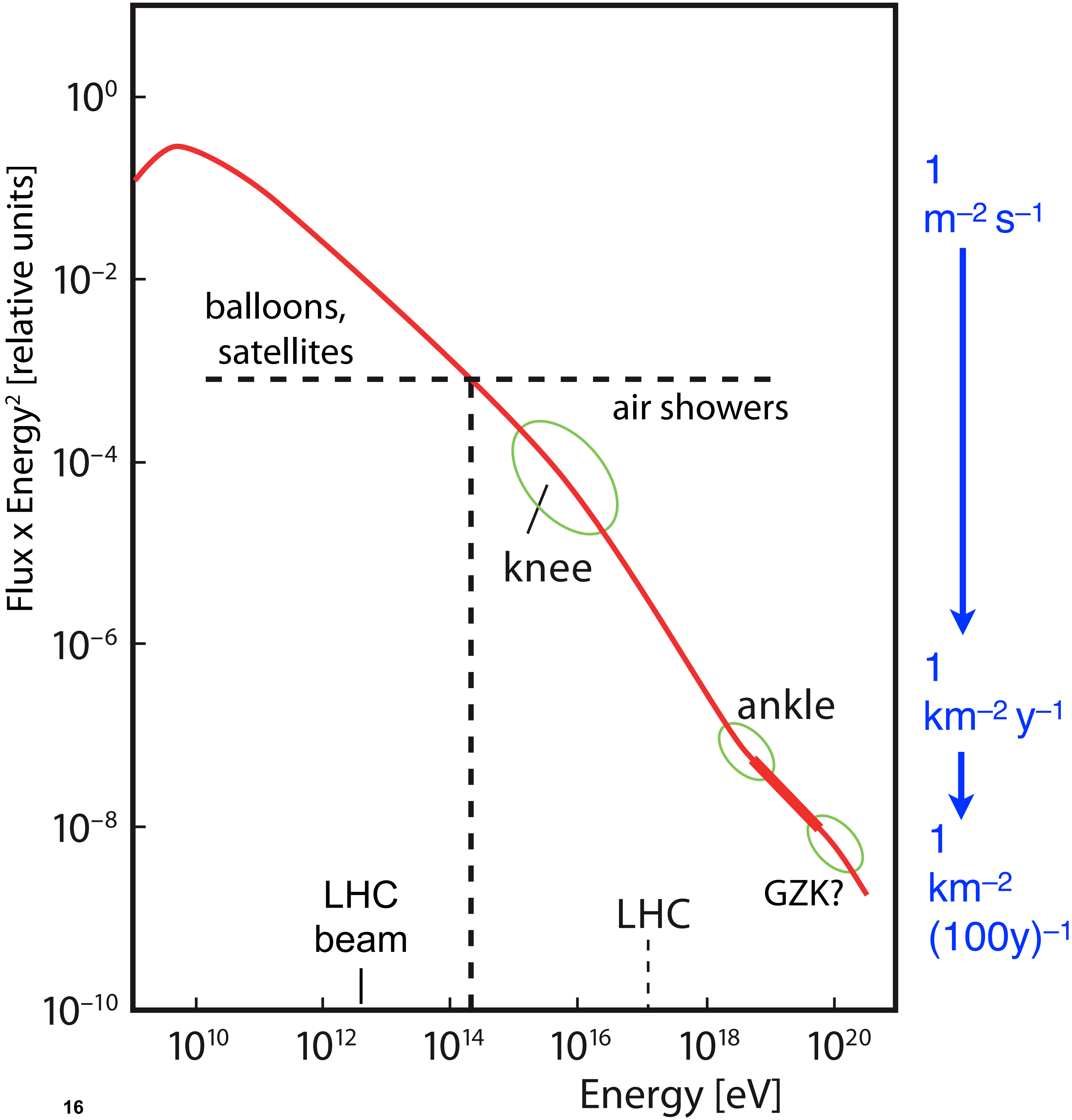
Cosmic radiations: nuclei

Victor Hess 1912



π^0 decay feeds electromagnetic part

$\pi^{\pm}$ decay feeds muonic part



element abundances:
15 My in galaxy & halo

energy density ~like light, magnetic field, CMB; equiv. to 3 SN/century at 10% eff.

powerlaw spectrum
$dN/dE \sim E^{-3}$
10 decades in energy;
flux range very large

stochastic acceleration in shocked plasma, confined by mag. fields

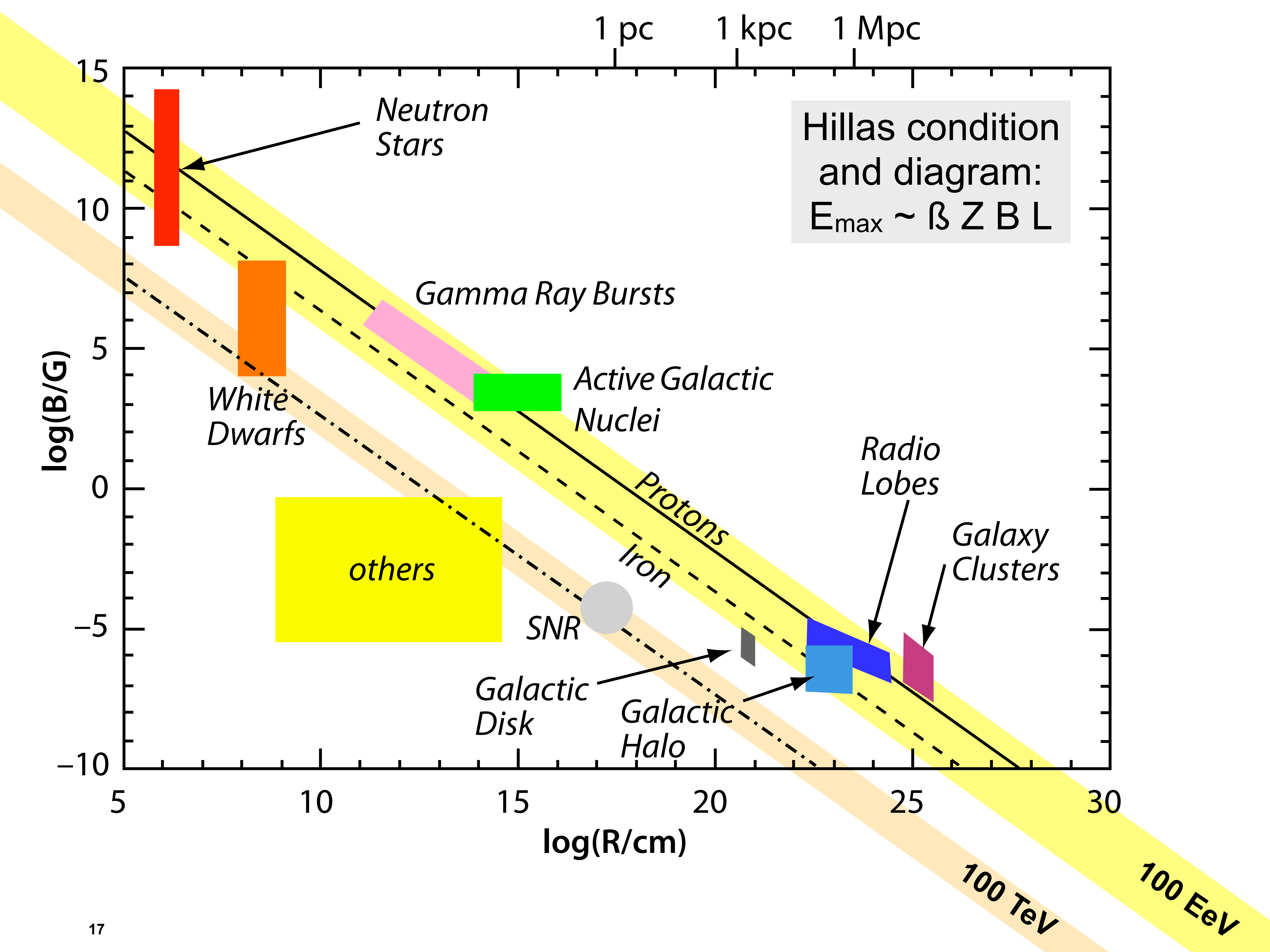
knee: p drop out first;
end of SN acceleration?

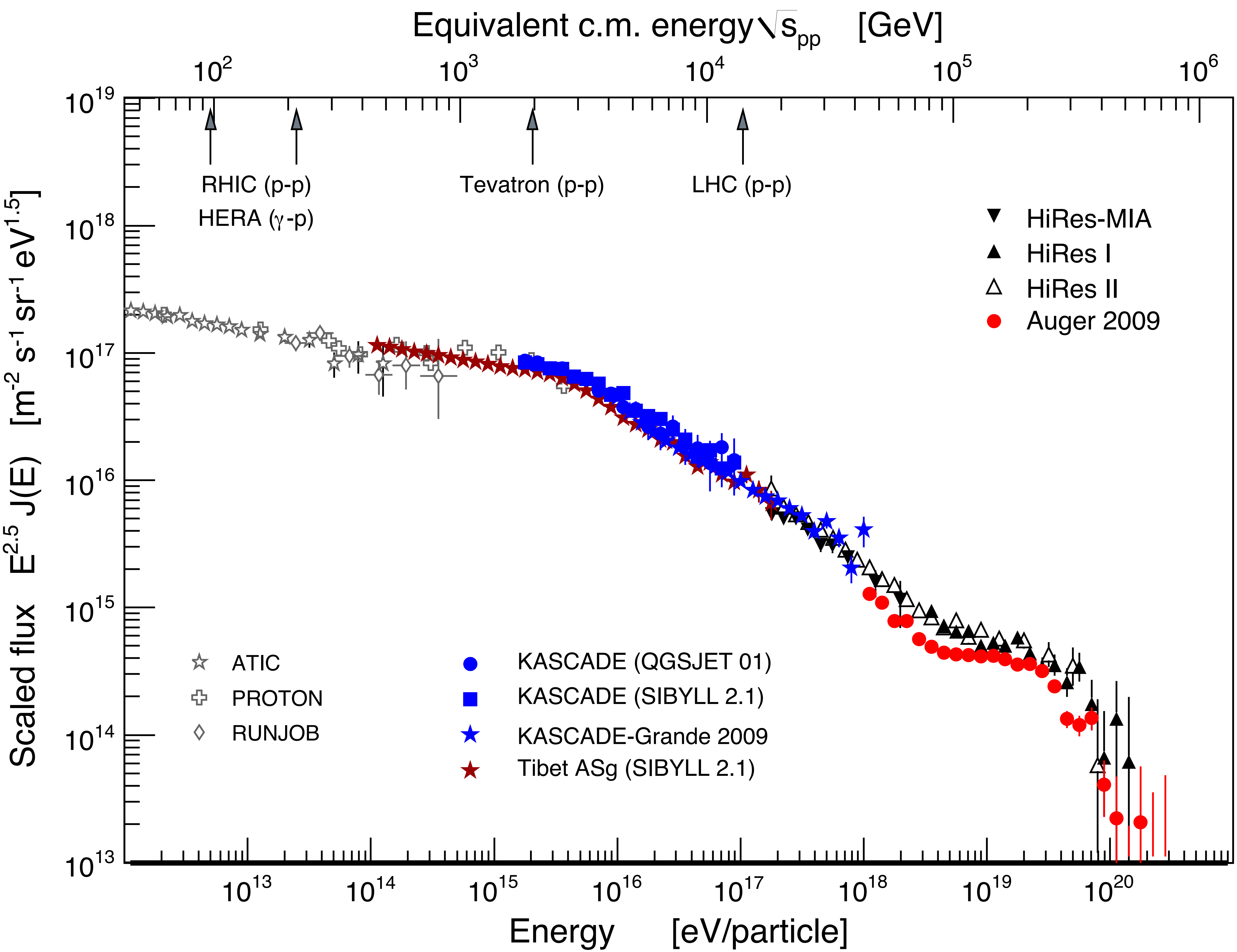
isotropic directions

ankle: harder component, extraglactic

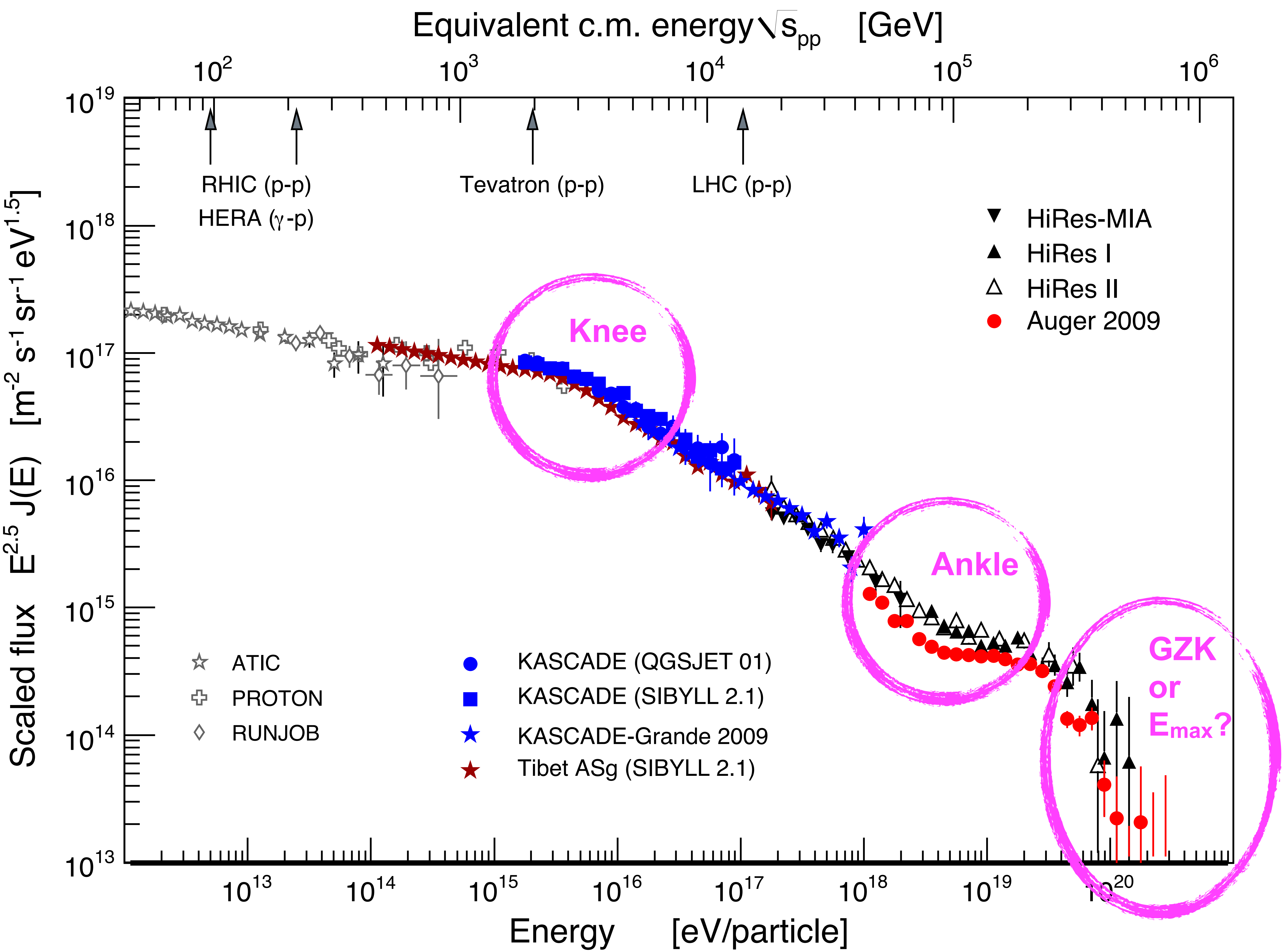
GZK: flux suppression above 60 EeV

composition?
sources?
propagation?
particle physics?

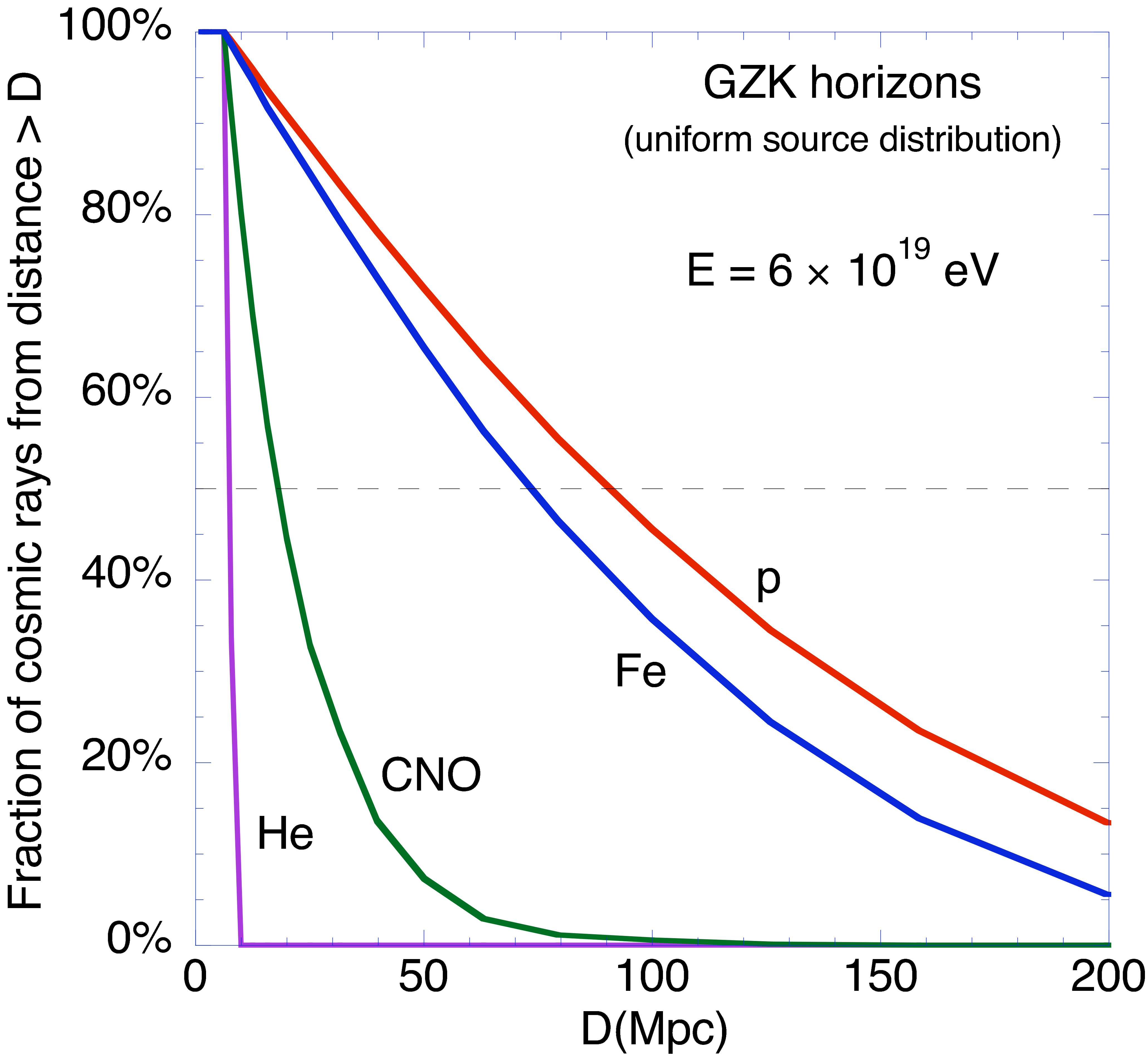

1 pc
1 kpc
1 Mpc
Hillas condition
and diagram:
$E_{max} \sim ß Z B L$
Neutron
Stars
White
Dwarfs
Gamma Ray Bursts
Active Galactic
Nuclei
Radio
Lobes
Galaxy
Clusters
Protons
Iron
others
SNR
Galactic
Disk
Galactic
Halo
100 TeV
100 EeV
log(B/G)
15
10
5
0
−5
−10
log(R/cm)
5
10
15
20
25
30



Equivalent c.m. energy $\sqrt{s_{pp}}$ [GeV]
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger 2009
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2009
Tibet ASg (SIBYLL 2.1)
Scaled flux $E^{2.5}$ J(E) [m^{-2} s^{-1} sr^{-1} $eV^{1.5}$]
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Energy [eV/particle]

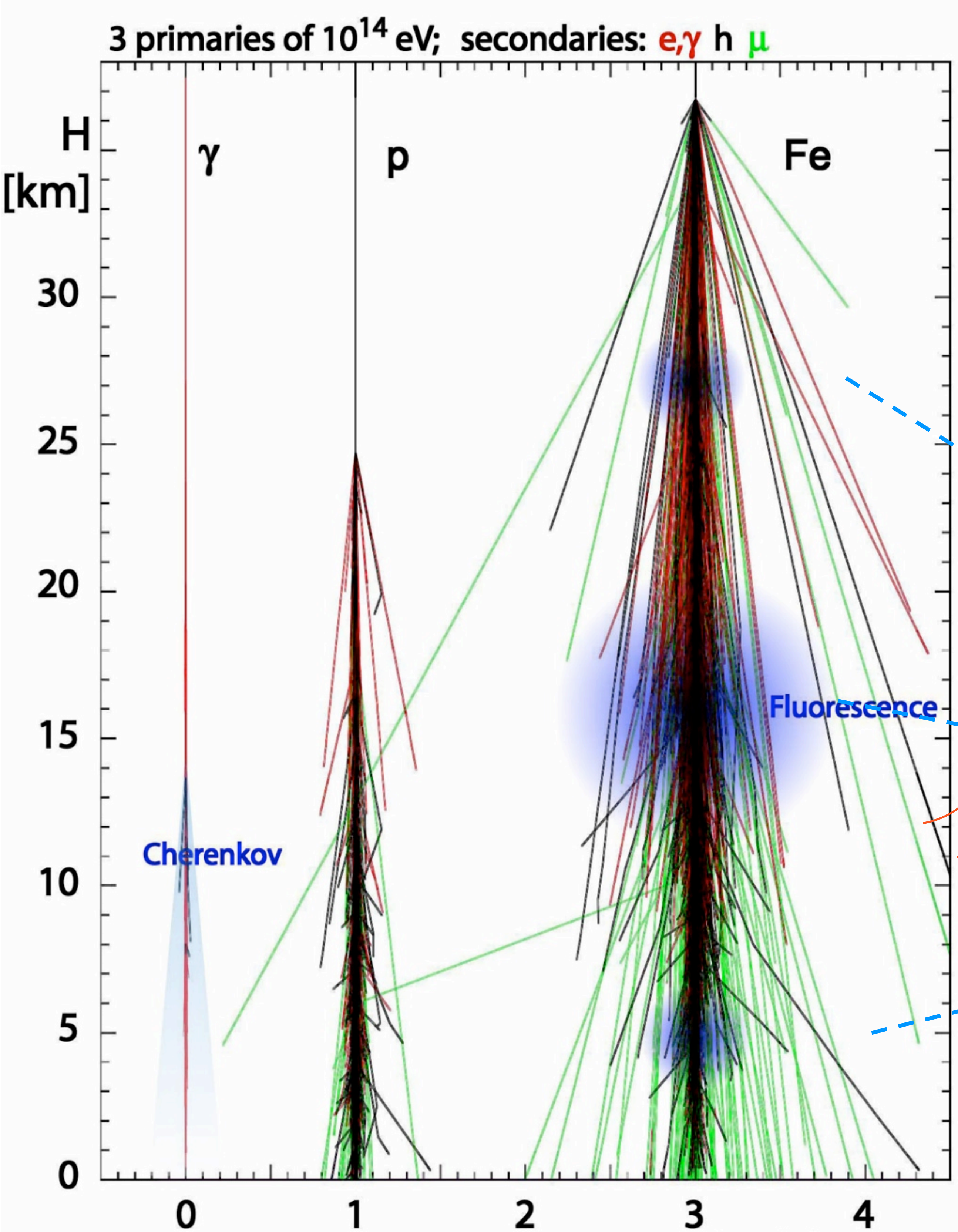


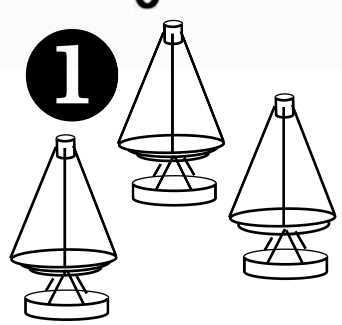
Equivalent c.m. energy $\sqrt{s_{pp}}$ [GeV]
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger 2009
Knee
Ankle
GZK or E_{max}?
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2009
Tibet ASg (SIBYLL 2.1)
Scaled flux $E^{2.5}$ J(E) [m^{-2} s^{-1} sr^{-1} $eV^{1.5}$]
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Energy [eV/particle]


GZK horizons
(uniform source distribution)
E = 6 × 10^19 eV
Fraction of cosmic rays from distance > D
100%
80%
60%
40%
20%
0%
p
Fe
CNO
He
0
50
100
150
200
D(Mpc)

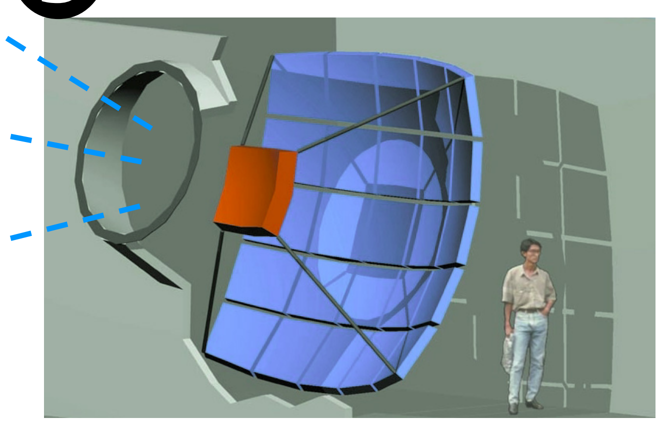
❶ Cherenkov telescopes
❷ particle detector arrays
❸ Fluorescence telescopes
❹ Radio antenna

HYBRID detection: more than one method!



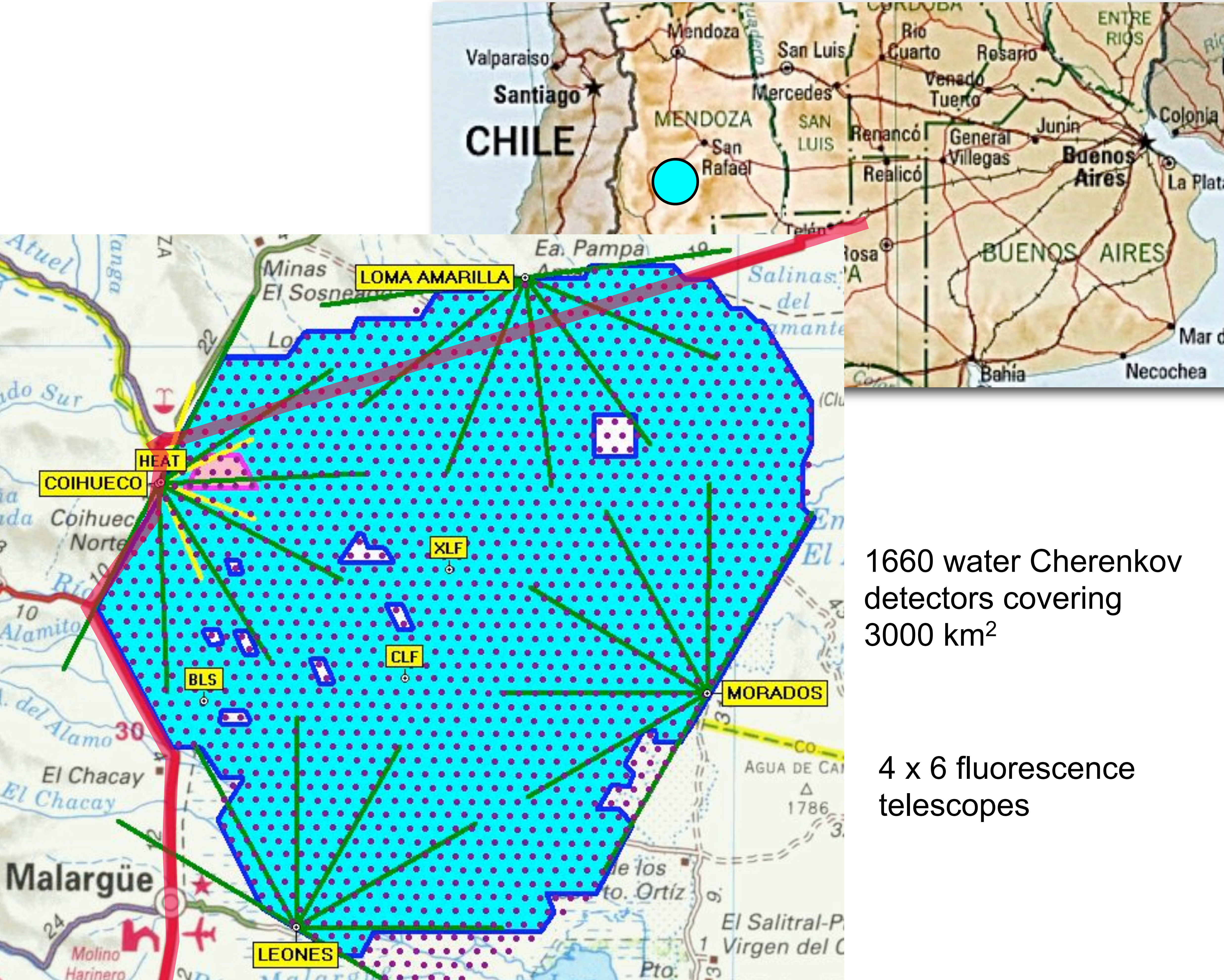
❶


❷


❸


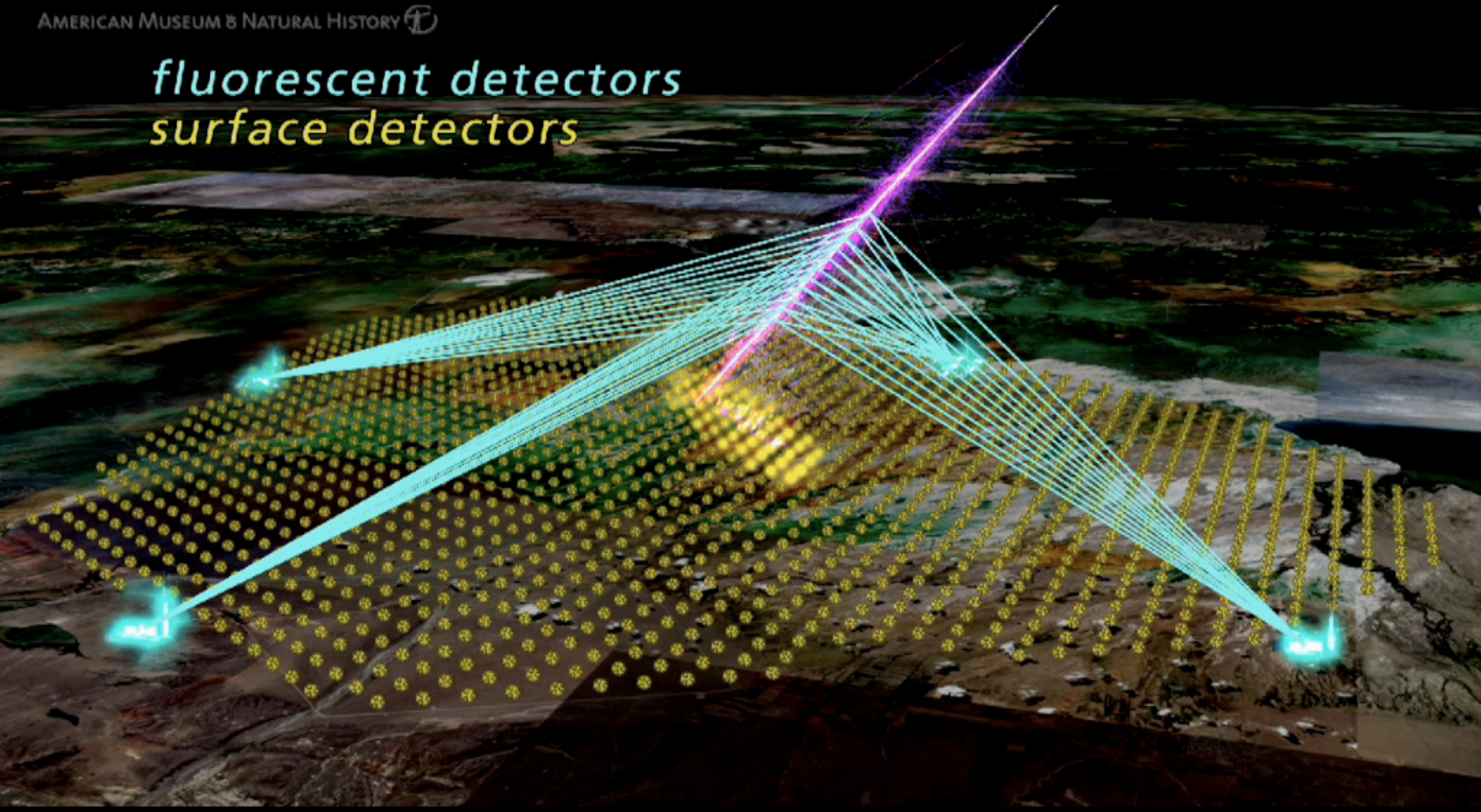
❹


PIERRE AUGER OBSERVATORY



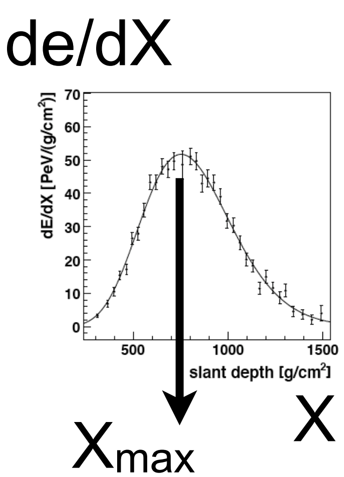
1660 water Cherenkov detectors covering 3000 km^2

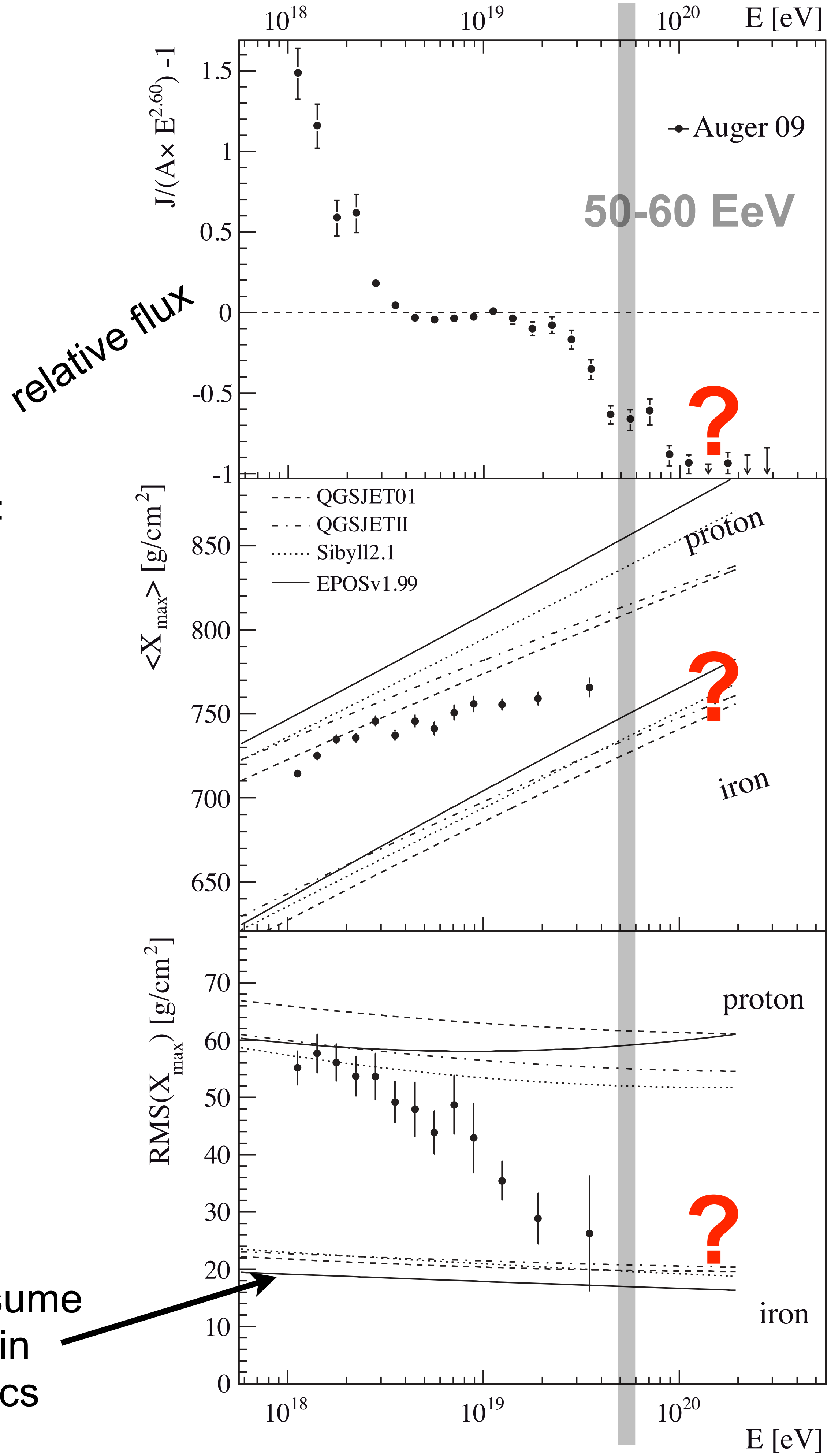
4 x 6 fluorescence telescopes


AMERICAN MUSEUM & NATURAL HISTORY
fluorescent detectors
surface detectors

spectrum: convoluted information about sources, particles and propagation

shower profile: independent, best estimator of primary particle mass

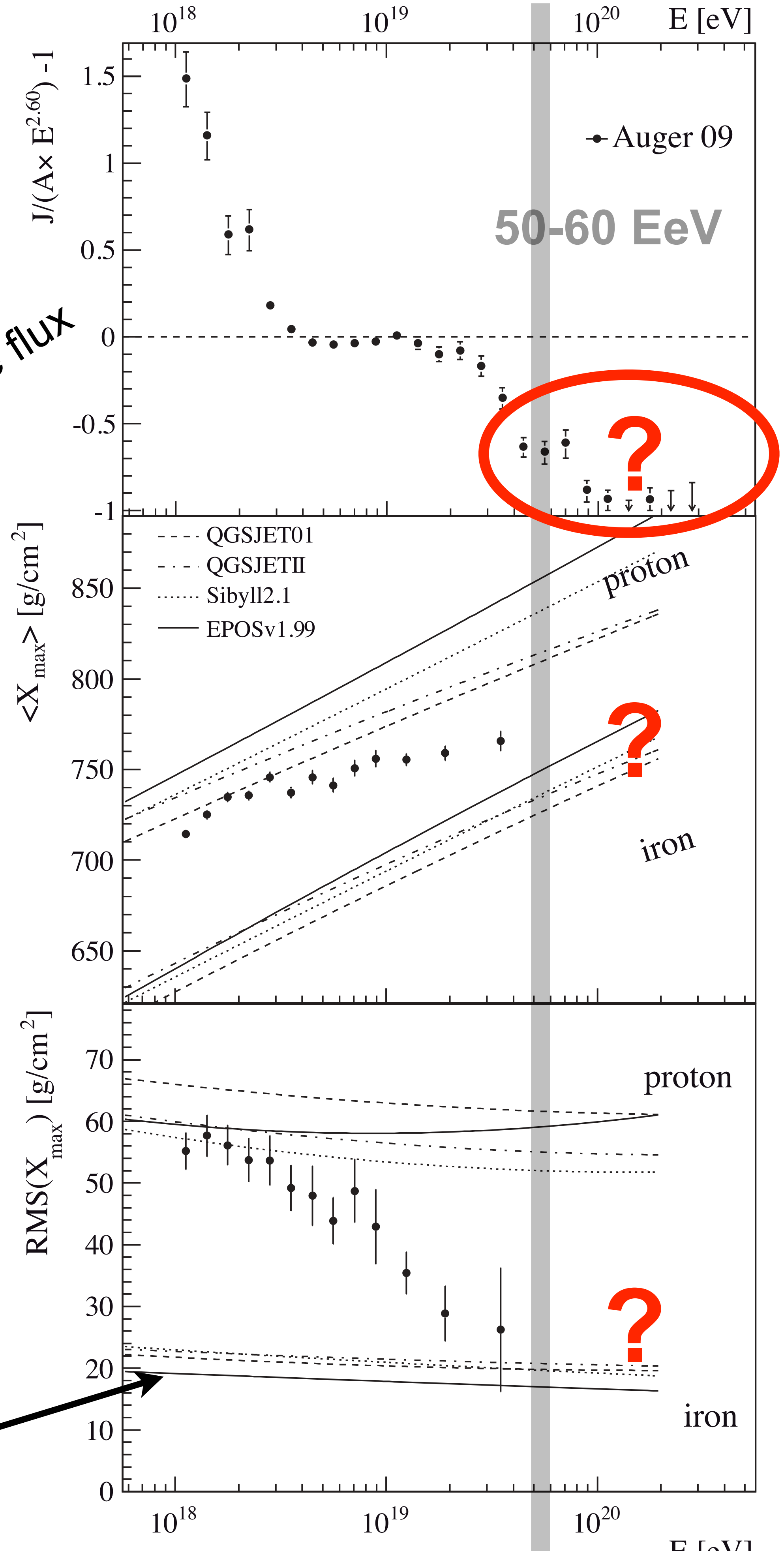




models assume no change in basic physics

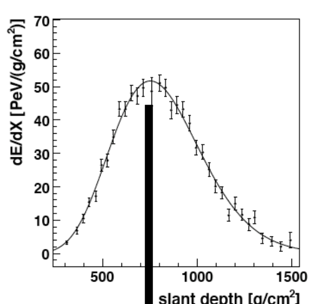
spectrum:
convoluted
information
about
sources,
particles and
propagation

relative flux



shower profile:
independent,
best estimator
of primary
particle mass

de/dX

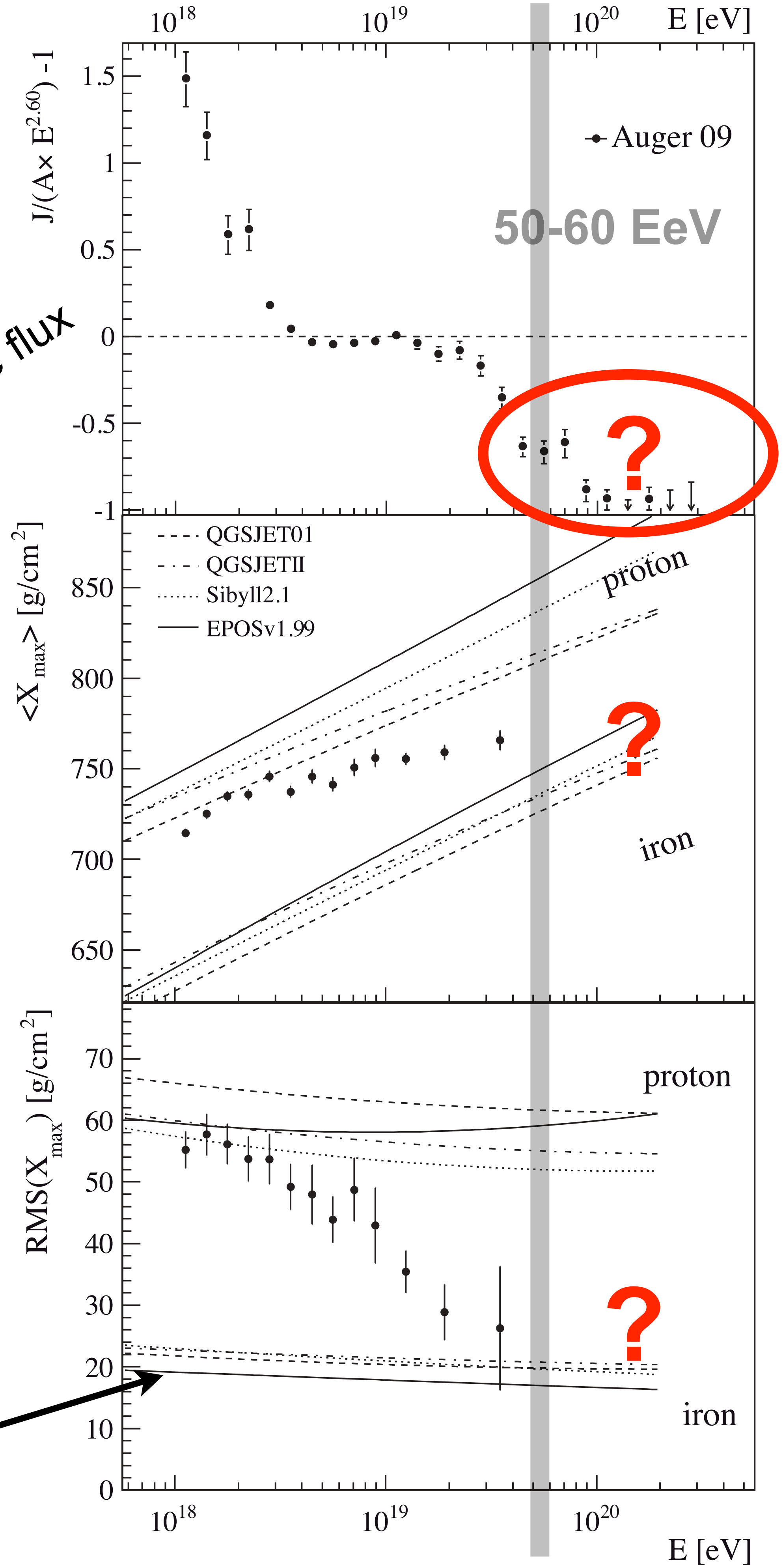


X_{max} X

models assume
no change in
basic physics

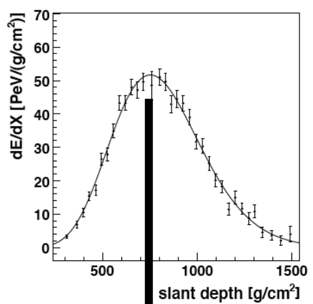
spectrum: convoluted information about sources, particles and propagation

relative flux



shower profile: independent, best estimator of primary particle mass

de/dX

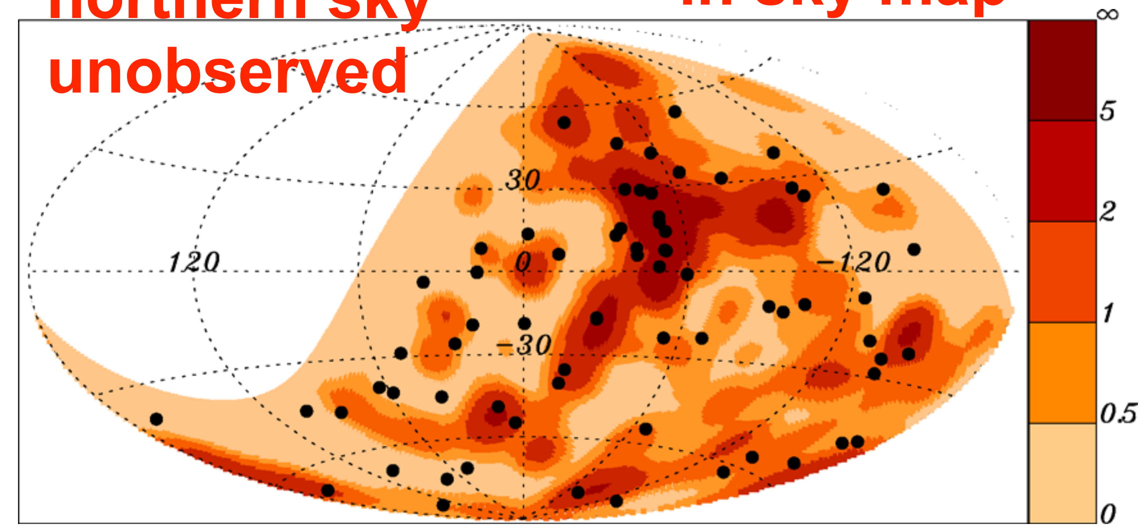


X_{max} X

models assume no change in basic physics

northern sky unobserved

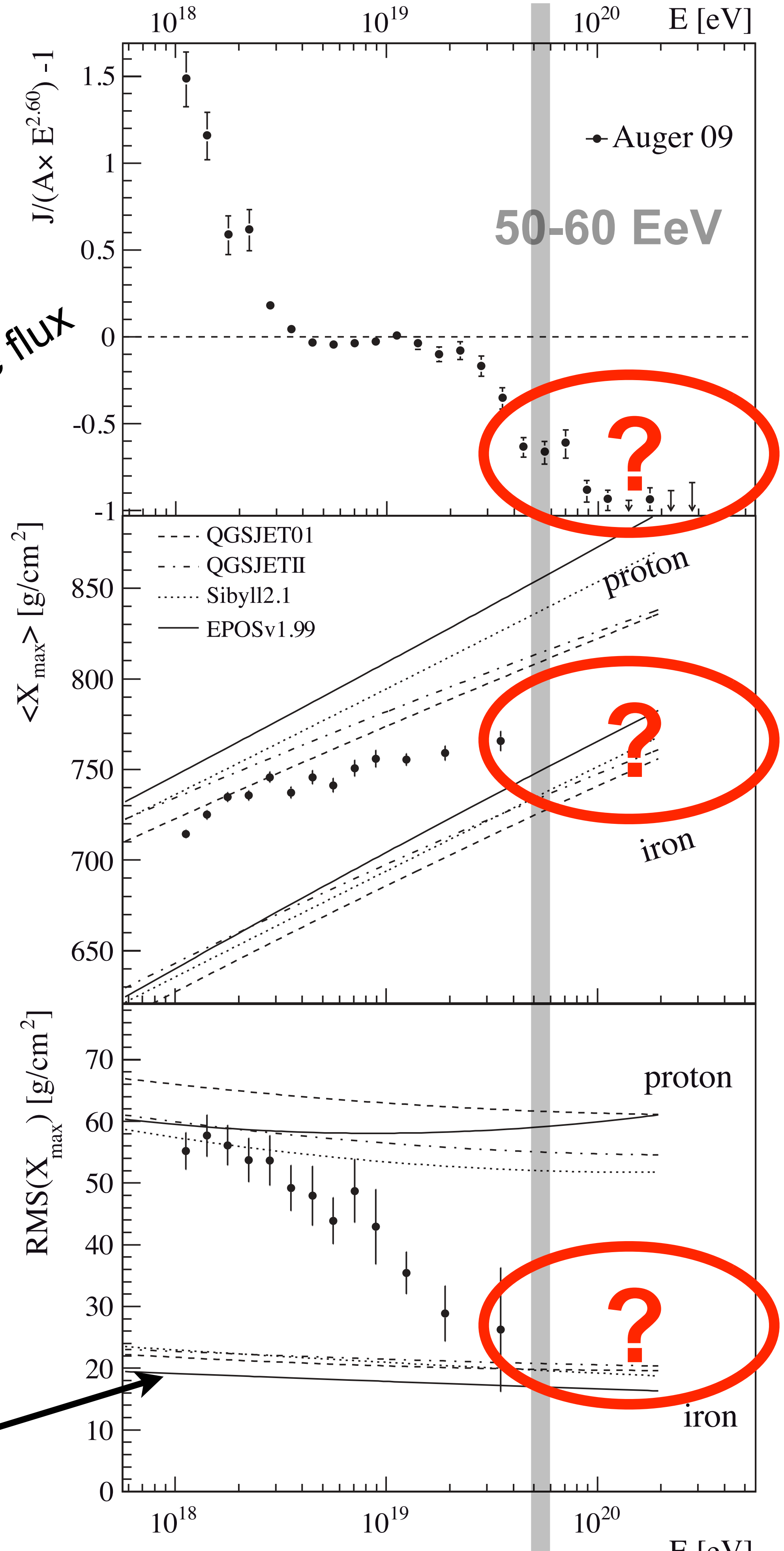
few events in sky map



http://arxiv.org/abs/1009.1855 as of Sep 10, 2010

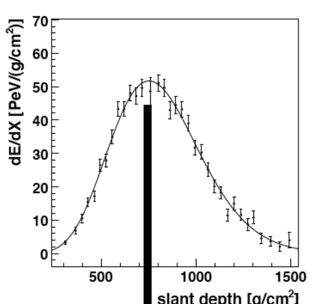
spectrum: convoluted information about sources, particles and propagation

relative flux



shower profile: independent, best estimator of primary particle mass

de/dX



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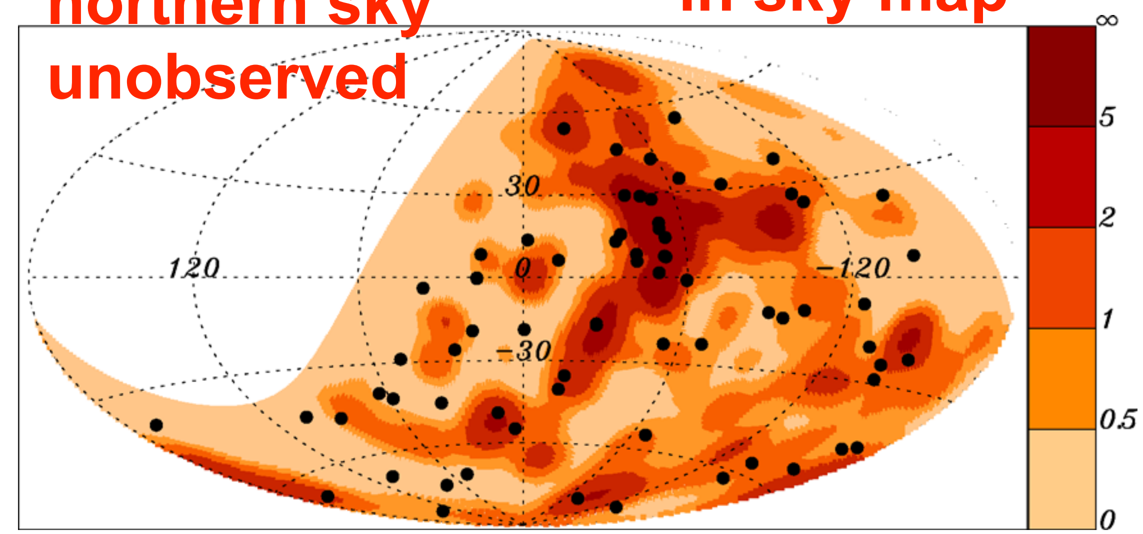

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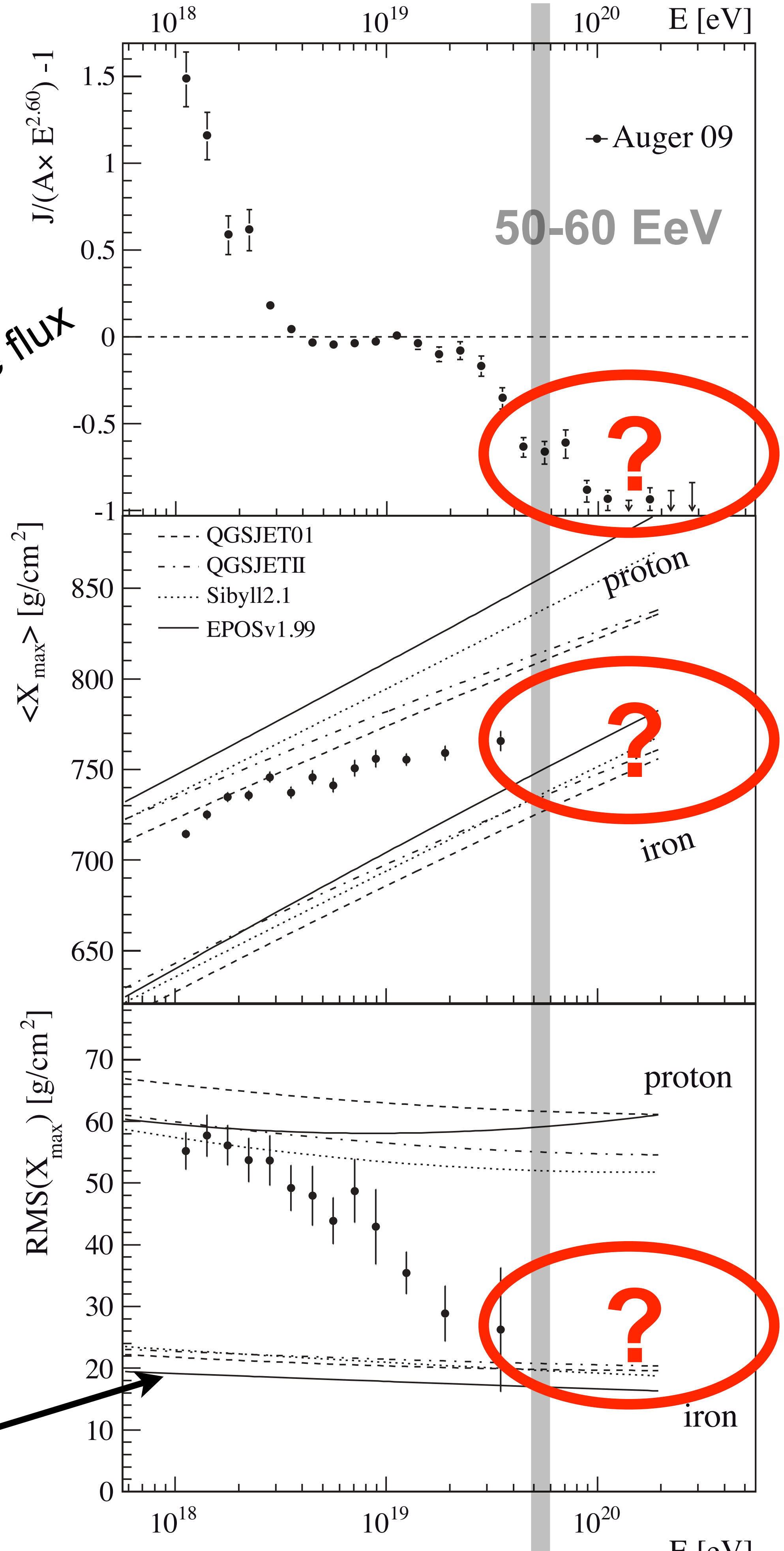
composition at and above the GZK threshold?

alternative explanations like increasing cross section?

particle physics at $\sqrt{s}$ > 350 TeV

spectrum: convoluted information about sources, particles and propagation

relative flux



shower profile: independent, best estimator of primary particle mass

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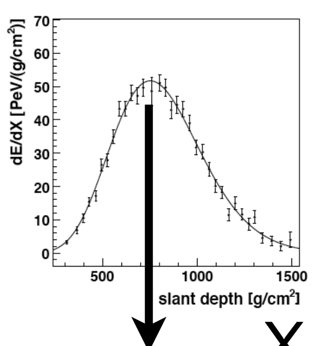

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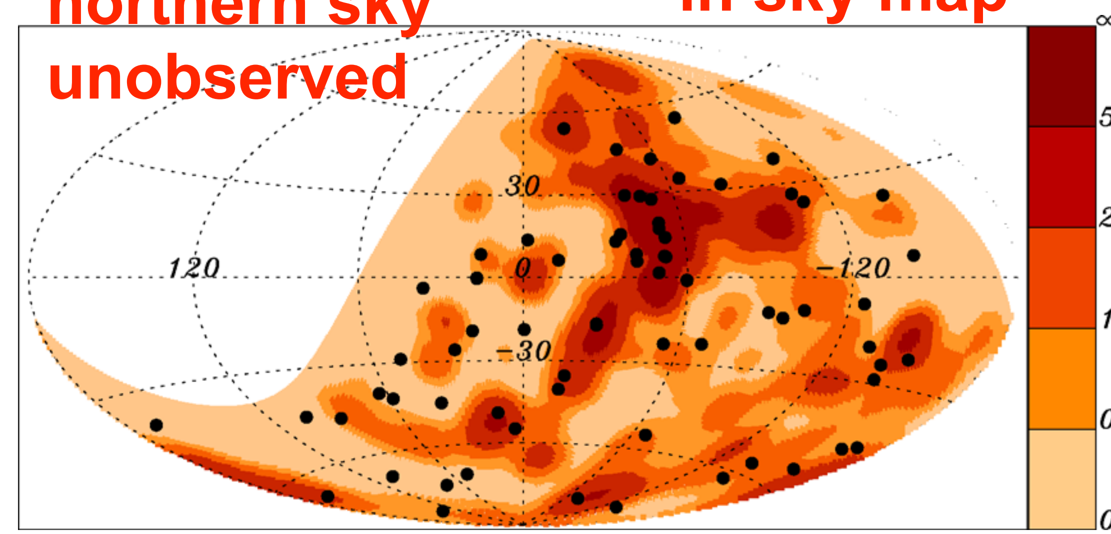

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composition at and above the GZK threshold?

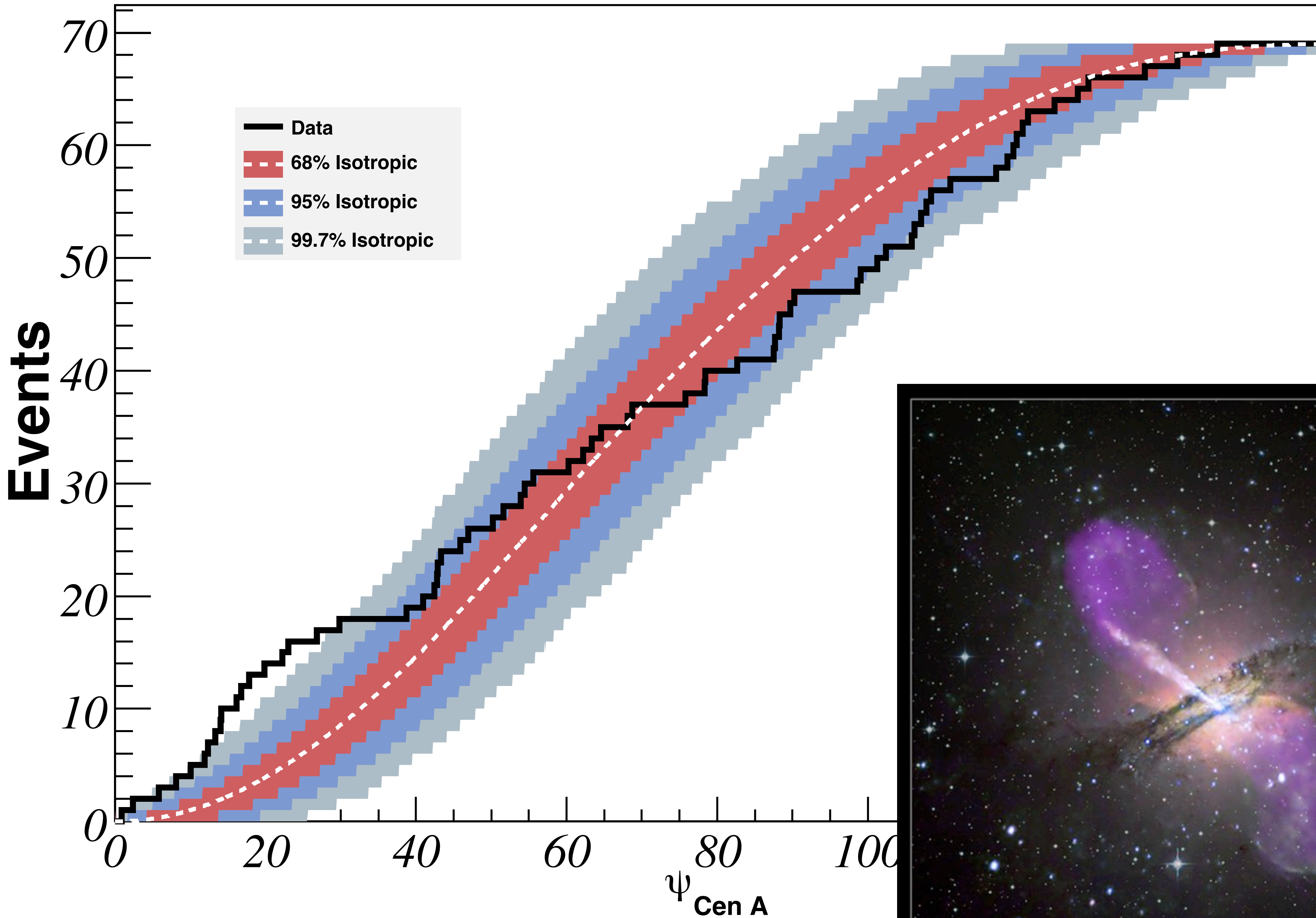
alternative explanations like increasing cross section?

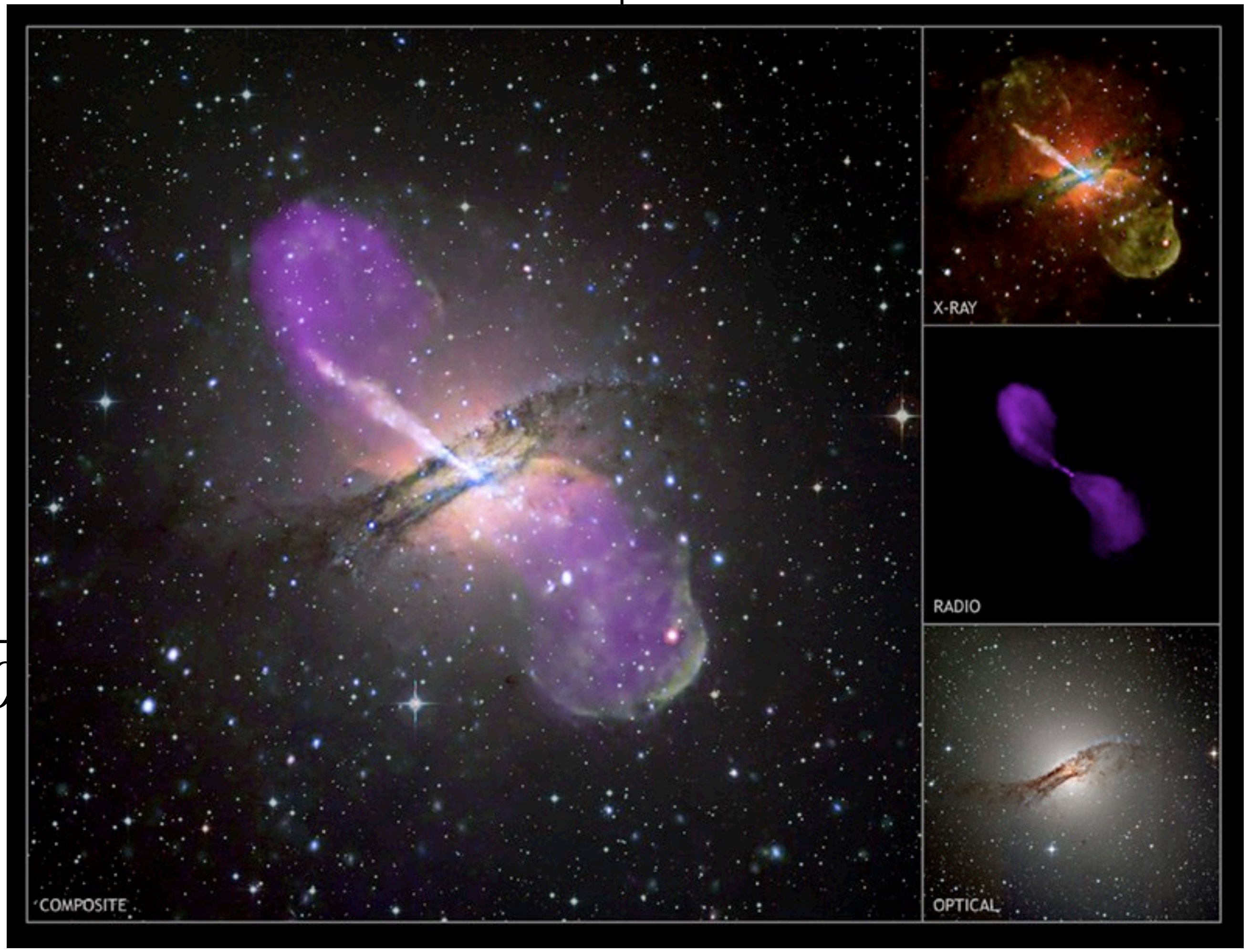
particle physics at $\sqrt{s}$ > 350 TeV

Addressing these questions needs much more statistics at the highest energies, i.e. a much larger area

Clustering around Centaurus A

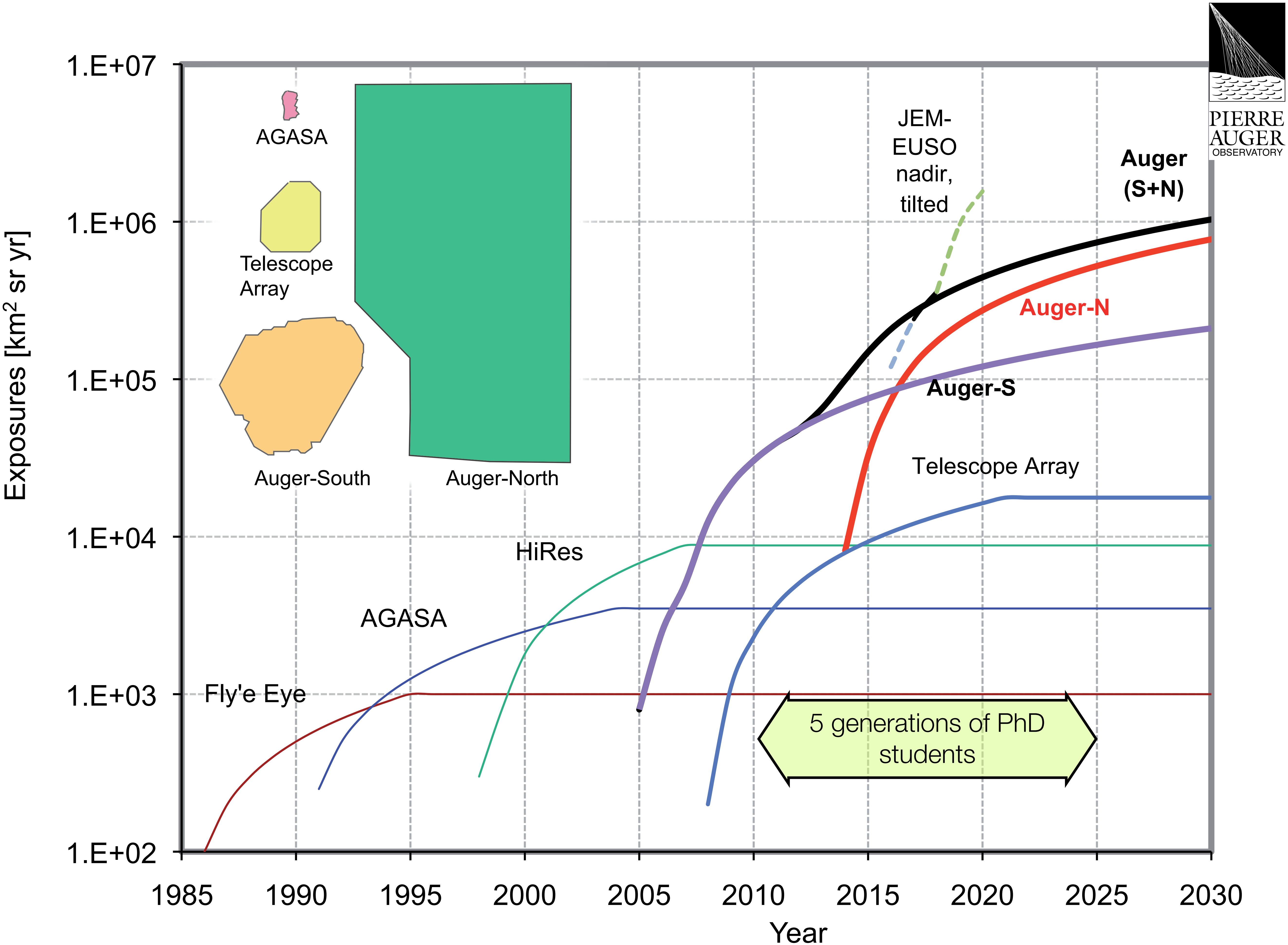
PIERRE AUGER OBSERVATORY



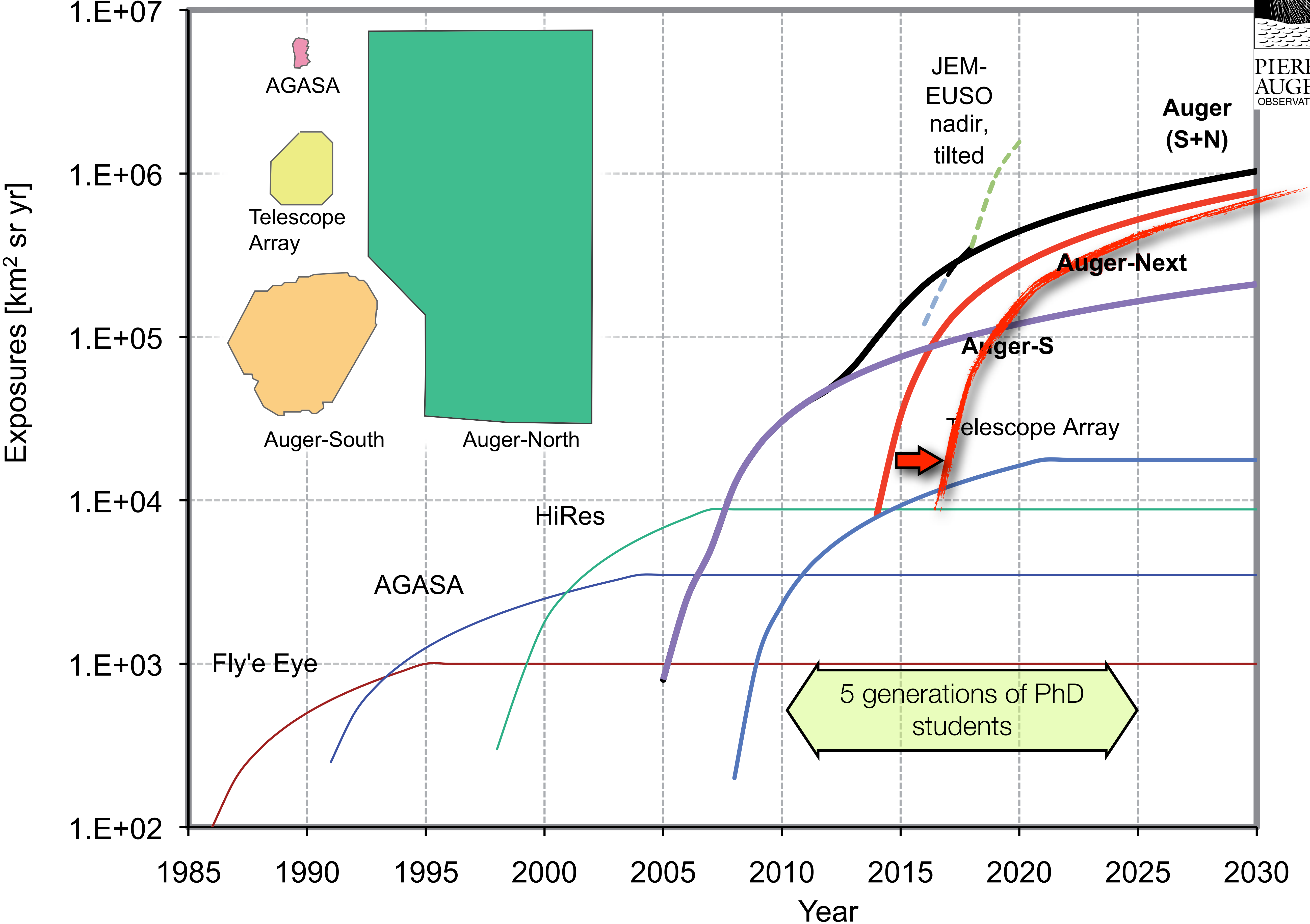


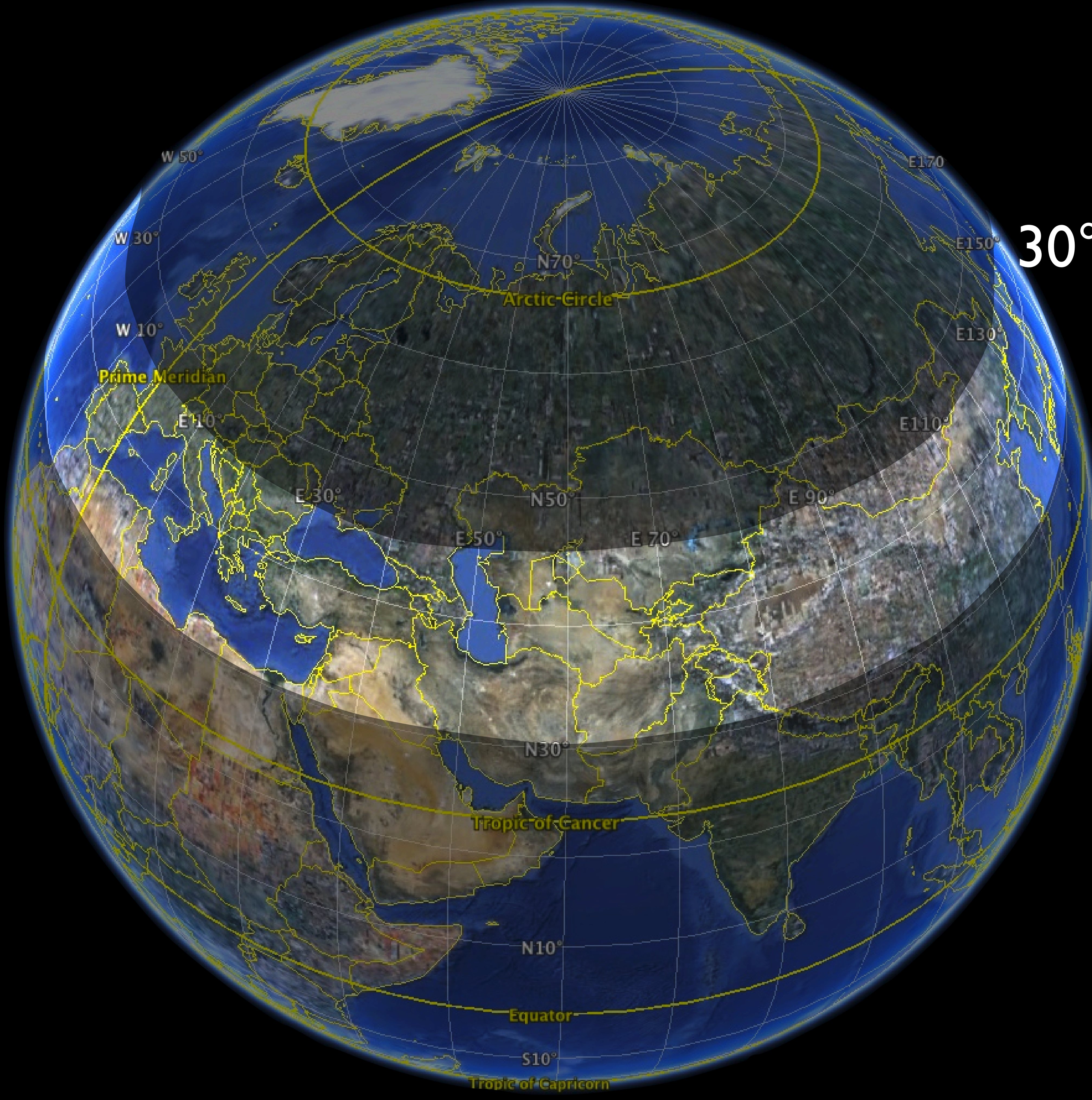
cumulative number of events with E ≥ 55 EeV as a function of angular distance [°] from Cen A.

13 arrival directions are within 18°, in which 3.2 arrival directions are expected if the flux were isotropic; K-S test gives 4% chance probability...



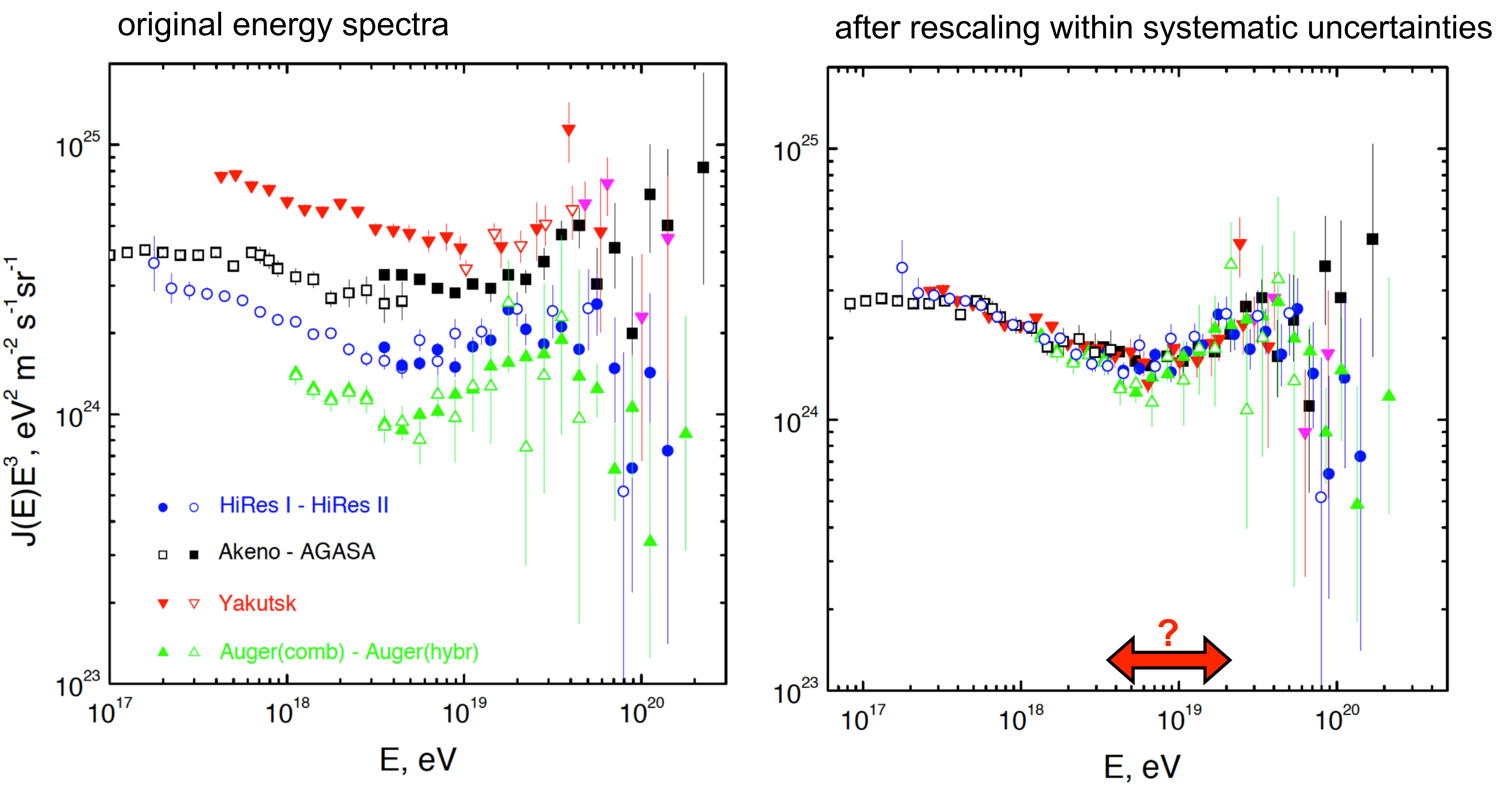
Exposures [km² sr yr]
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
AGASA
Telescope Array
Auger-South
Auger-North
JEM-EUSO nadir, tilted
Auger (S+N)
Auger-N
Auger-S
Telescope Array
HiRes
AGASA
Fly'e Eye
5 generations of PhD students
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
PIERRE AUGER OBSERVATORY


1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
Exposures [km² sr yr]
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
AGASA
Telescope Array
Auger-South
Auger-North
JEM-EUSO nadir, tilted
Auger (S+N)
Auger-Next
Auger-S
Telescope Array
HiRes
AGASA
Fly'e Eye
5 generations of PhD students


W 50°
W 30°
W 10°
Prime Meridian
E 10°
E 30°
E 50°
E 70°
E 90°
E 110°
E 130°
E 150°
E170
N70°
Arctic Circle
N50°
N30°
Tropic of Cancer
N10°
Equator
S10°
Tropic of Capricorn

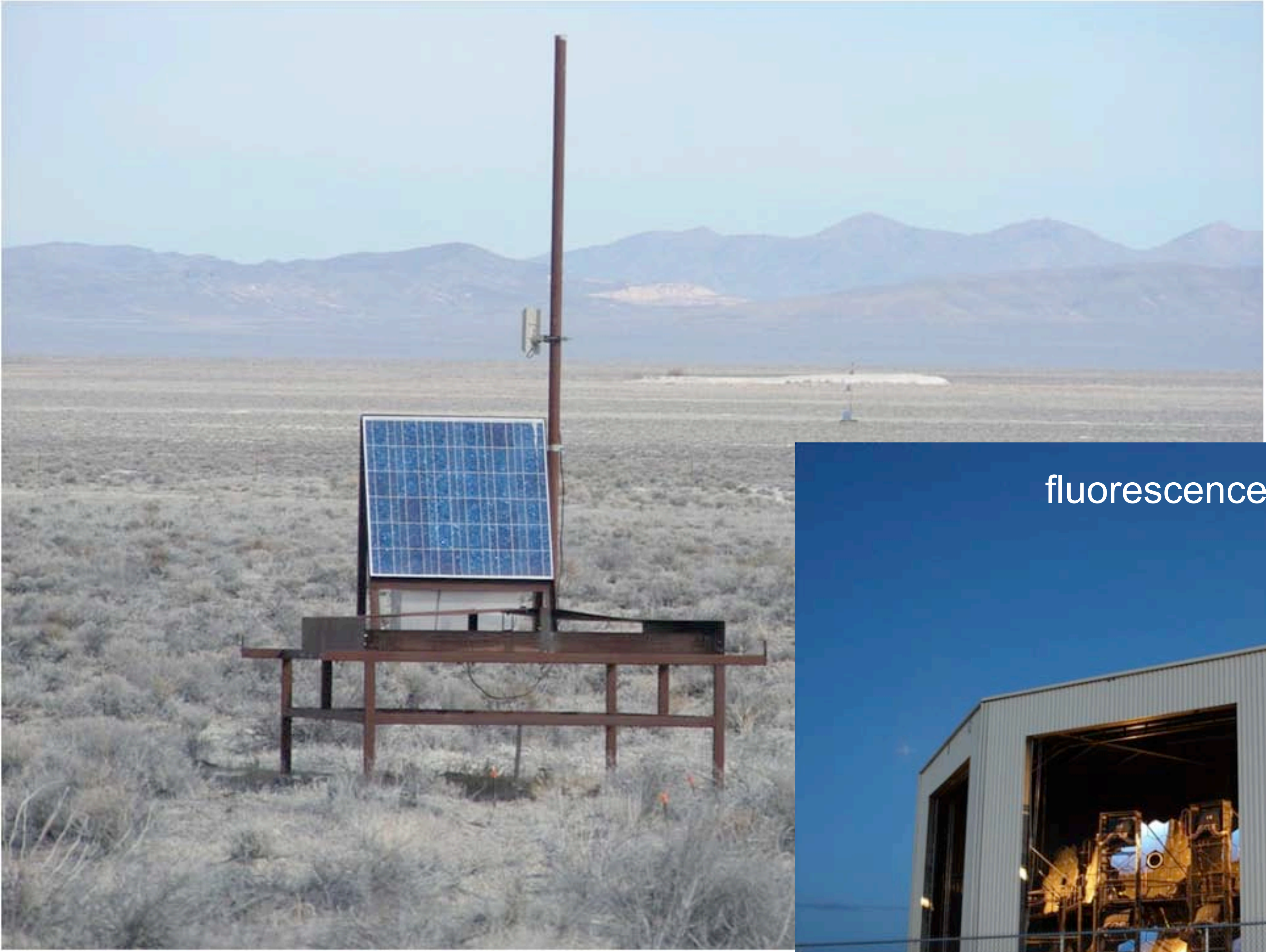
30°-45° N

Challenge: energy calibration at 10^{20} eV

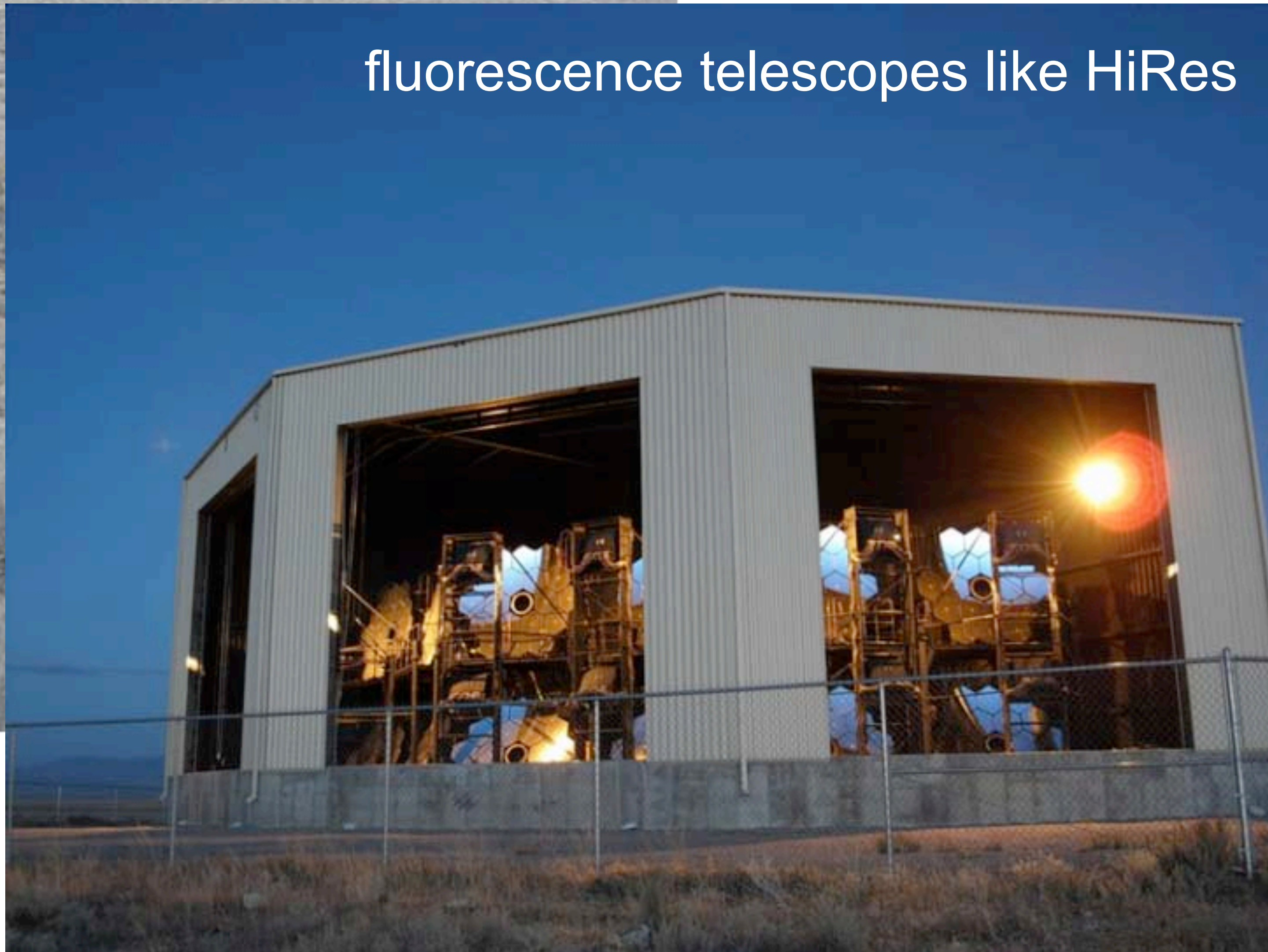


after Berezinsky 2009

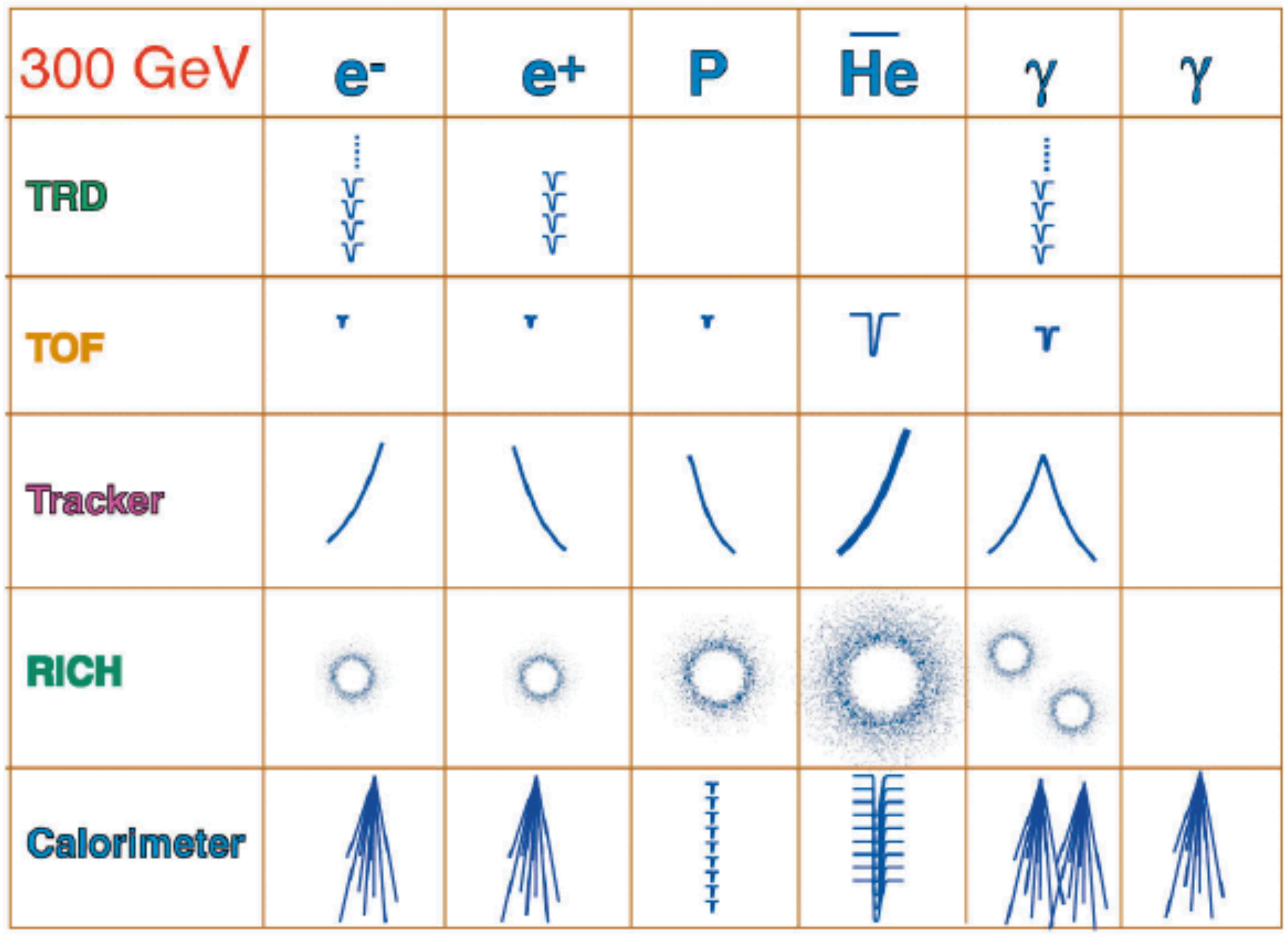
Telescope Array in Utah, 800 km^2, in operation

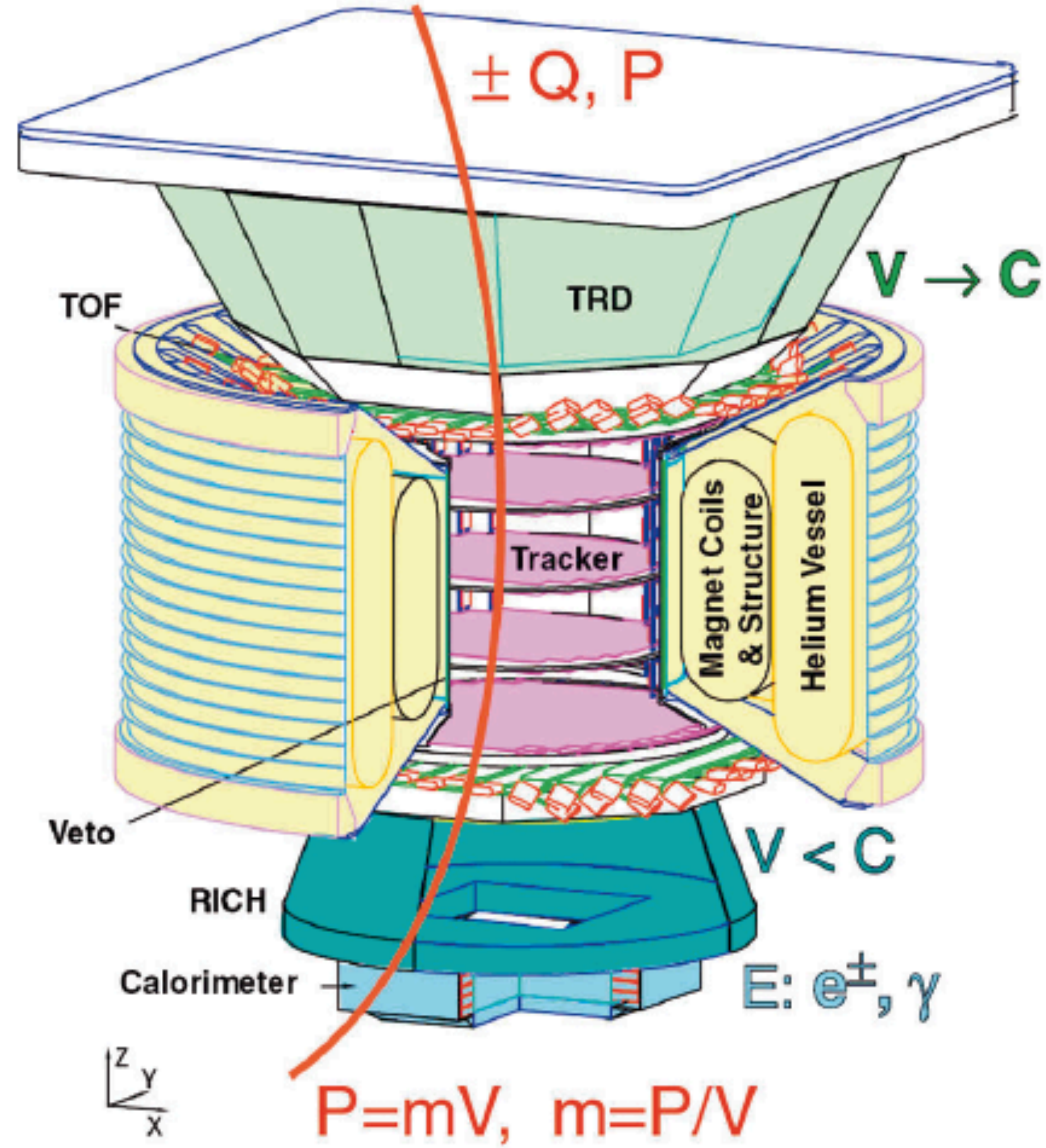


scintillators like AGASA



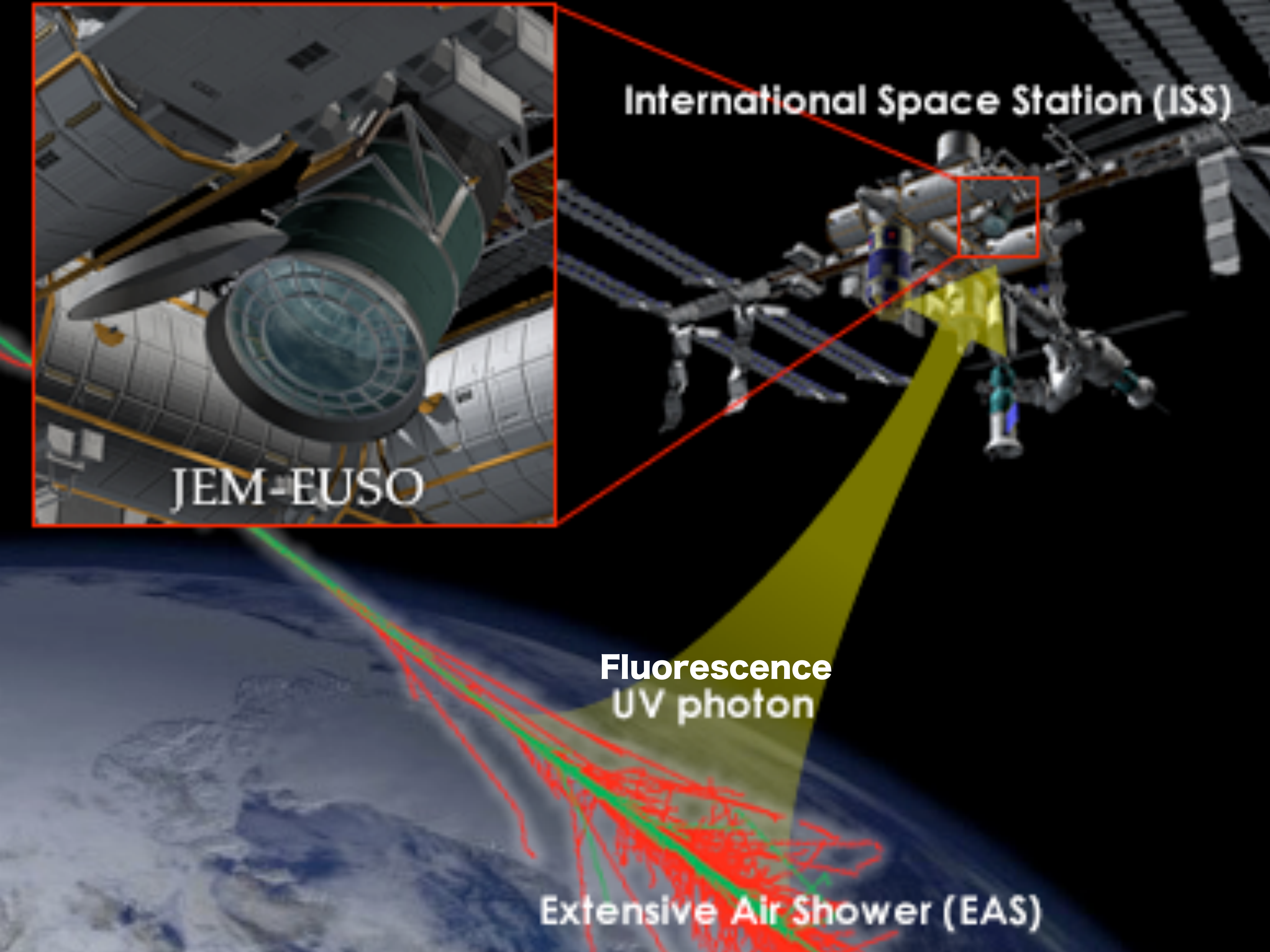
AMS (long at CERN)



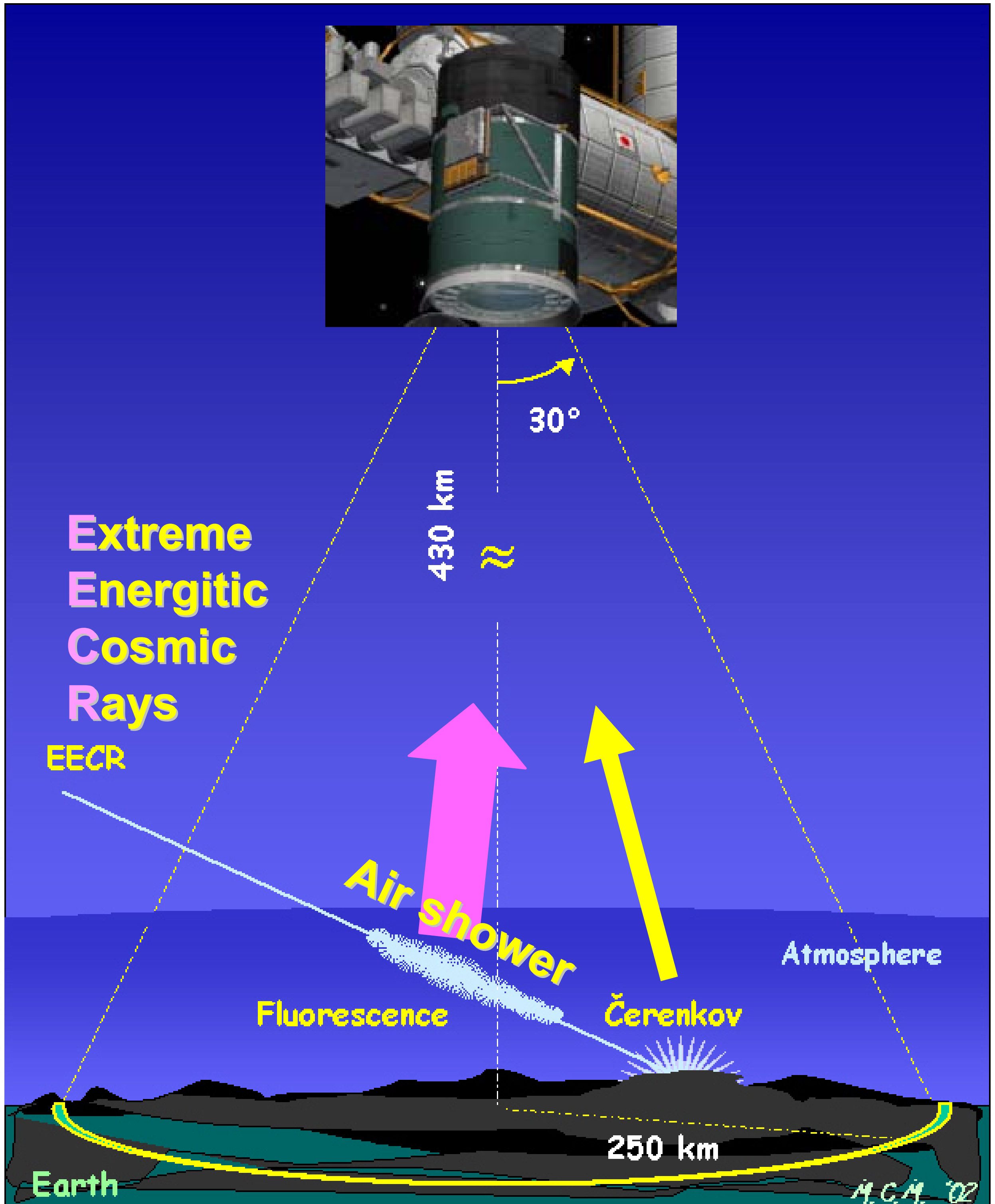


↑

even a single anti-Helium nucleus would be a sensation

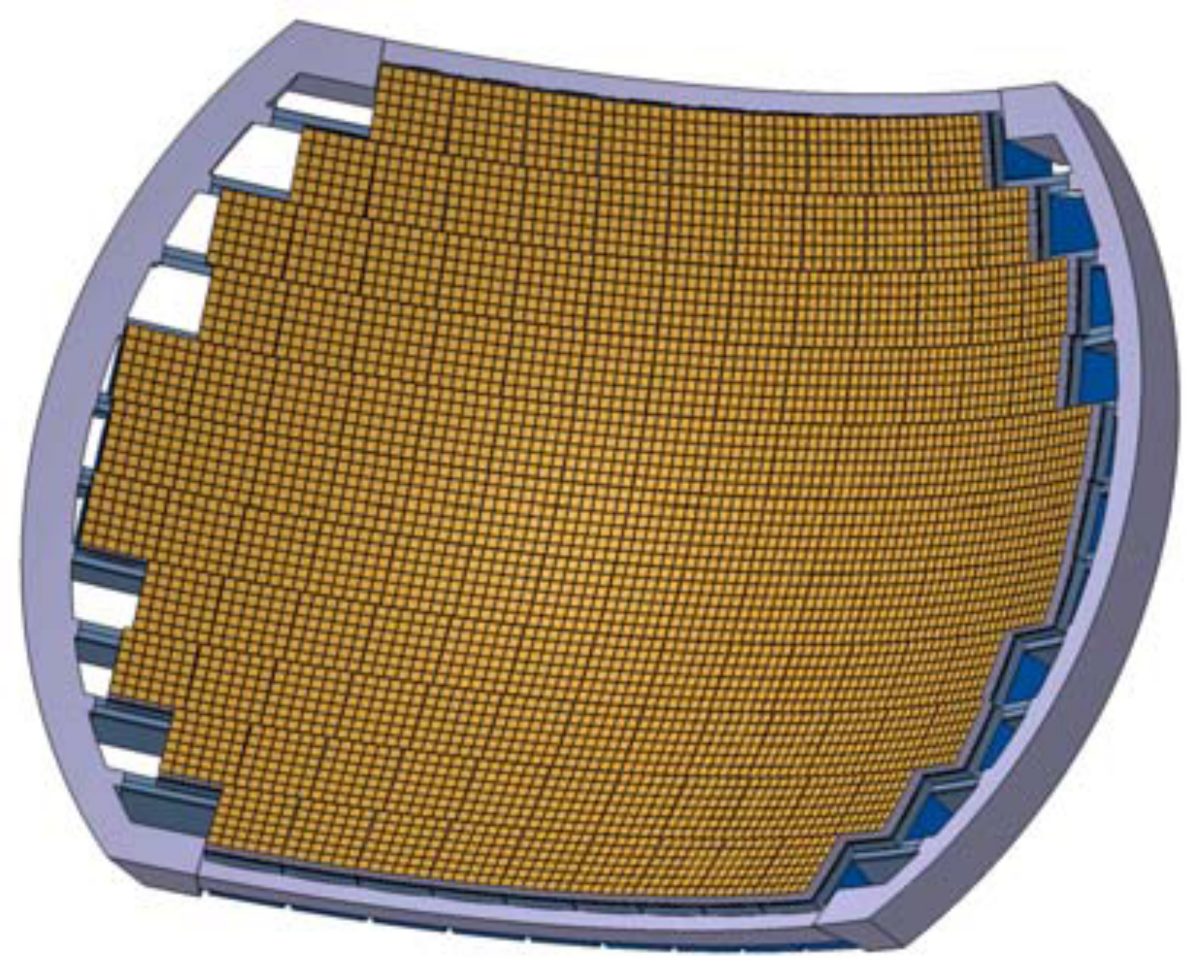

International Space Station (ISS)
JEM-EUSO
Fluorescence
UV photon
Extensive Air Shower (EAS)

JEM-EUSO Observational Principle



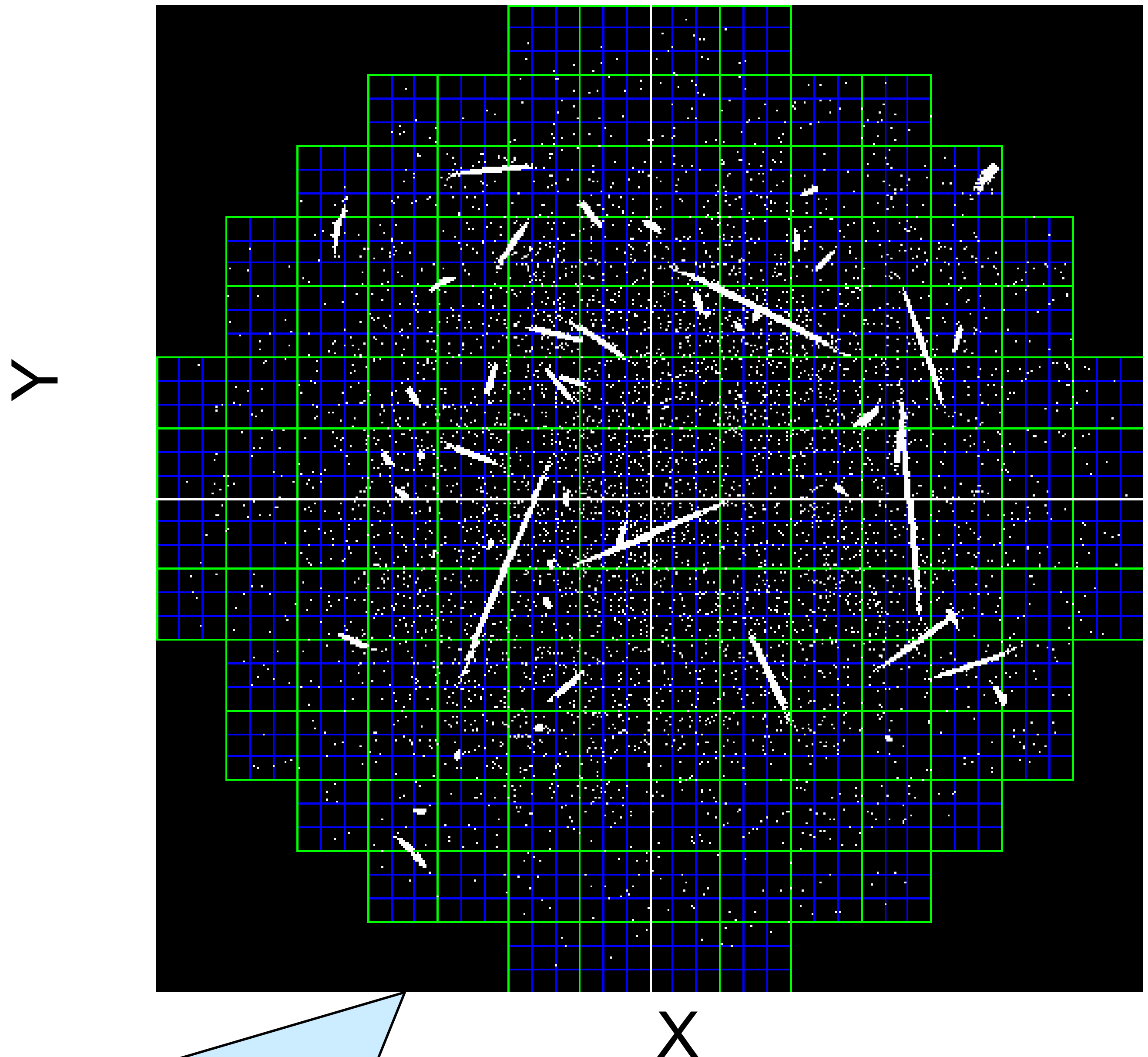
JEM-EUSO is a fluorescence telescope onboard the International Space Station ISS, connected to the Japanese Experiment Module.

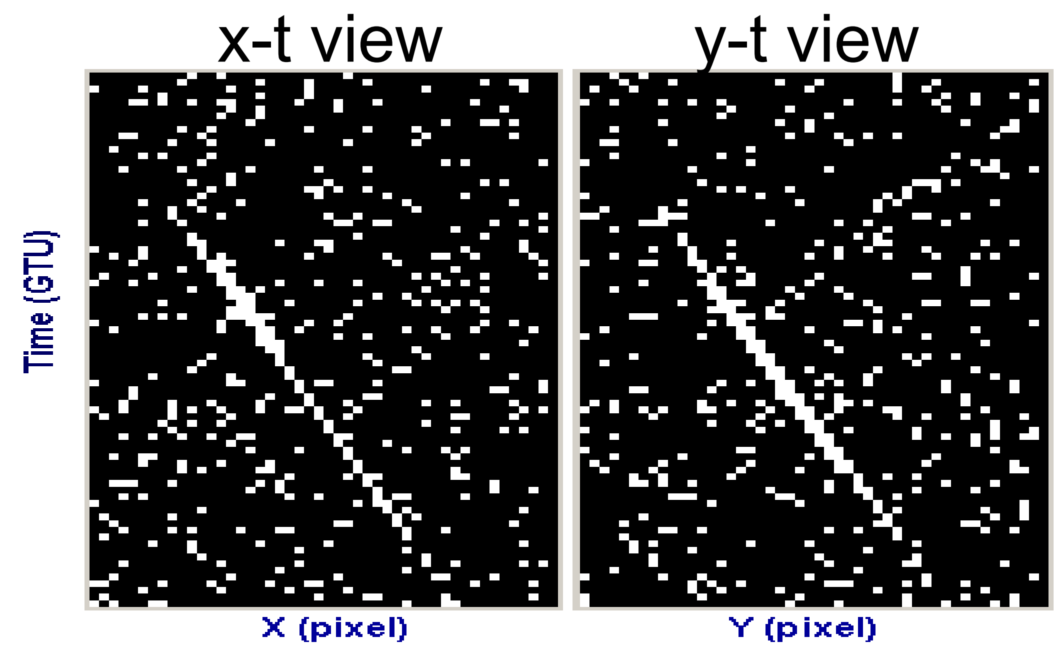
It is the largest refractor ever with 2.5 m diameter; the field of view is 60°. The focal surface has 300k pixels of PMT.

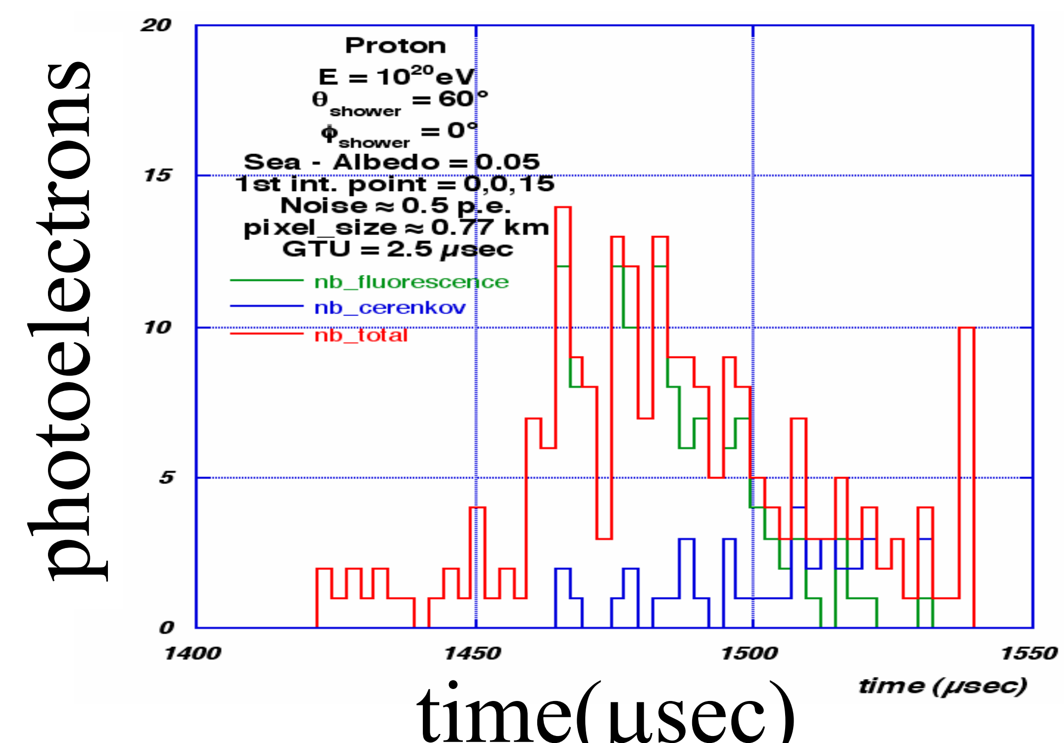


Air shower Image on the Focal Surface

simulation







50 events of 10^{20}eV proton showers are superimposed on the EUSO focal surface with 192 k pixels.

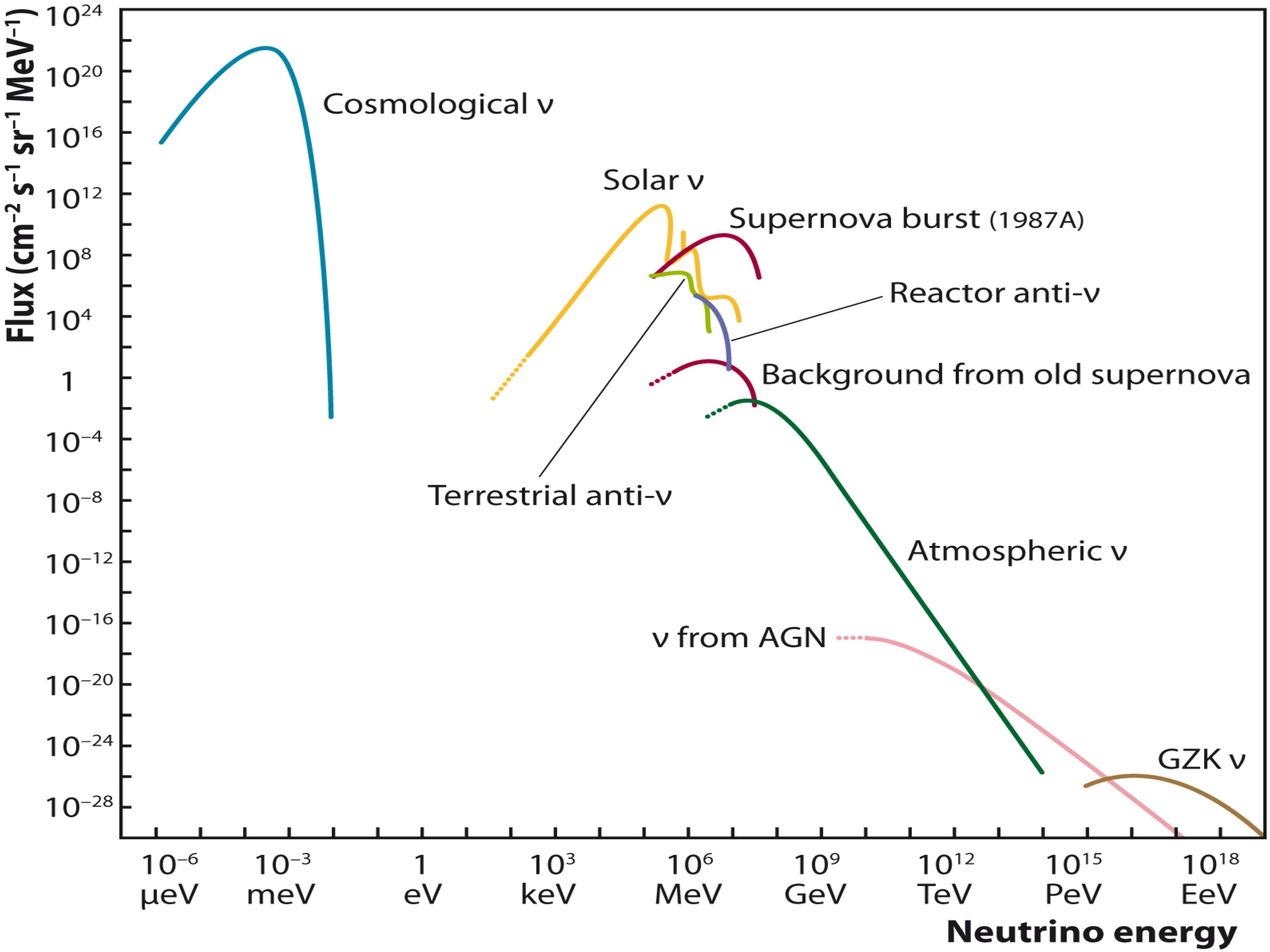
33

Proton E=10^{20}eV, $\theta=60^{o}$
GTU = 2.5 μsec

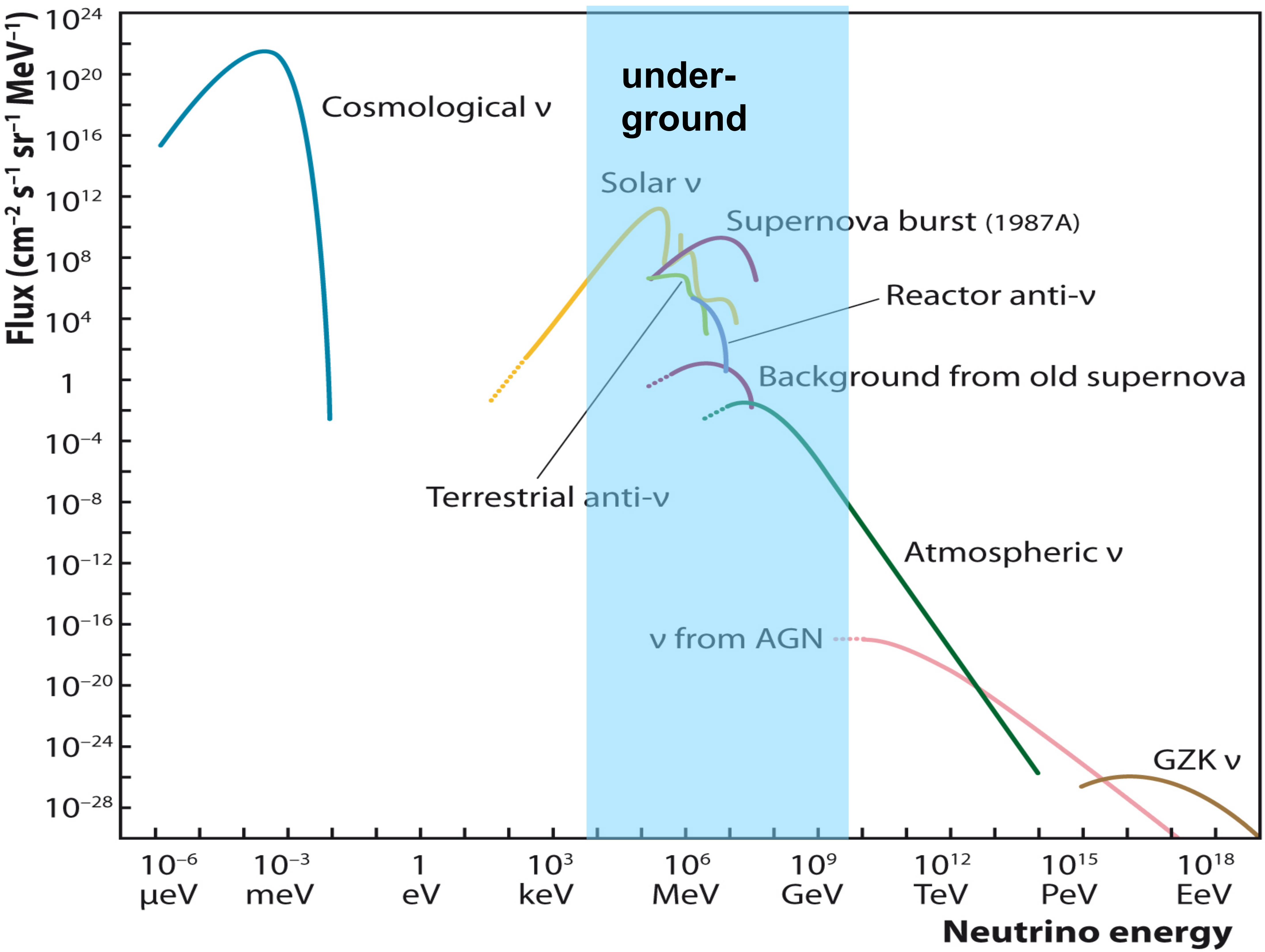
4

Cosmic radiations: neutrinos

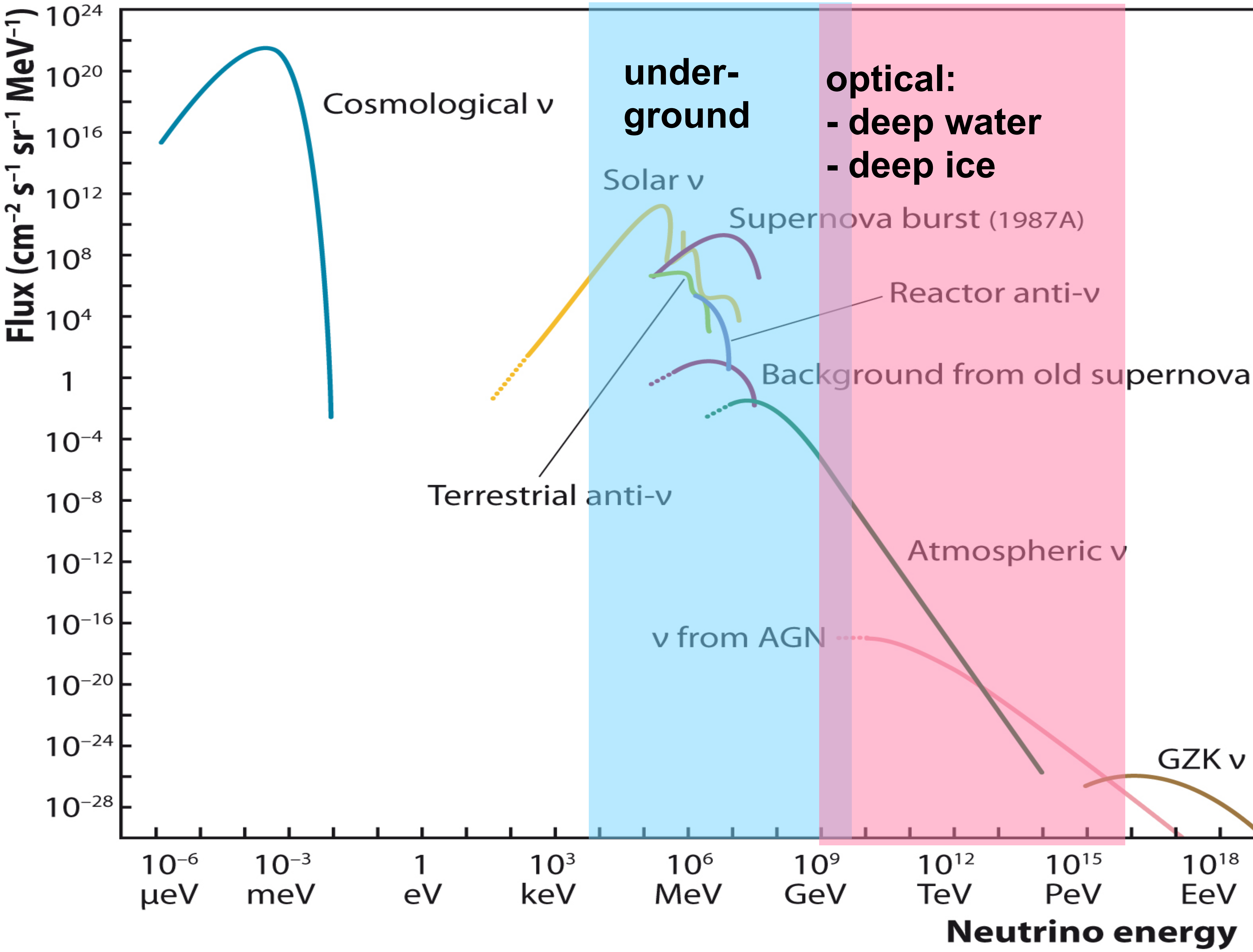
Fluxes of cosmic neutrinos



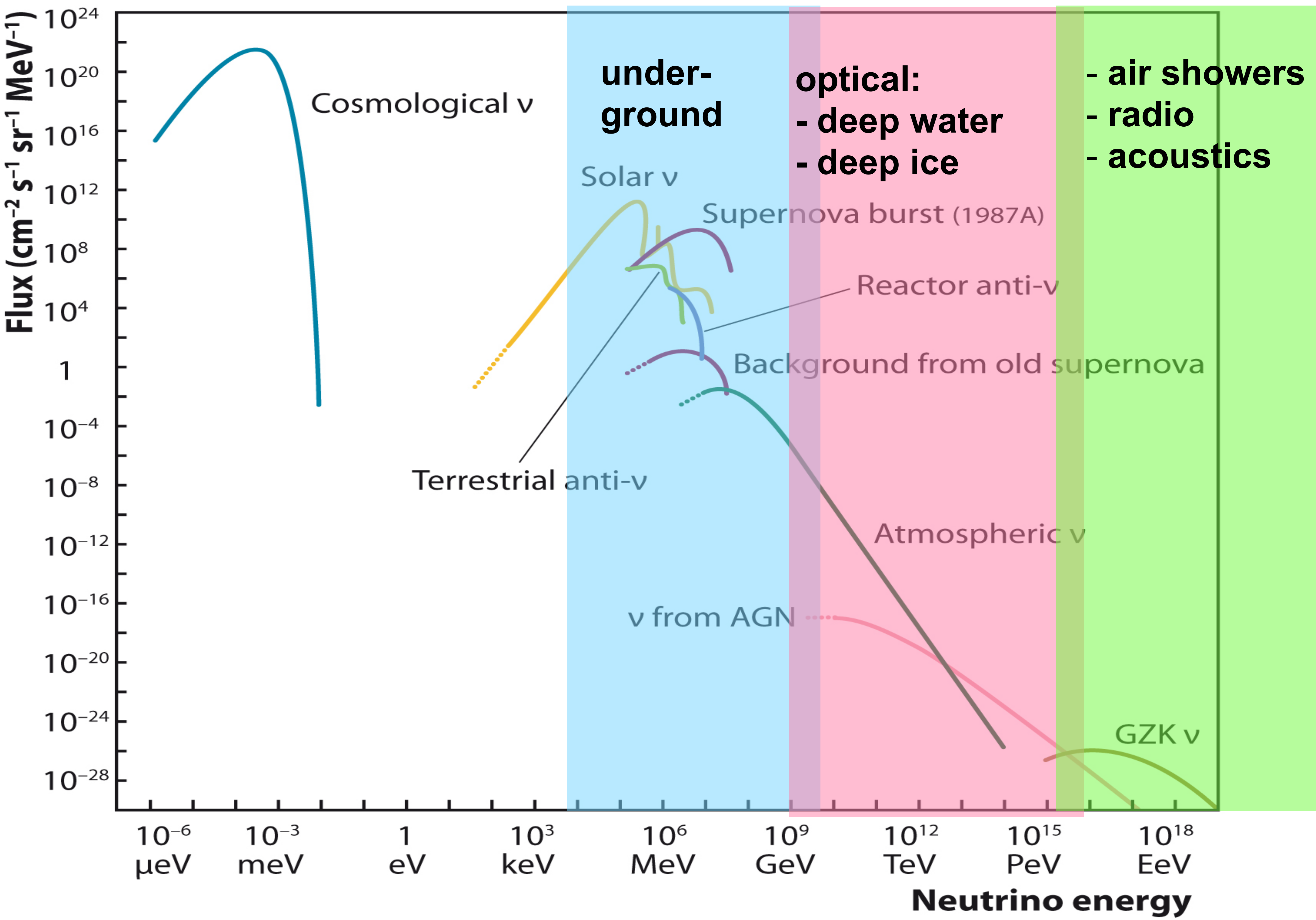
Fluxes of cosmic neutrinos



Fluxes of cosmic neutrinos

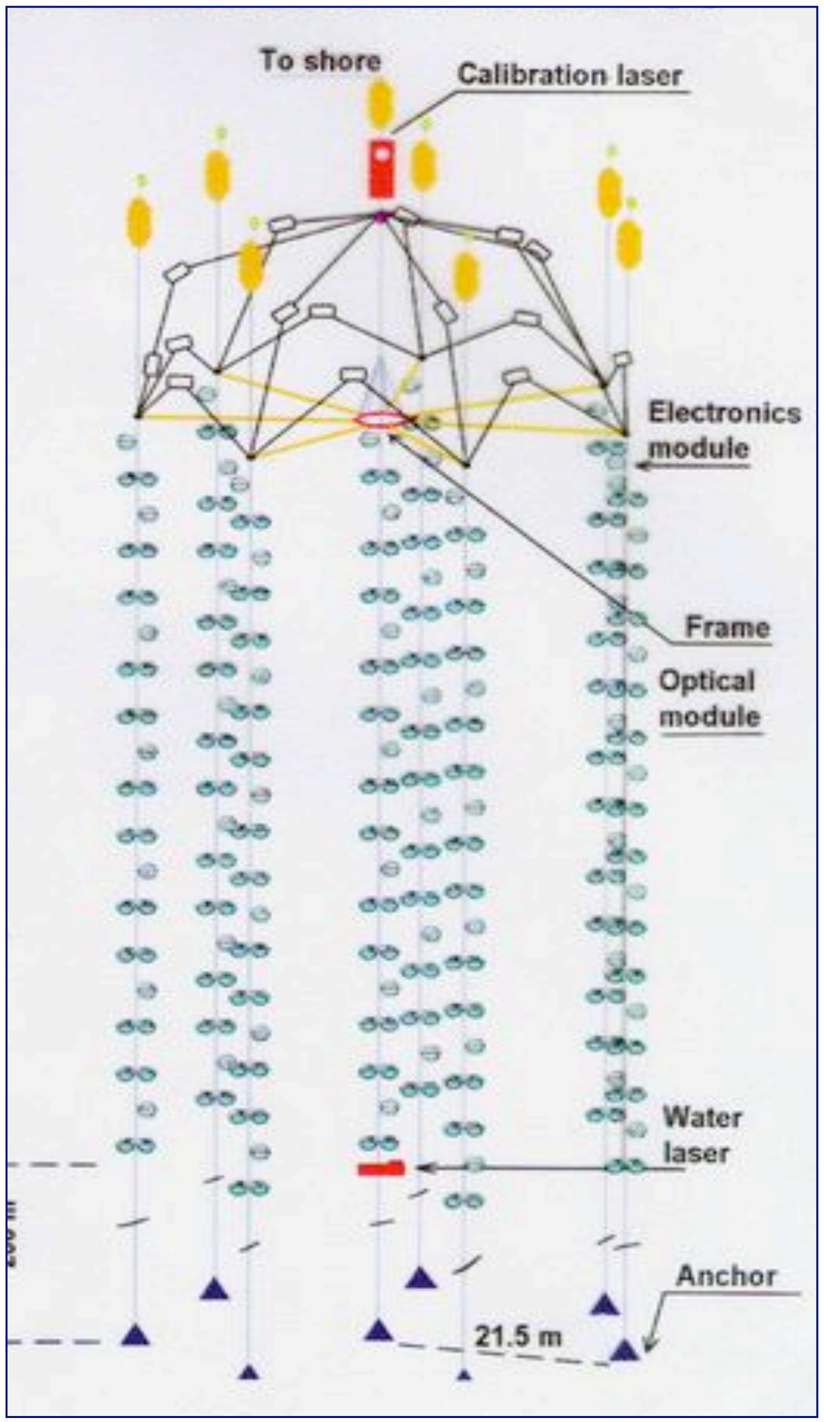


Fluxes of cosmic neutrinos

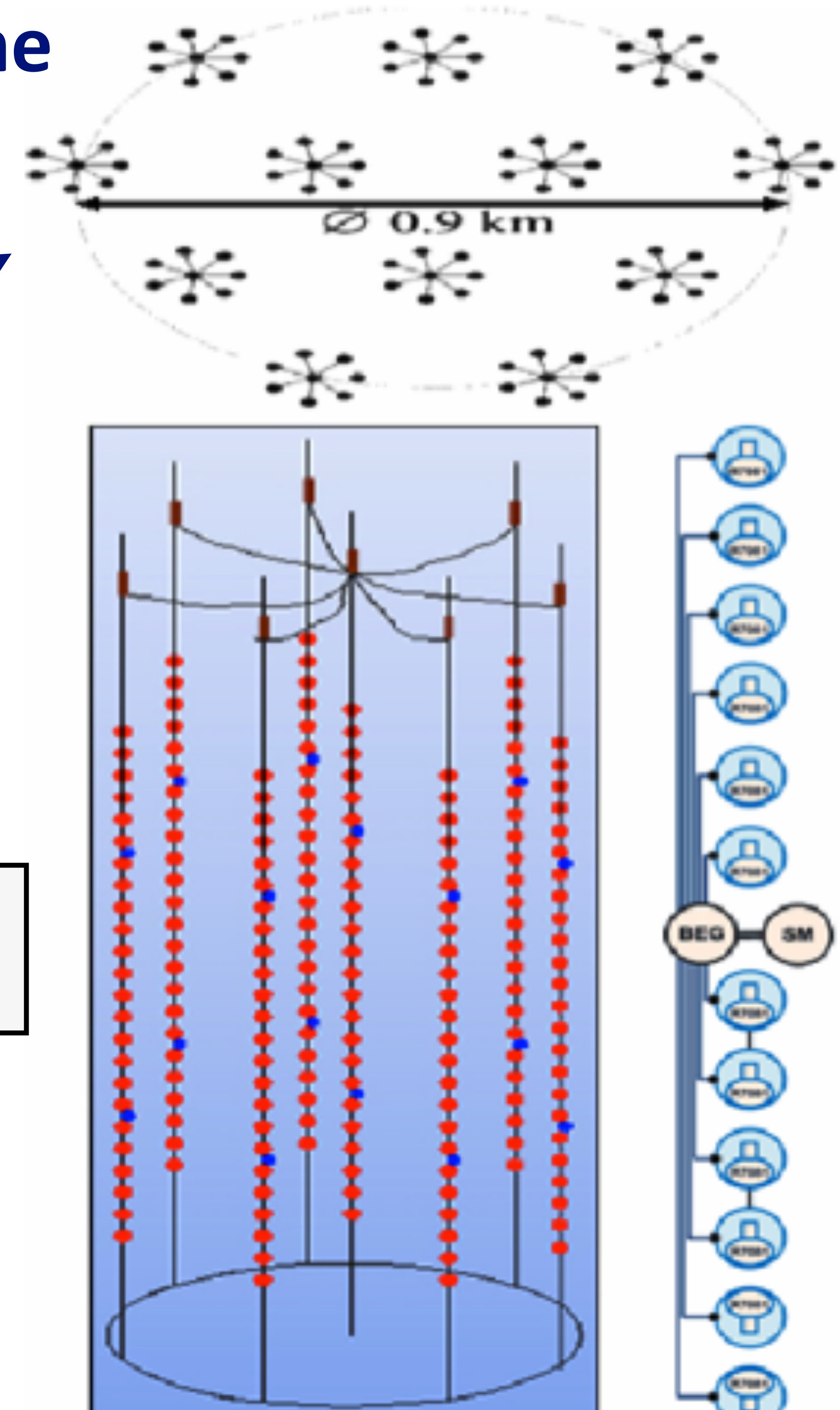


Baikal: from NT200 to GVD

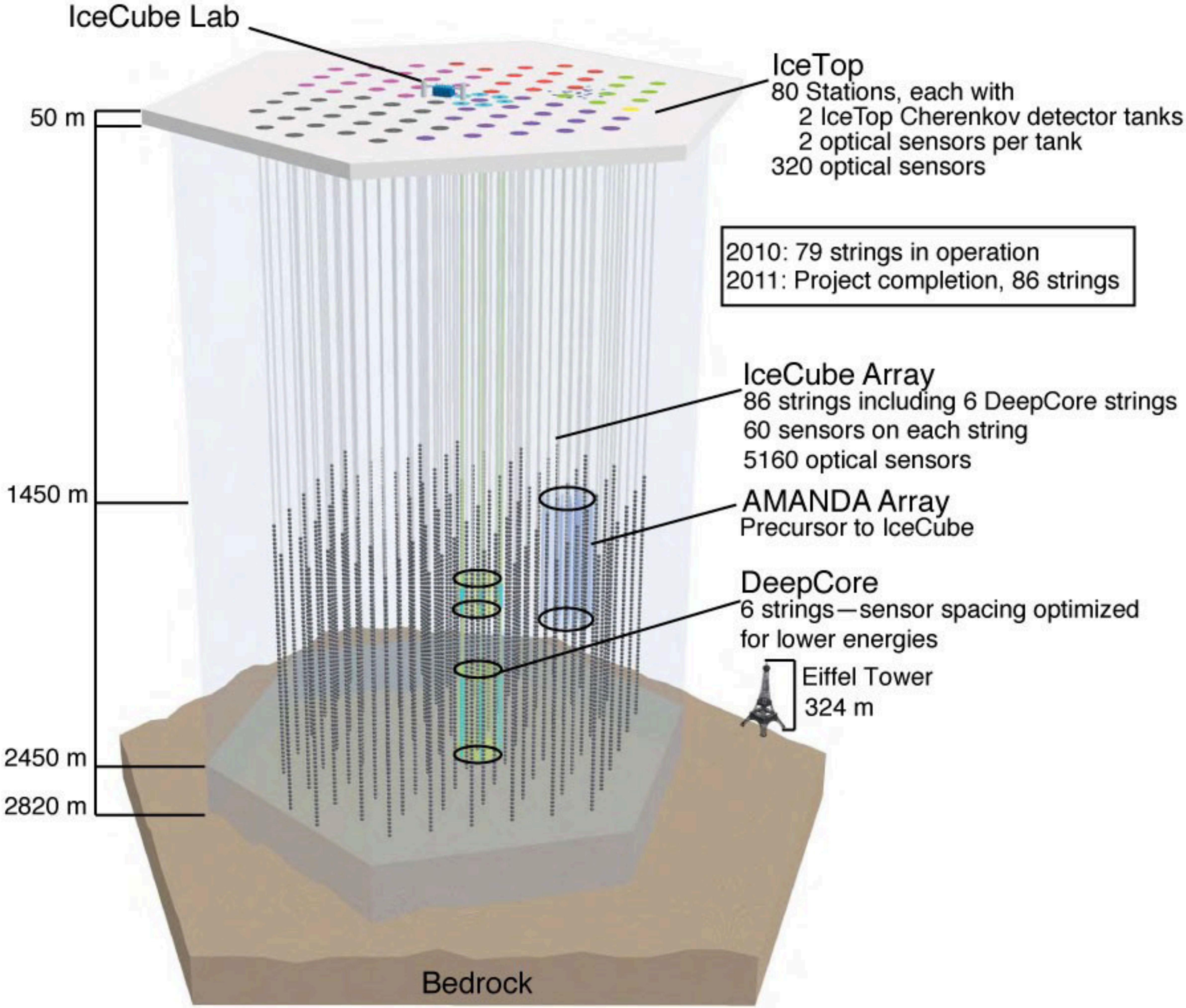
NT200



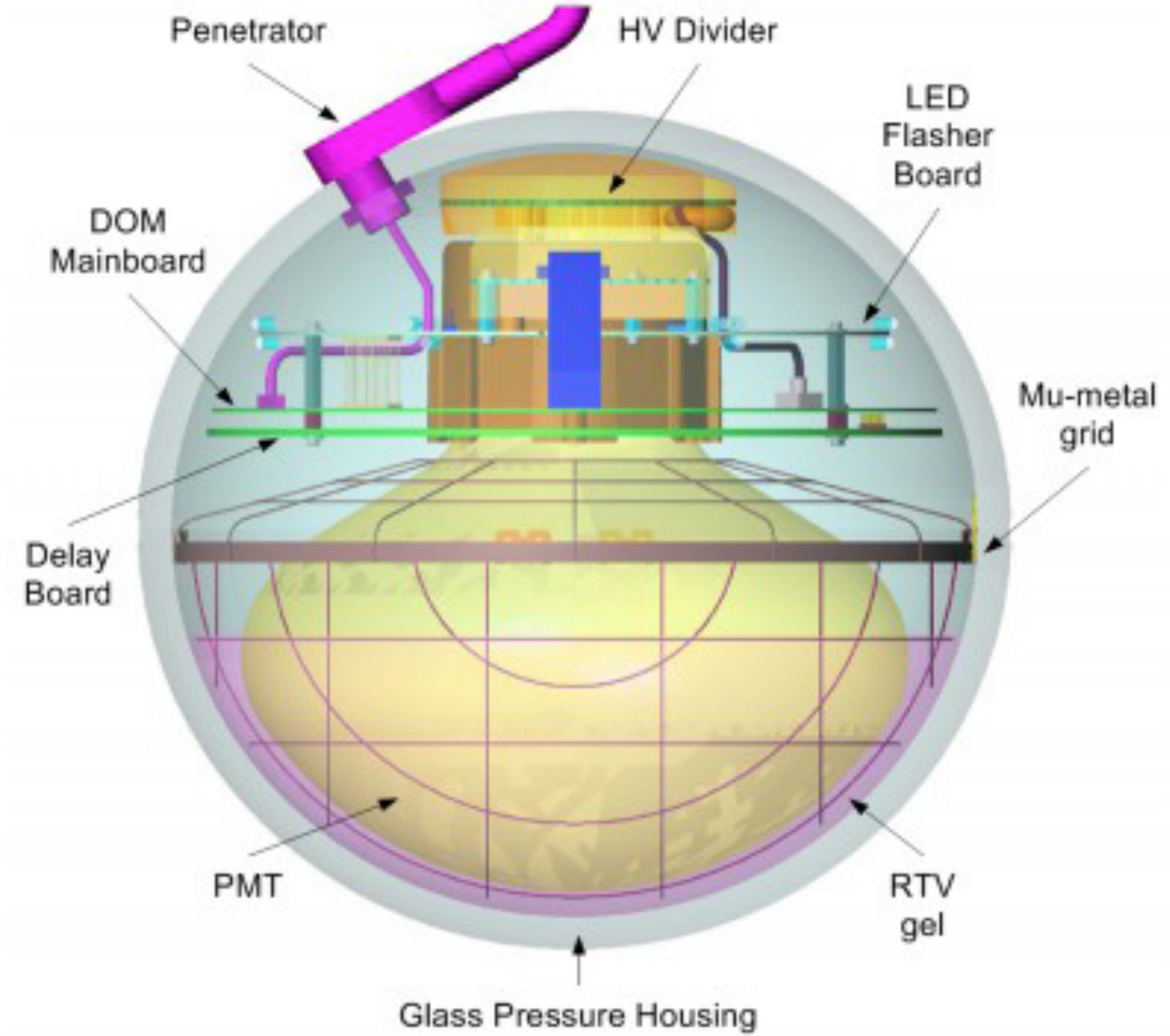
Gigaton Volume Detector (~0.25 km³)



NT200 (0.0001 km³)



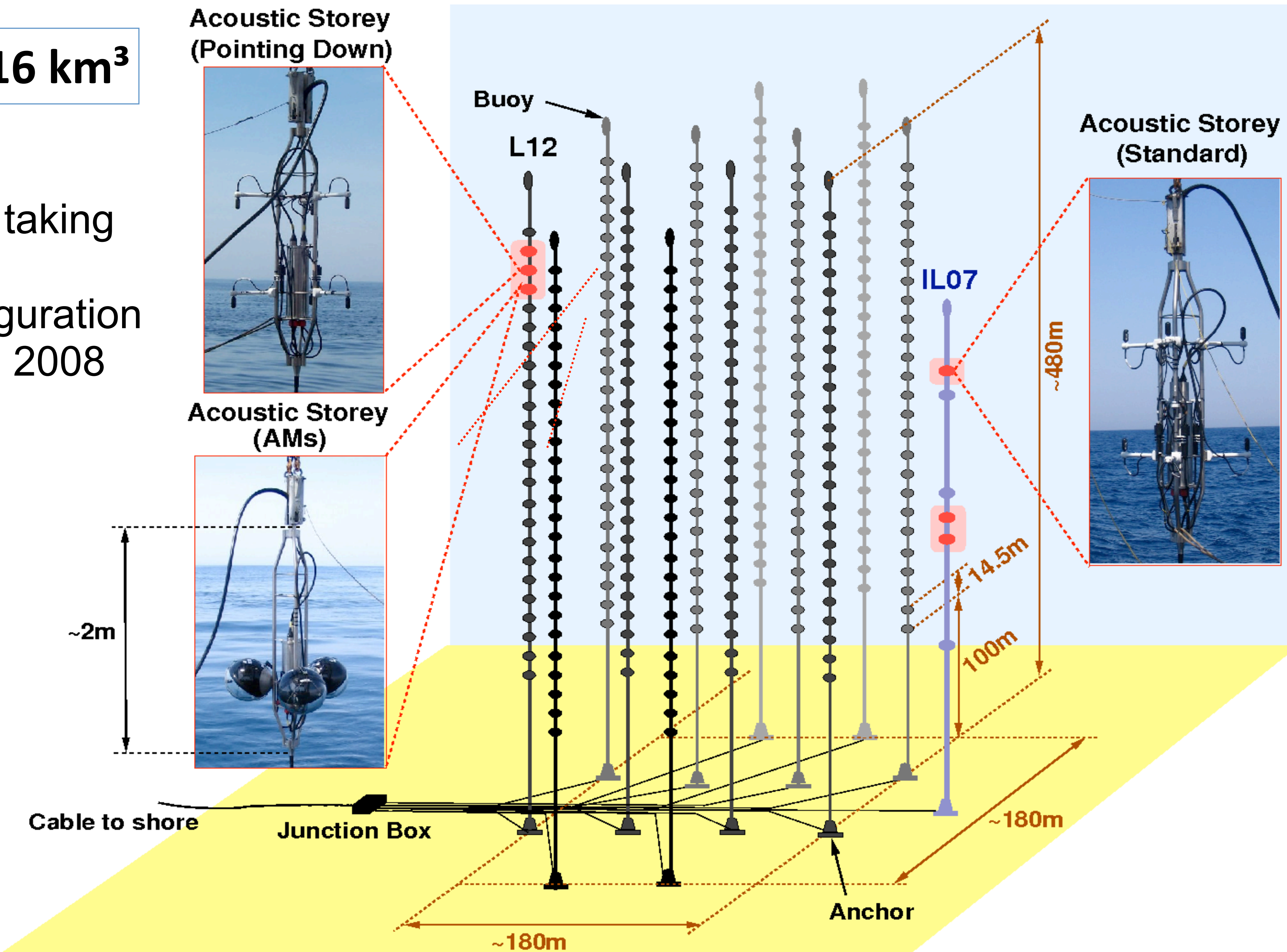
IceCube Lab
IceTop
80 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
320 optical sensors
50 m
2010: 79 strings in operation
2011: Project completion, 86 strings
IceCube Array
86 strings including 6 DeepCore strings
60 sensors on each string
5160 optical sensors
1450 m
AMANDA Array
Precursor to IceCube
DeepCore
6 strings—sensor spacing optimized
for lower energies
Eiffel Tower
324 m
2450 m
2820 m
Bedrock

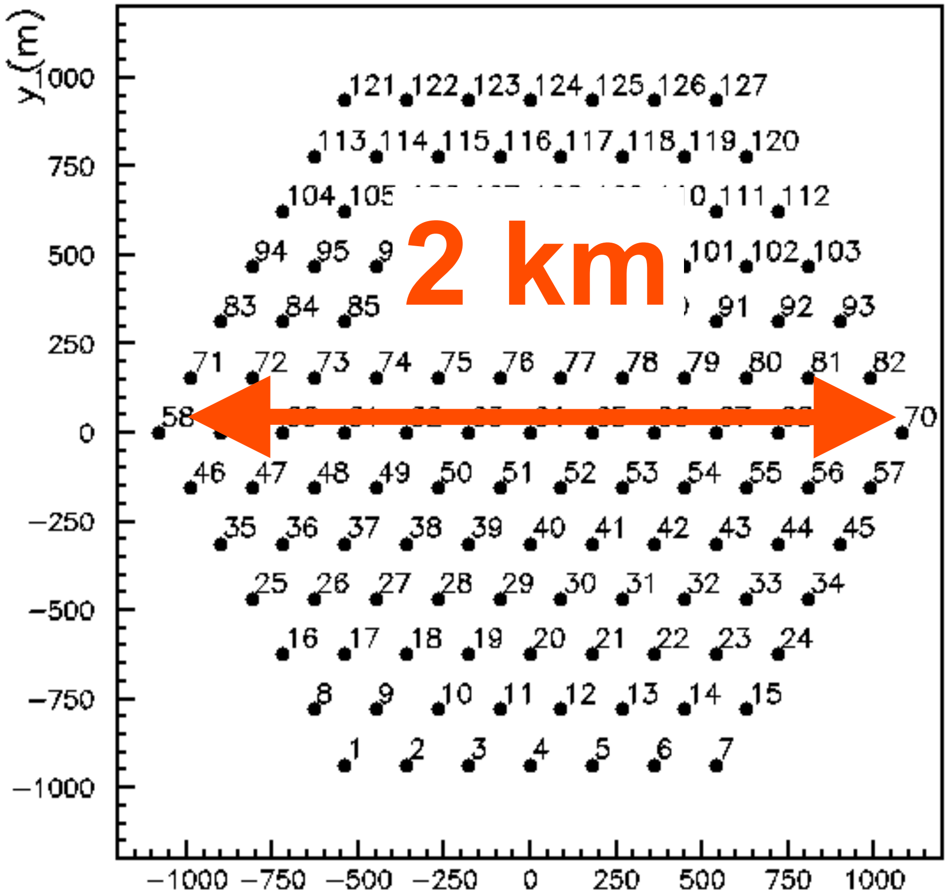

Penetrator
HV Divider
LED Flasher Board
DOM Mainboard
Mu-metal grid
Delay Board
PMT
RTV gel
Glass Pressure Housing

ANTARES

0.016 km³

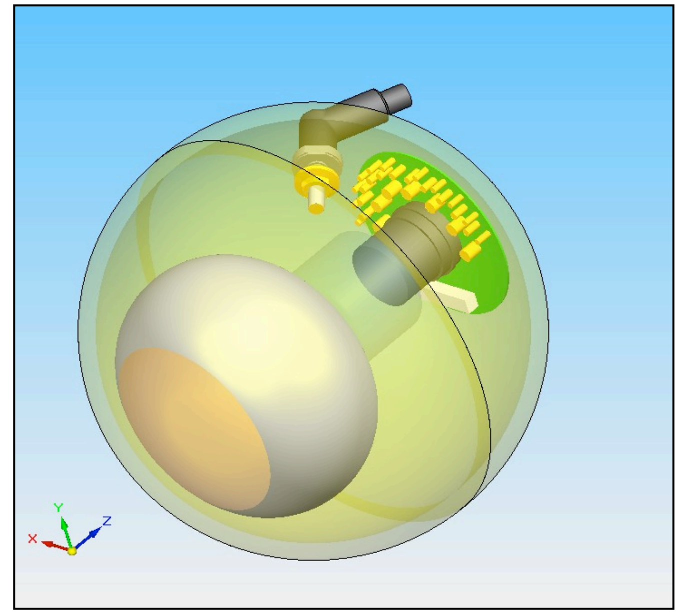
Data taking in full configuration since 2008

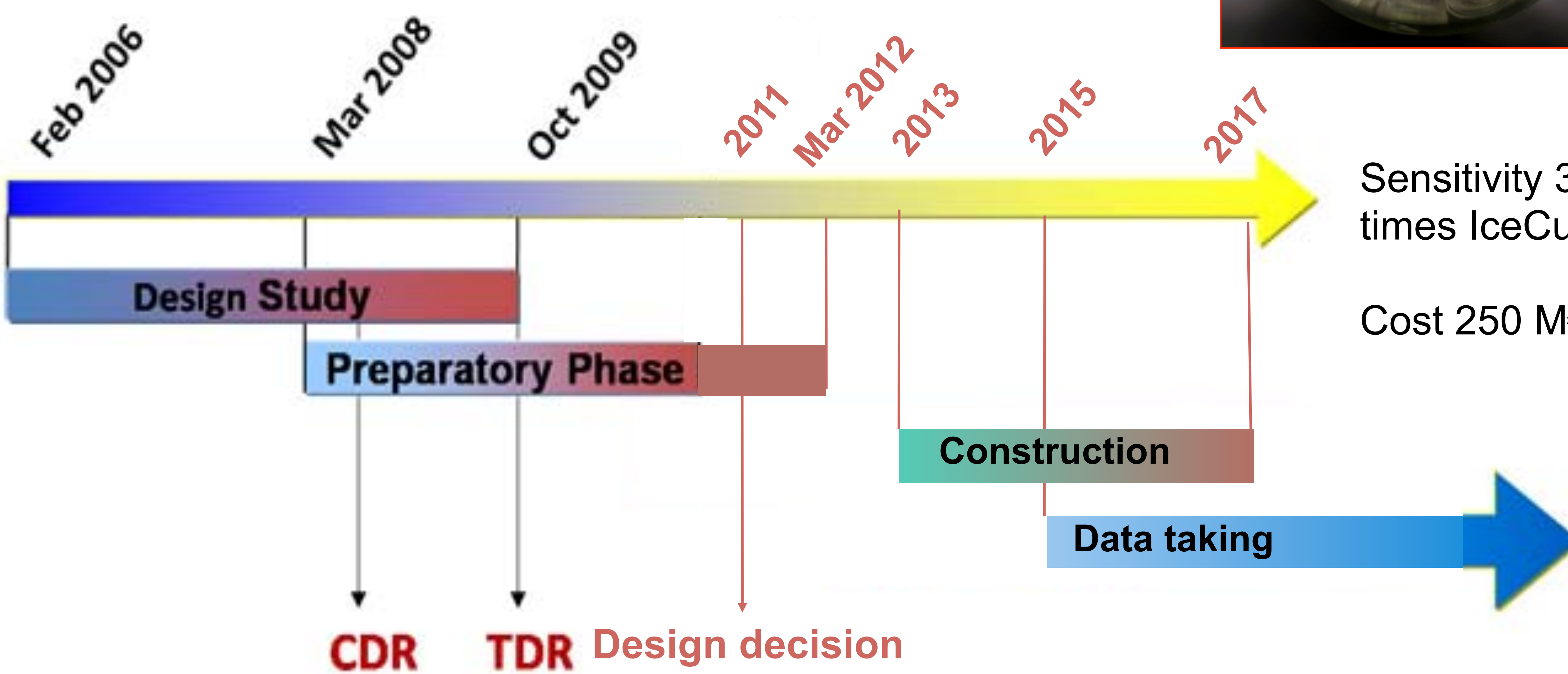




~ 4 km³

KM3NeT

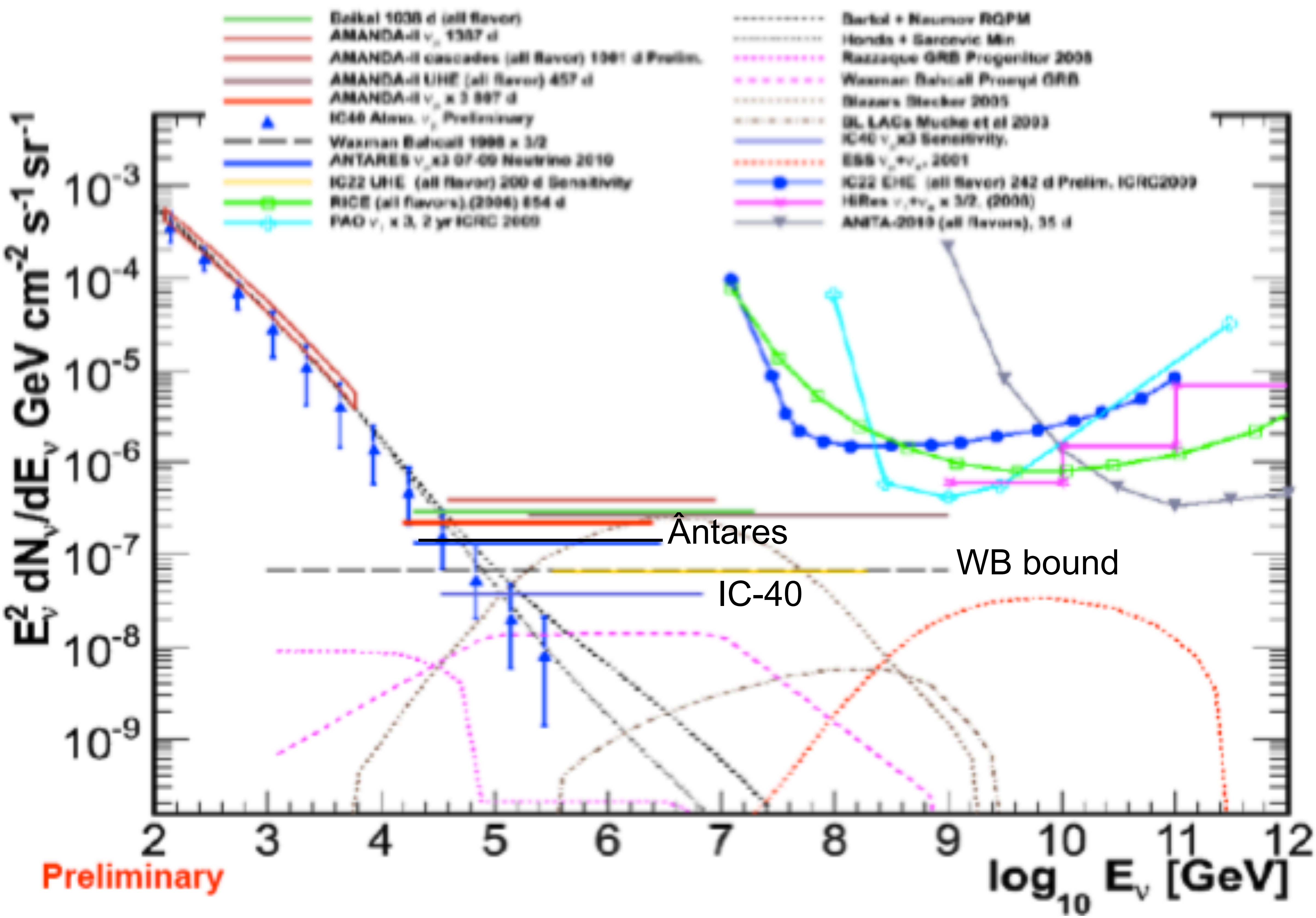


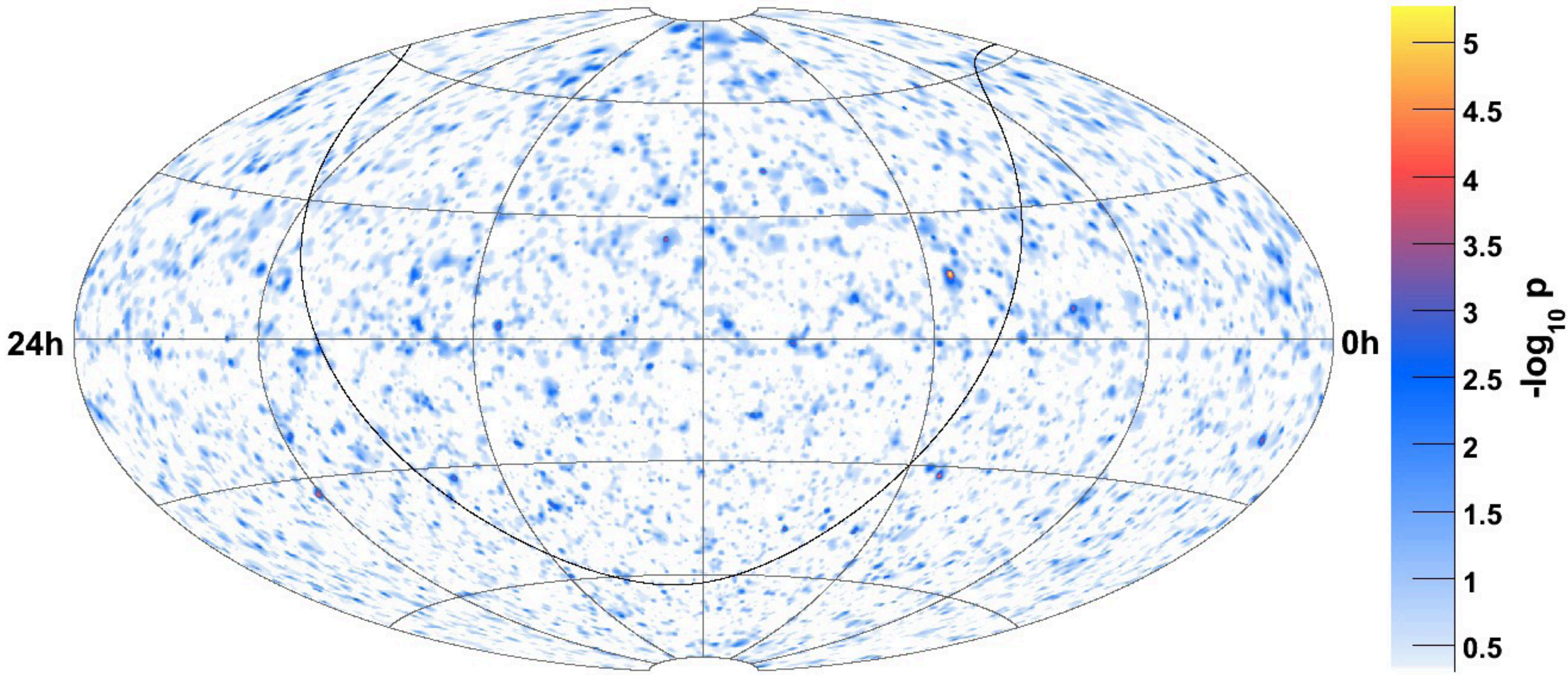


Sensitivity 3-6 times IceCube

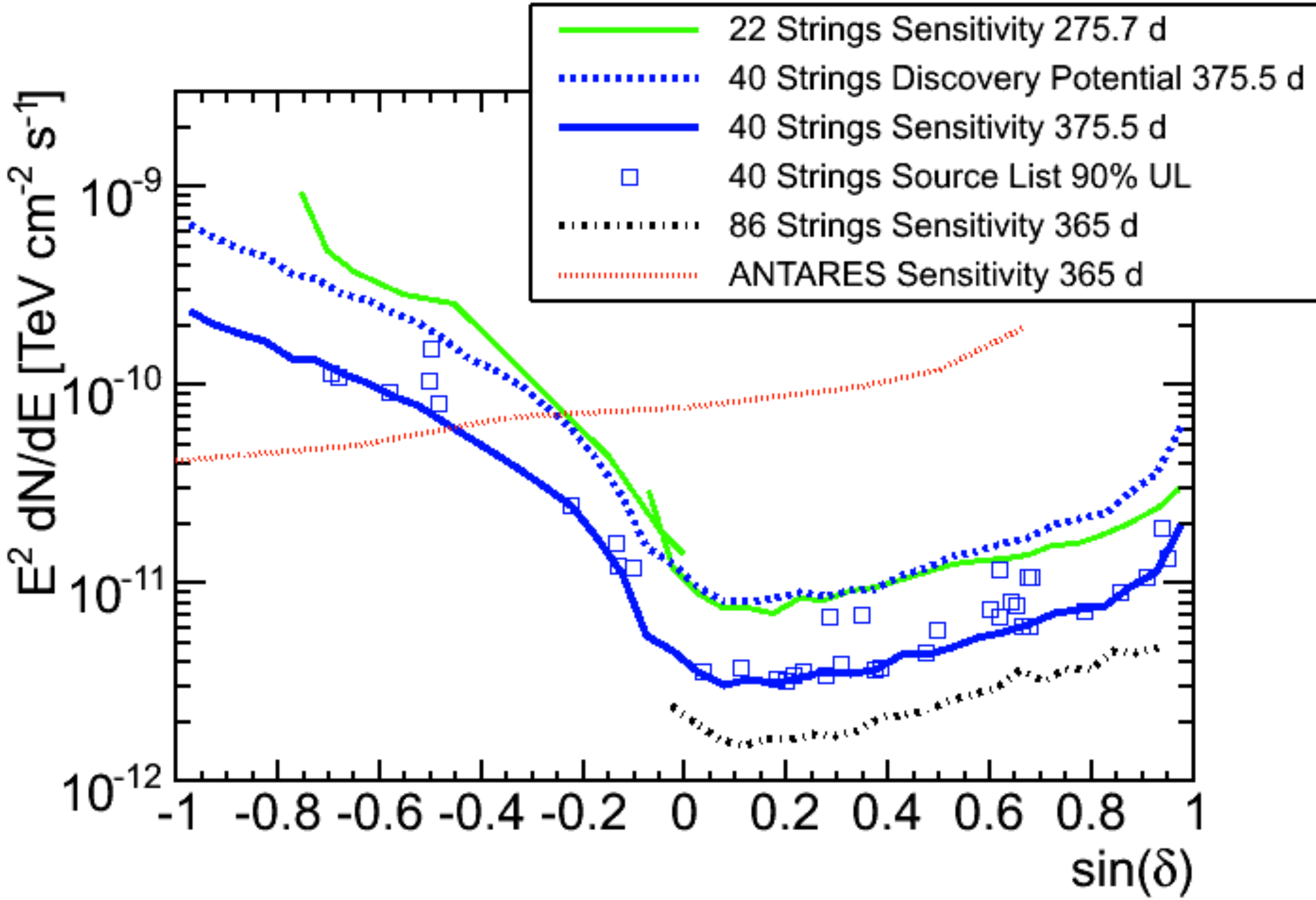
Cost 250 M€

Diffuse limits



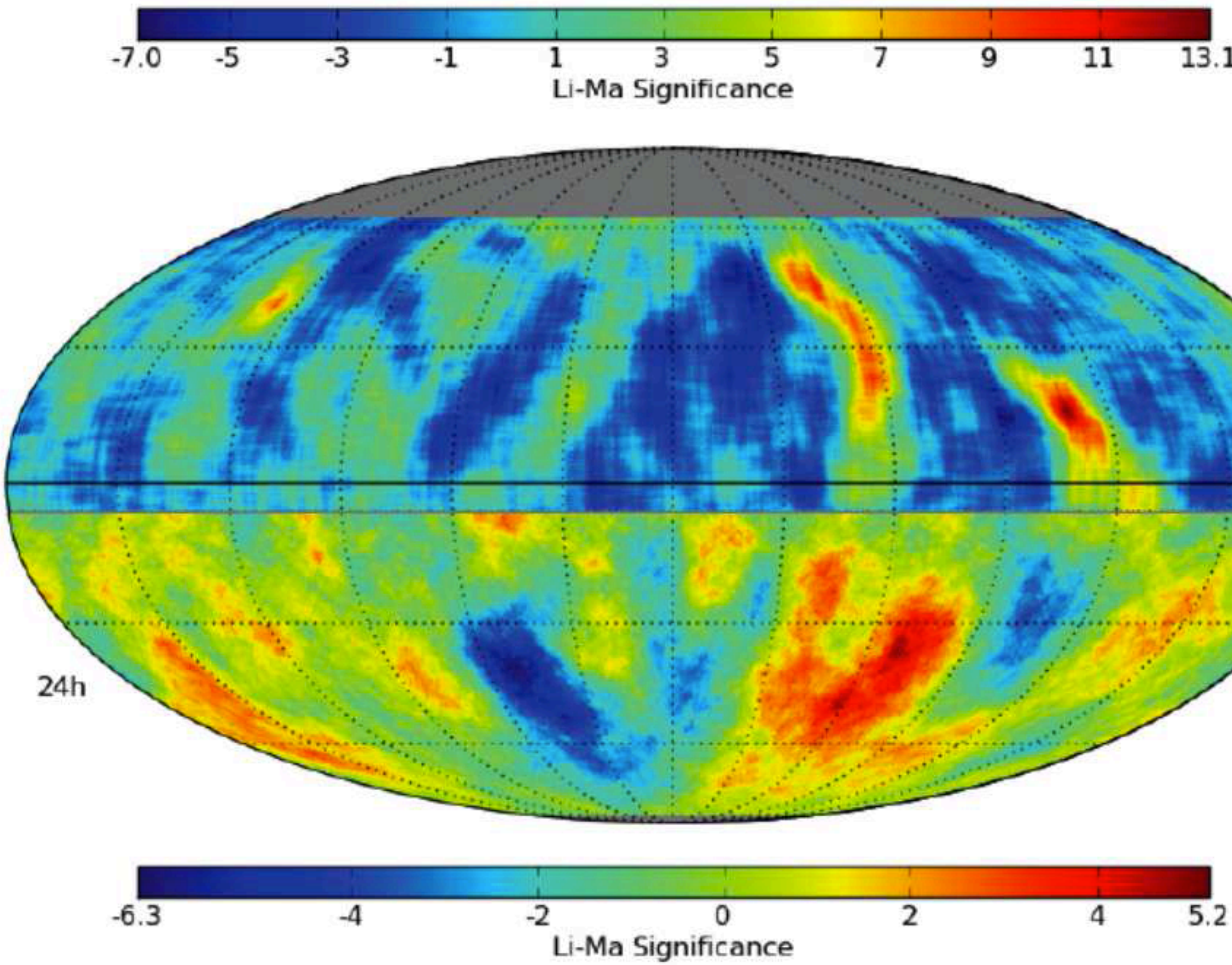


A PRE-TRIAL SIGNIFICANCE SKY MAP FOR THE ALL-SKY POINT SOURCE SEARCH USING IC40 DATA.



SENSITIVITY AND UPPER LIMITS (90% CL) PLOT FOR AN E-2 SPECTRUM, AS A FUNCTION OF DECLINATION. THE SOLID BLUE LINE REPRESENTS THE UPPER LIMIT SET BY THE IC40 DATA, WITH THE GREEN LINE REPRESENTING THE UPPER LIMIT SET BY THE IC22 DATA. THE SQUARES REPRESENT THE UPPER LIMITS SET FOR THE 39 SOURCES SELECTED *A-PRIORI*.

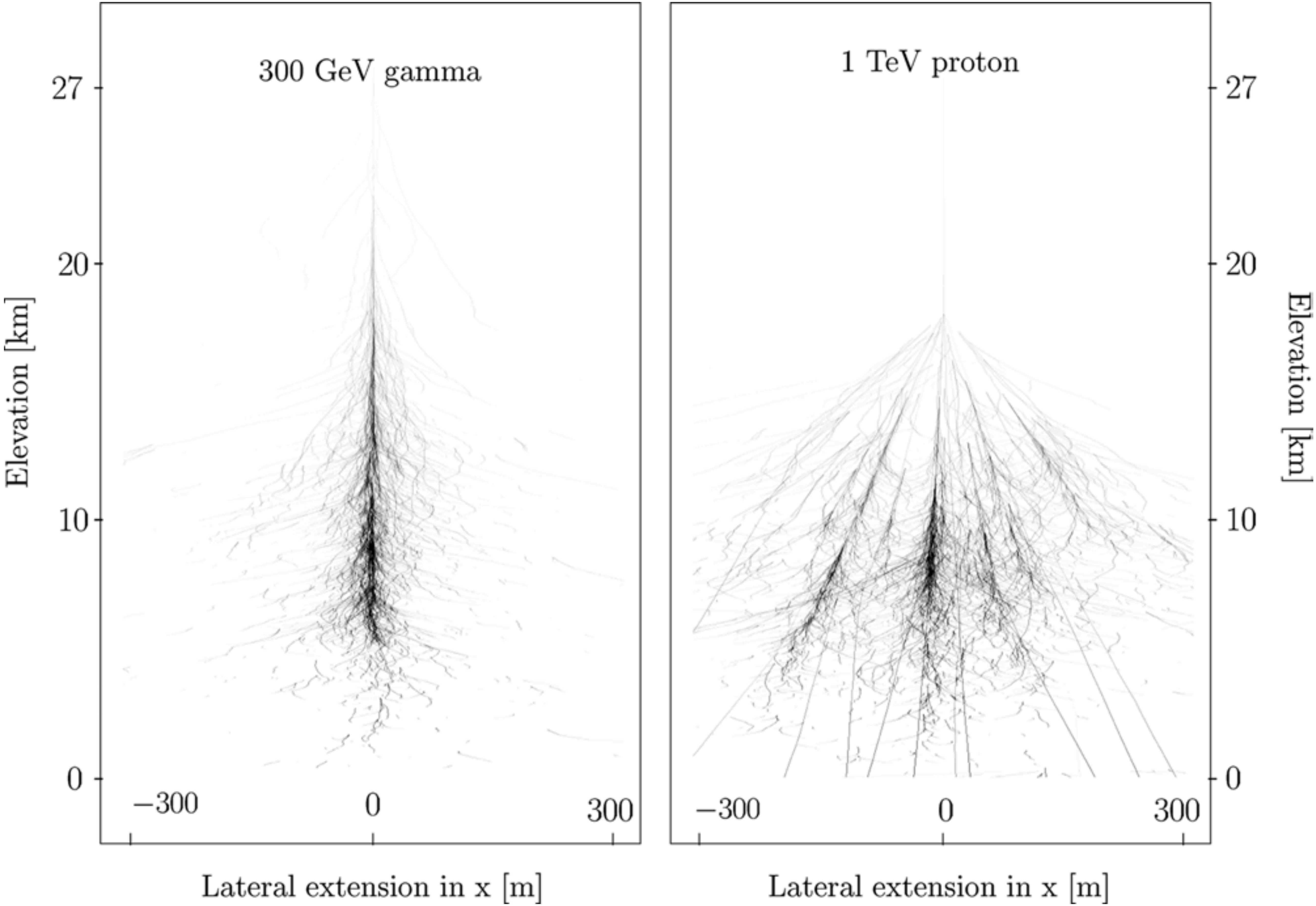
Muon astronomy?

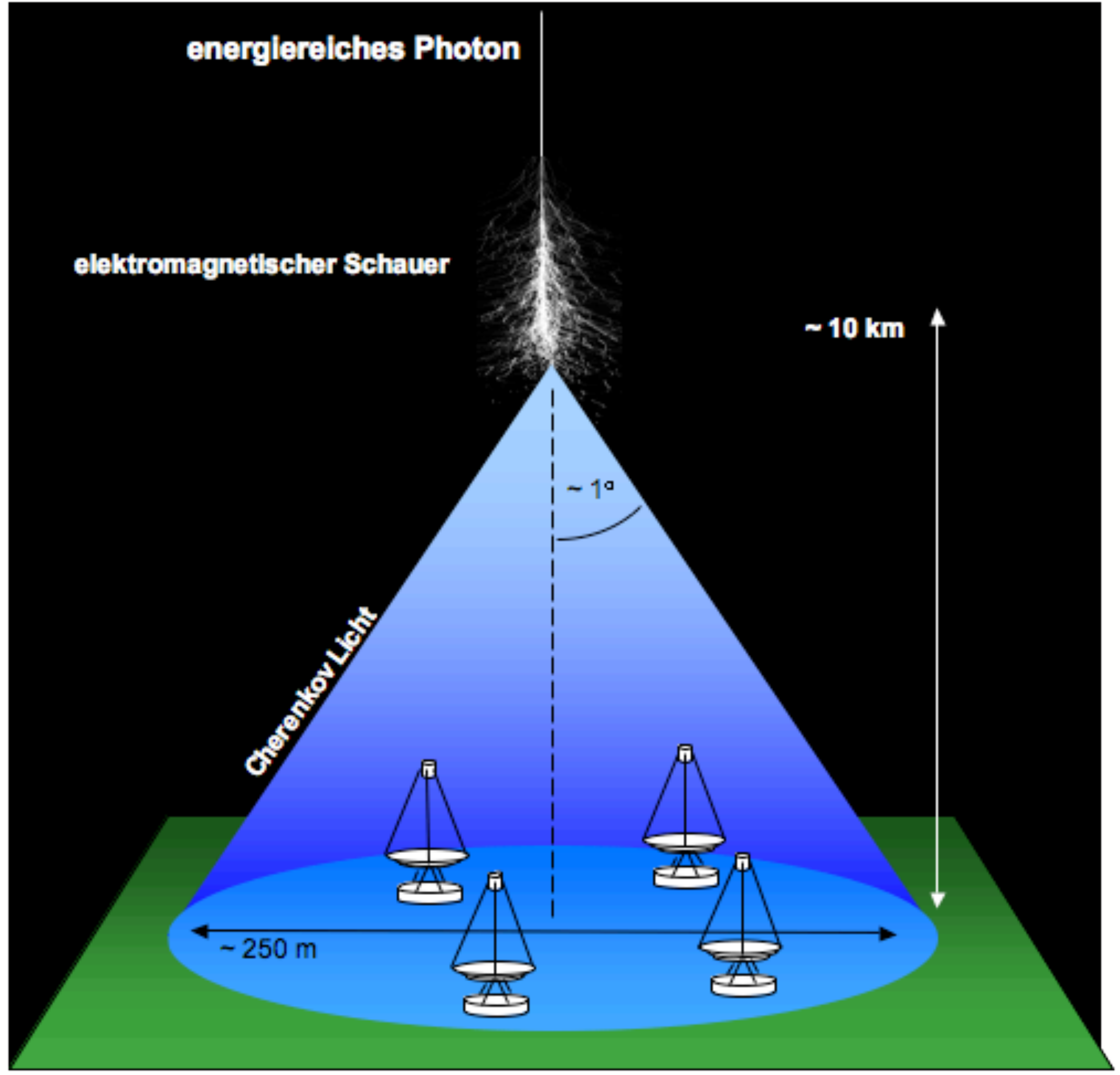


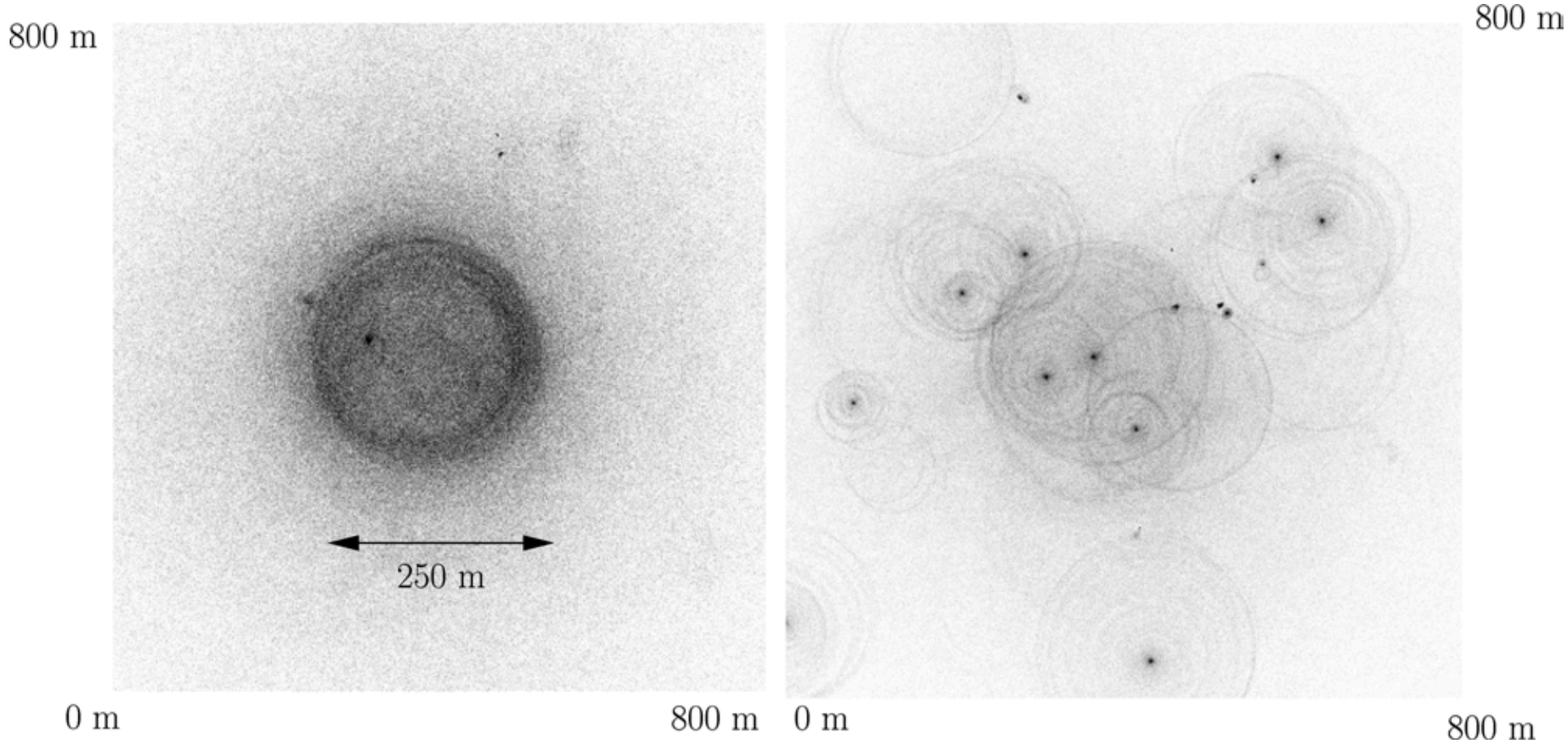
The arrival direction of cosmic-ray muons recorded with 40 IceCube strings (Southern Hemisphere). The variations are of order 10–3 on a uniform distribution. The color scale represents the relative intensity. The dots indicate the directions of Vela, the brightest gamma-ray source in the sky, and Geminga. Also shown is the muon data of Milagro obtained by the same method (Northern Hemisphere).

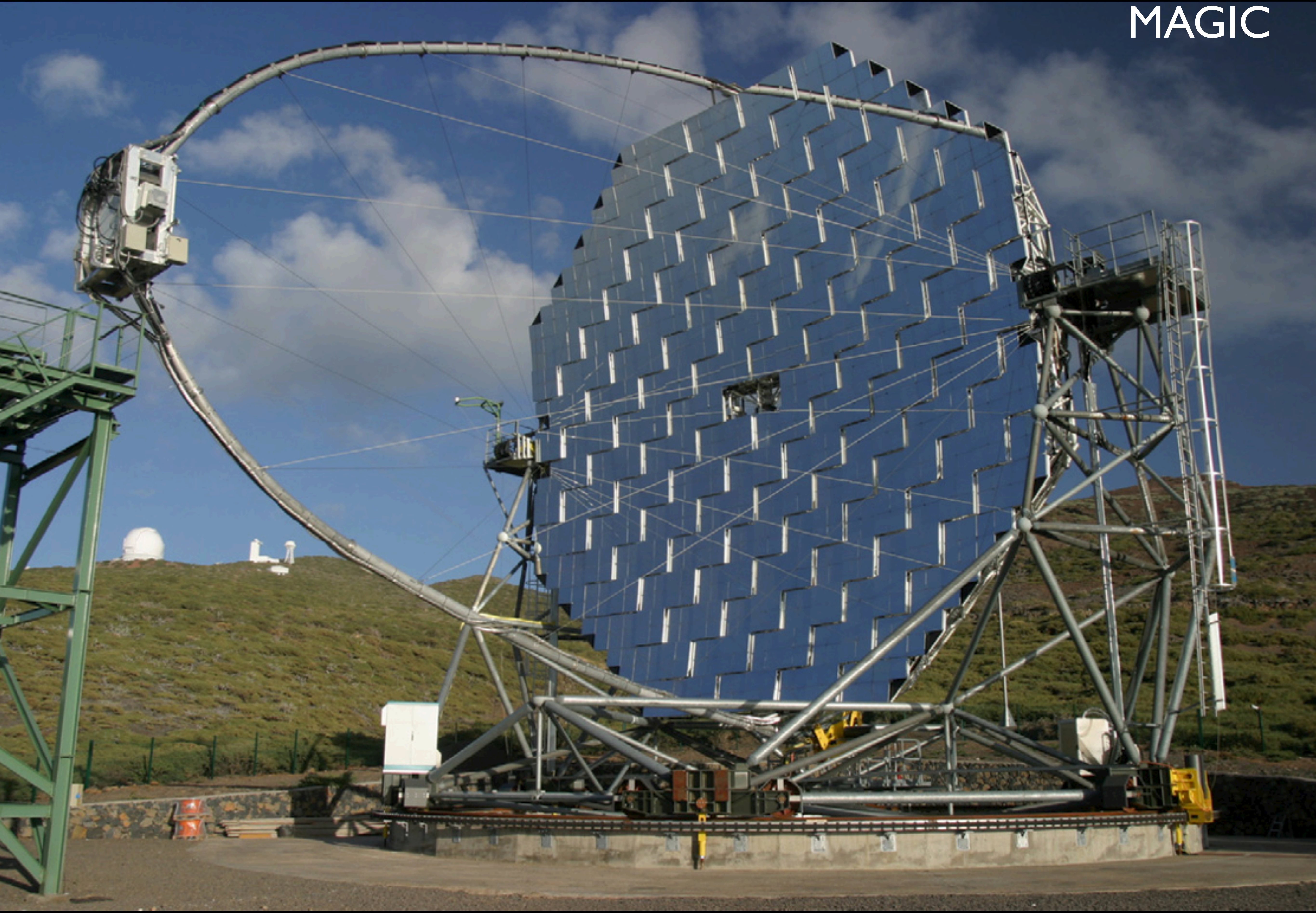
From F.Halzen, ISVHECRI 2010

Cosmic radiations: photons


300 GeV gamma
1 TeV proton
Elevation [km]
27
20
10
0
−300
0
300
Lateral extension in x [m]

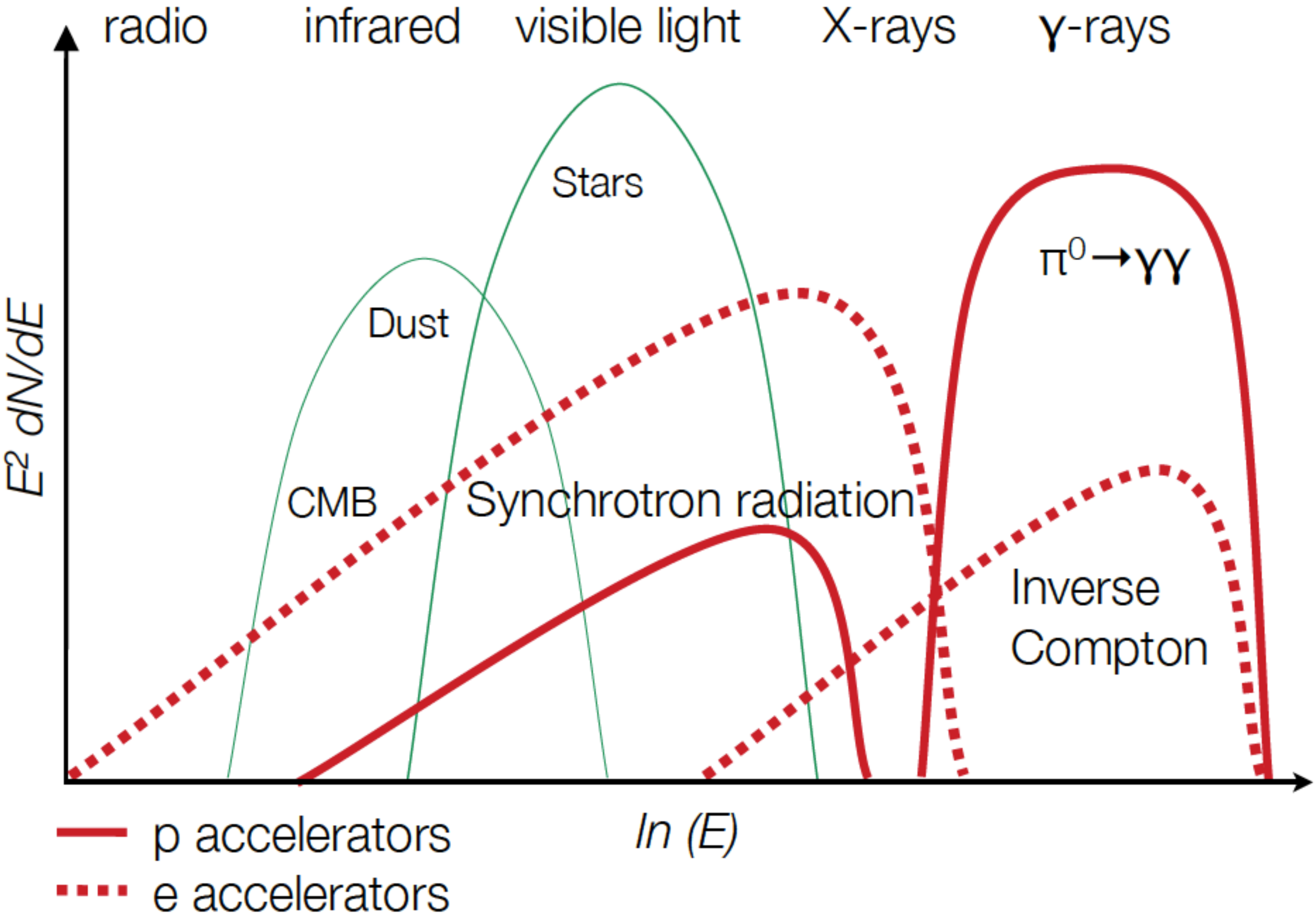

energiereiches Photon
elektromagnetischer Schauer
~ 10 km
~ 1°
Cherenkov Licht
~ 250 m

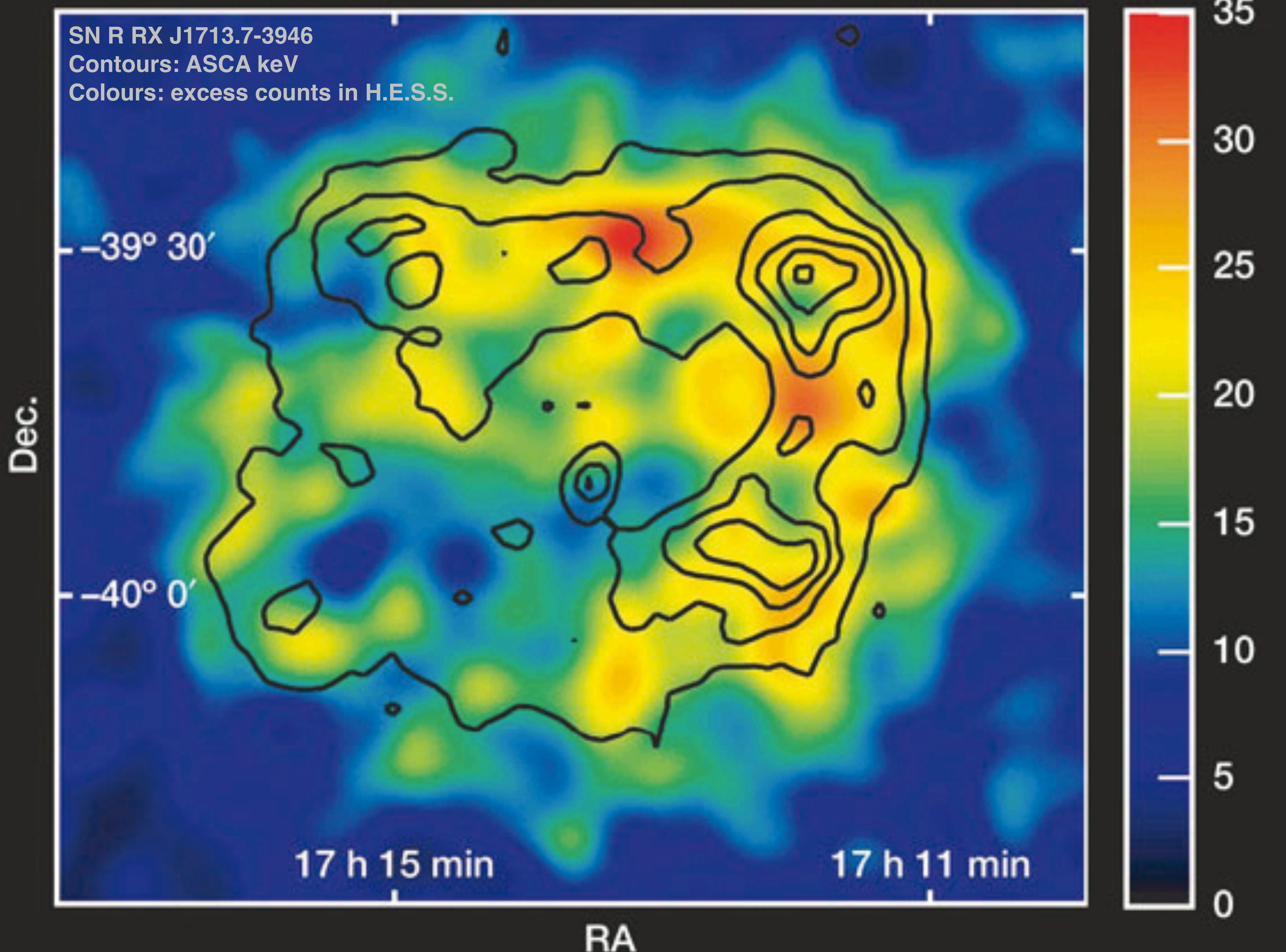

800 m
250 m
0 m
800 m
800 m
0 m
800 m


MAGIC

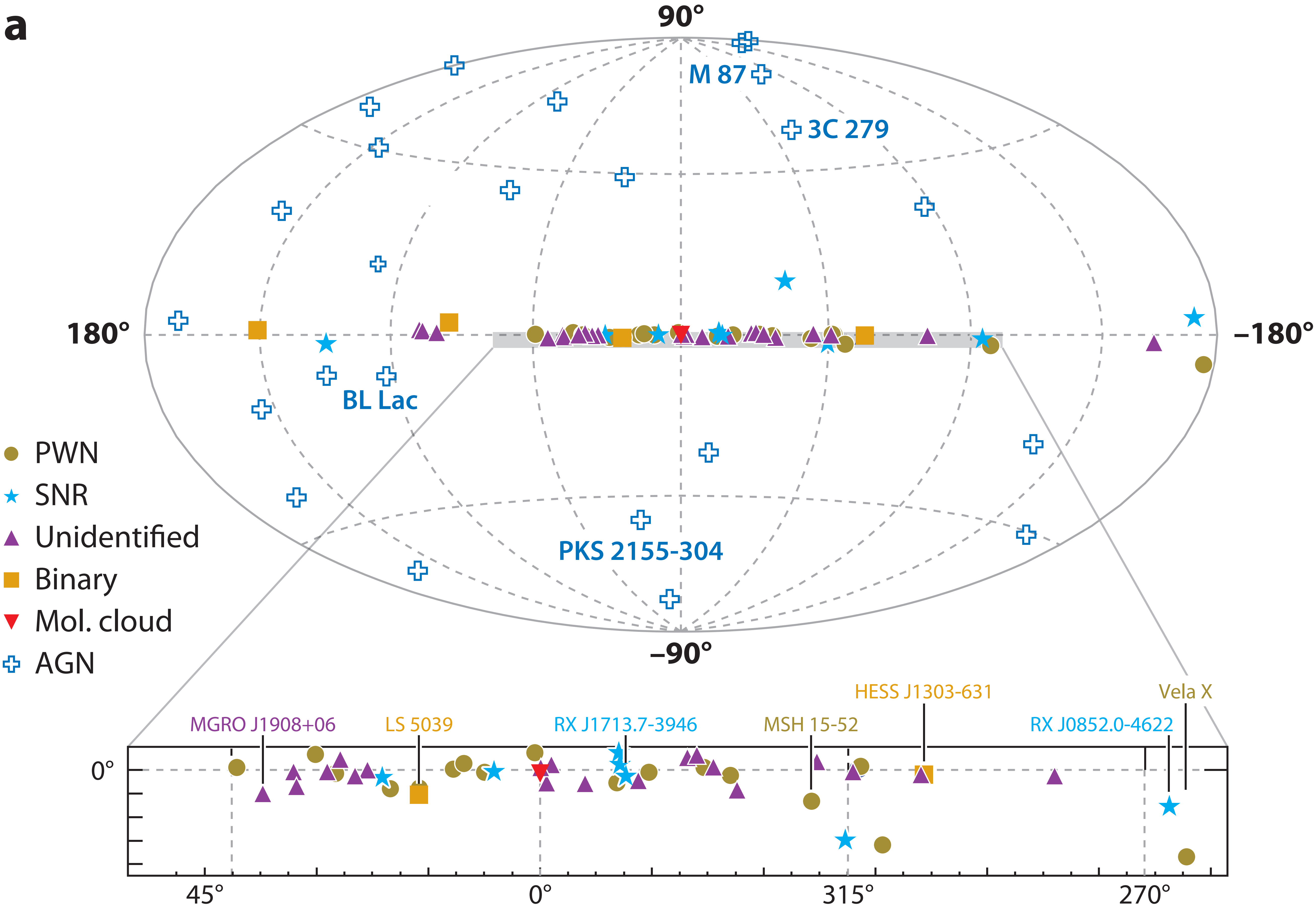

H.E.S.S.

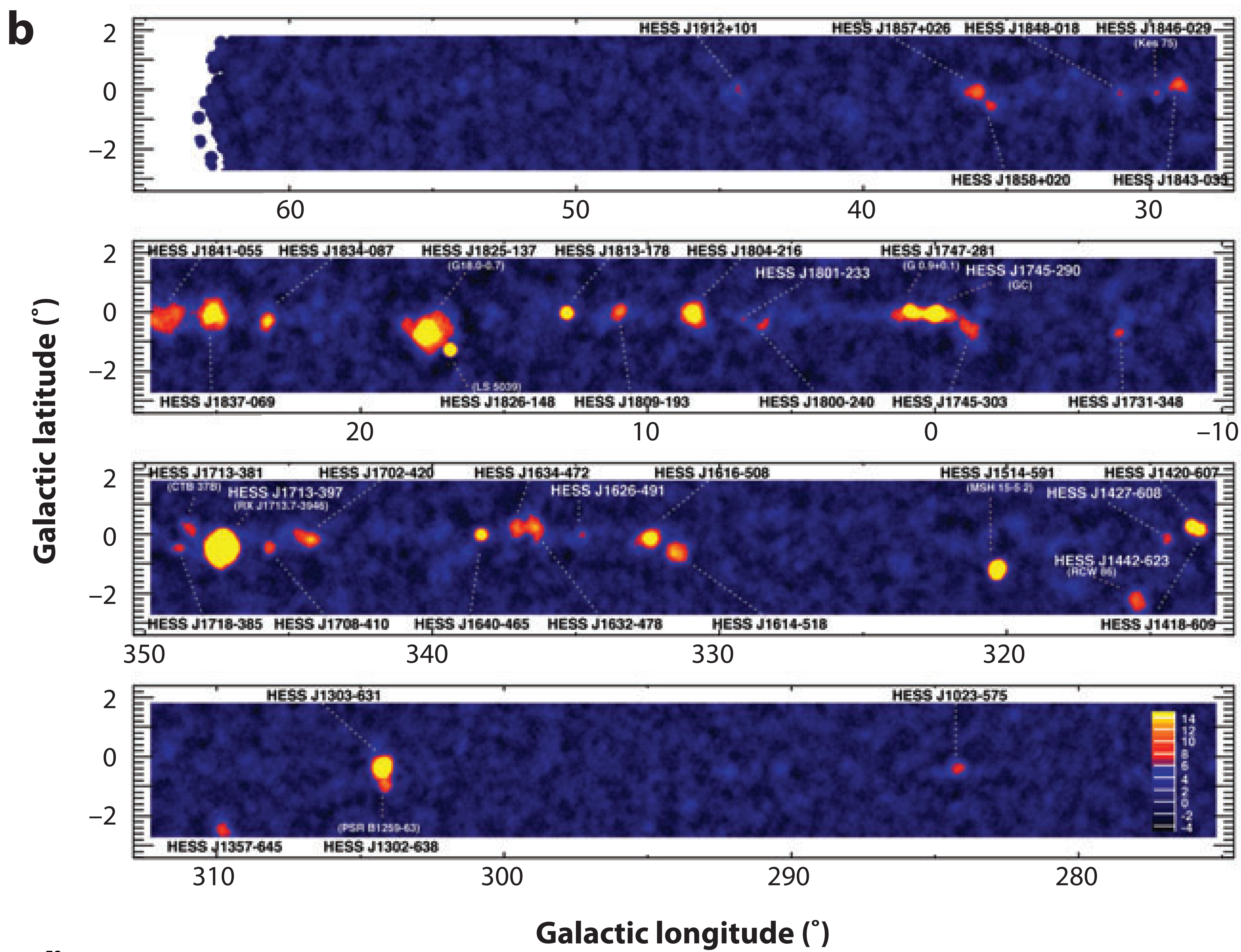

VERITAS


radio
infrared
visible light
X-rays
γ-rays
$E^2\ dN/dE$
Stars
$\pi^0 \rightarrow \gamma\gamma$
Dust
CMB
Synchrotron radiation
Inverse
Compton
ln (E)
p accelerators
e accelerators



SN R RX J1713.7-3946
Contours: ASCA keV
Colours: excess counts in H.E.S.S.
−39° 30′
−40° 0′
17 h 15 min
17 h 11 min
Dec.
RA
35
30
25
20
15
10
5
0


a
90°
M 87
3C 279
180°
–180°
BL Lac
PKS 2155-304
–90°
PWN
SNR
Unidentified
Binary
Mol. cloud
AGN
MGRO J1908+06
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
Vela X
0°
45°
0°
315°
270°

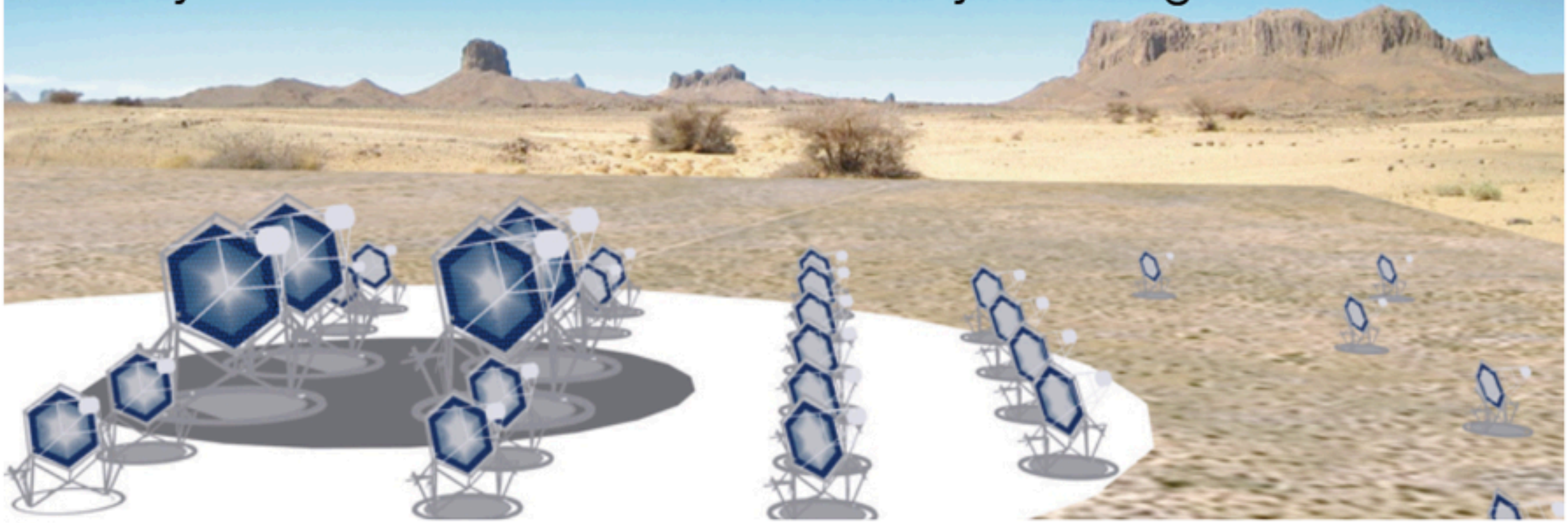

b
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G 0.9+0.1)
HESS J1745-290
(GC)
HESS J1837-069
(LS 5039)
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-348
HESS J1713-381
(CTB 37B)
HESS J1713-397
(RX J1713.7-3946)
HESS J1702-420
HESS J1634-472
HESS J1626-491
HESS J1616-508
HESS J1514-591
(MSH 15-5 2)
HESS J1420-607
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
HESS J1303-631
HESS J1023-575
(PSR B1259-63)
HESS J1357-645
HESS J1302-638
Galactic latitude (°)
Galactic longitude (°)

The Cherenkov Telescope Array

- Increase sensitivity
- Extend energy range
- Improve angular resolution
- Observatory with flexible and robotic operation
- Arrays in North and South for full sky coverage

CTA: an advanced facility for ground-based γ-ray astronomy and astro-particle physics

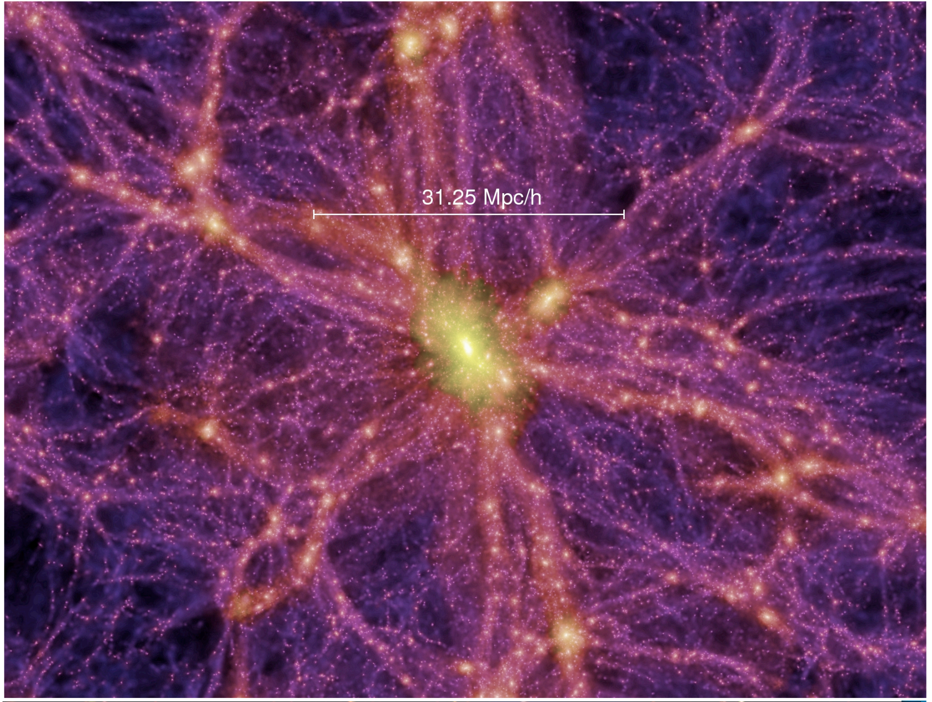
taken from Schlenstedt 2009

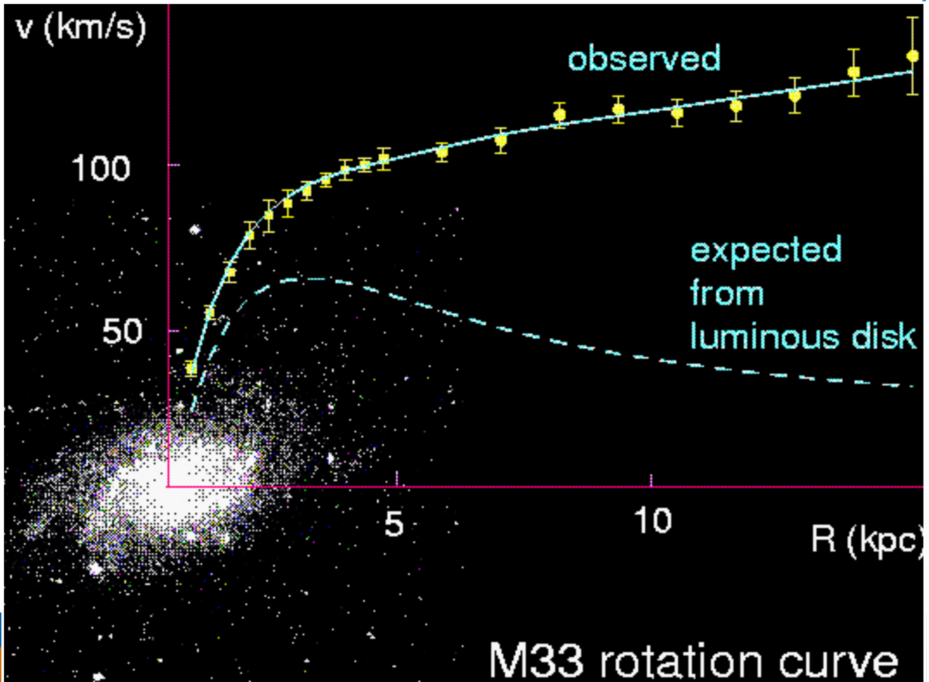


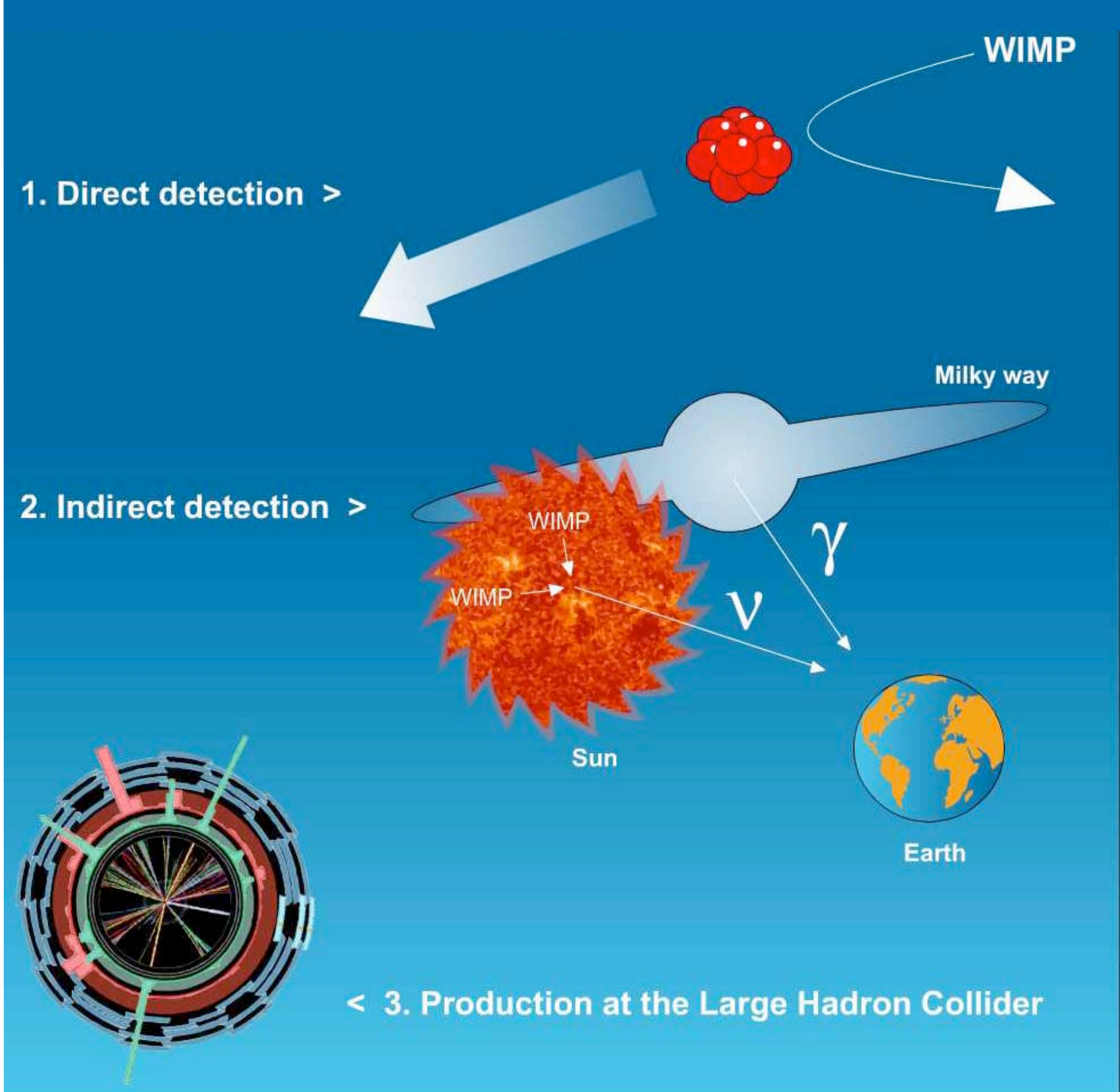
50 to 100 large, medium and small telescopes

Where and what is the Dark Matter?

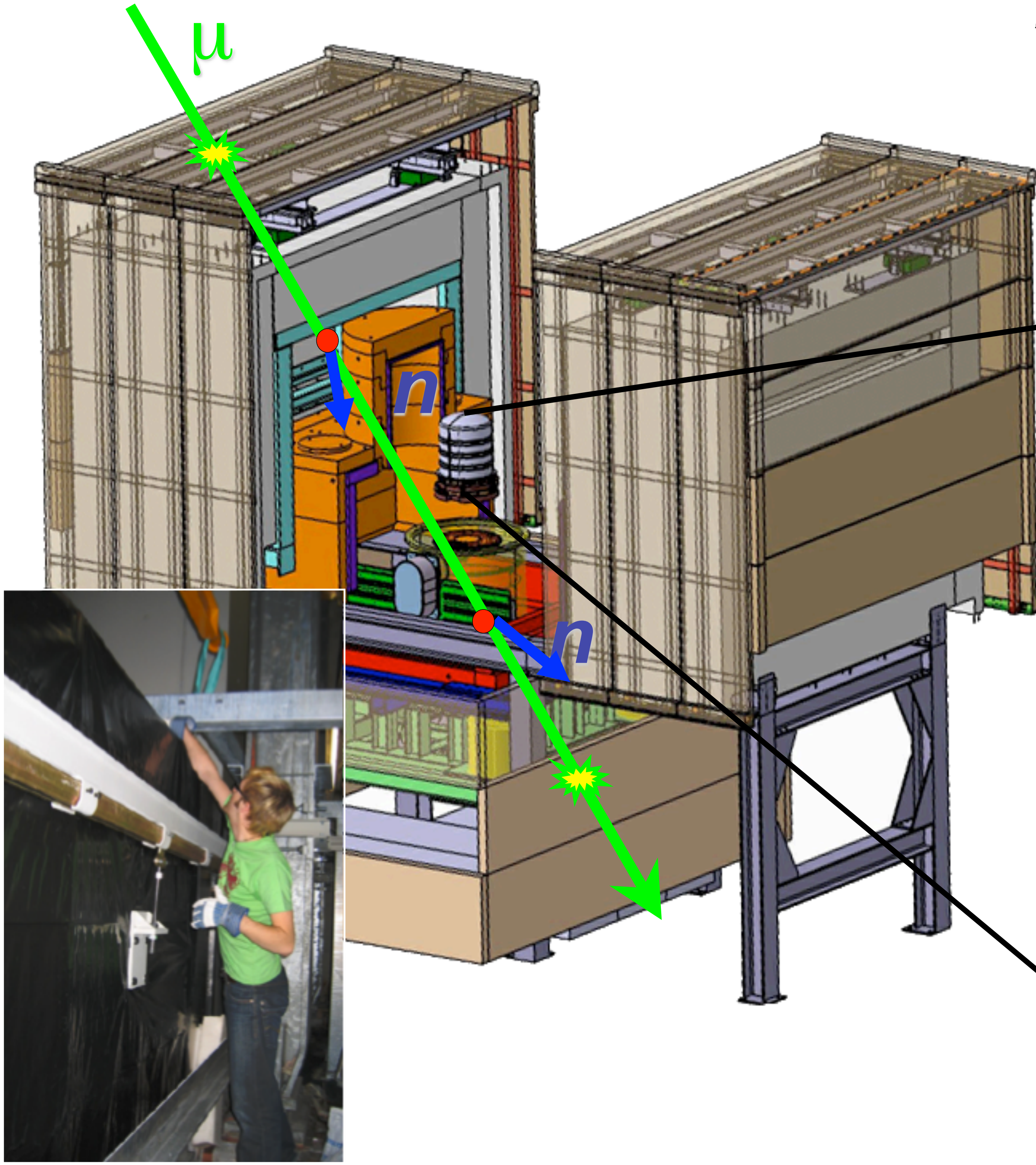
The quest for Dark Matter

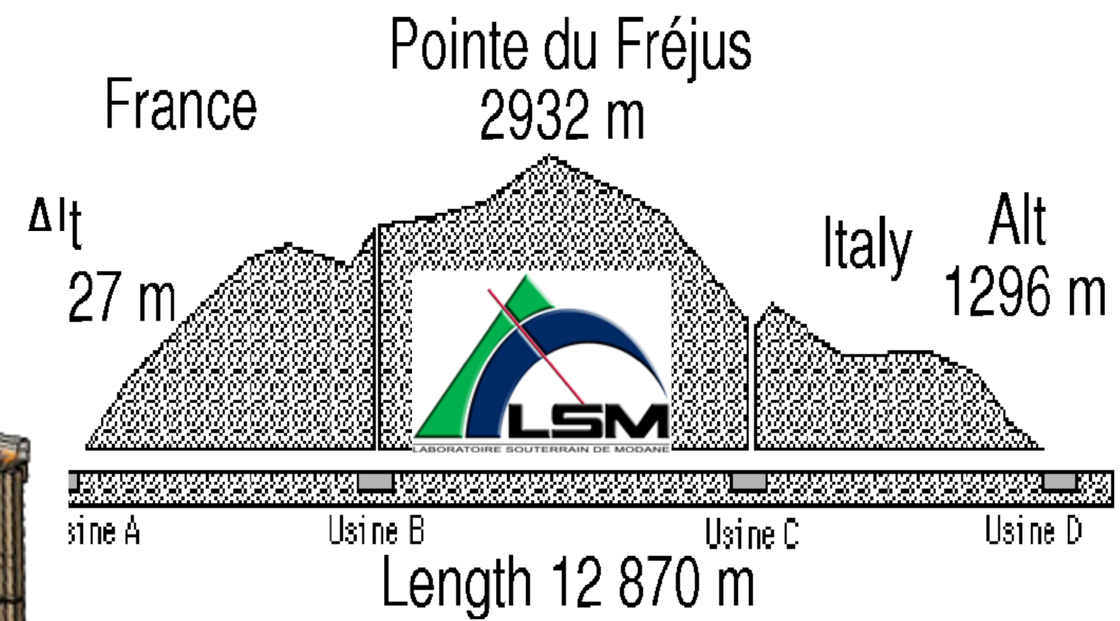


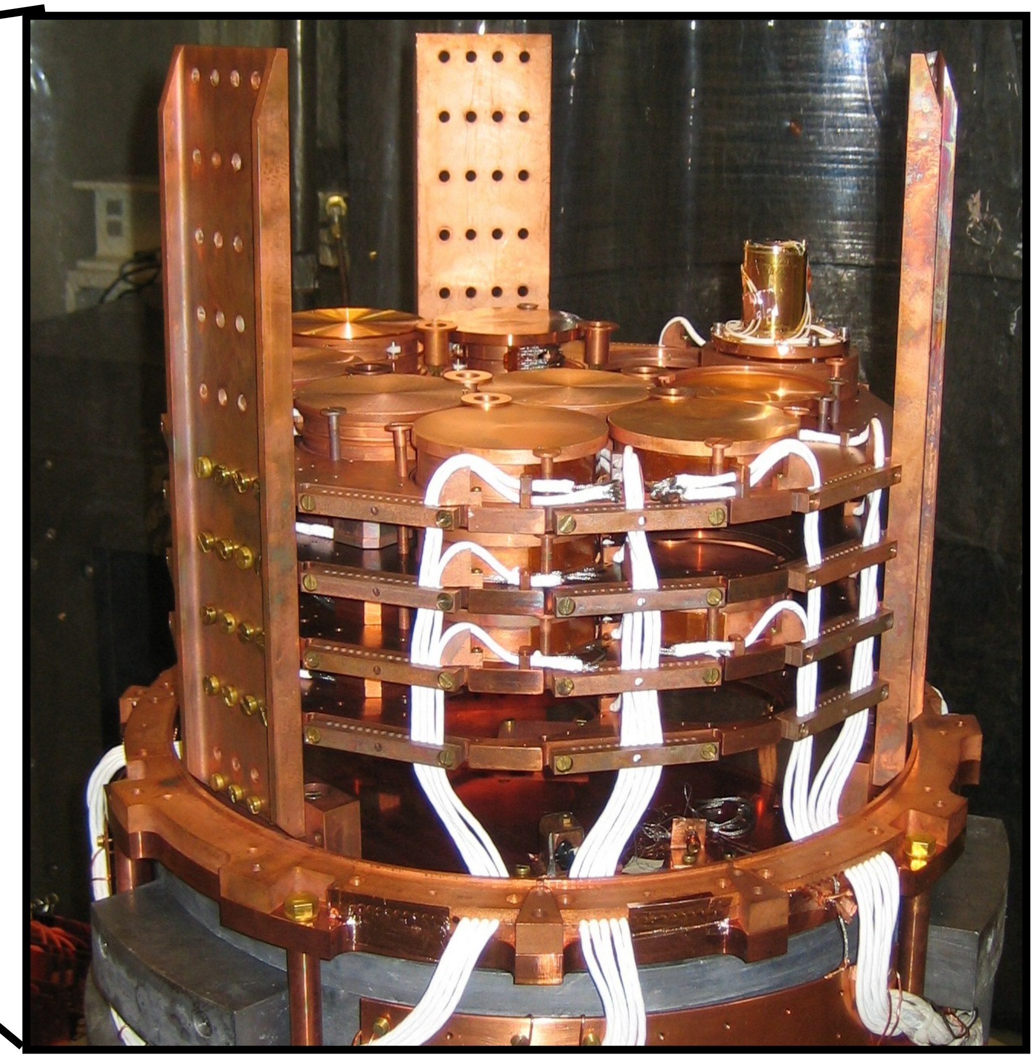




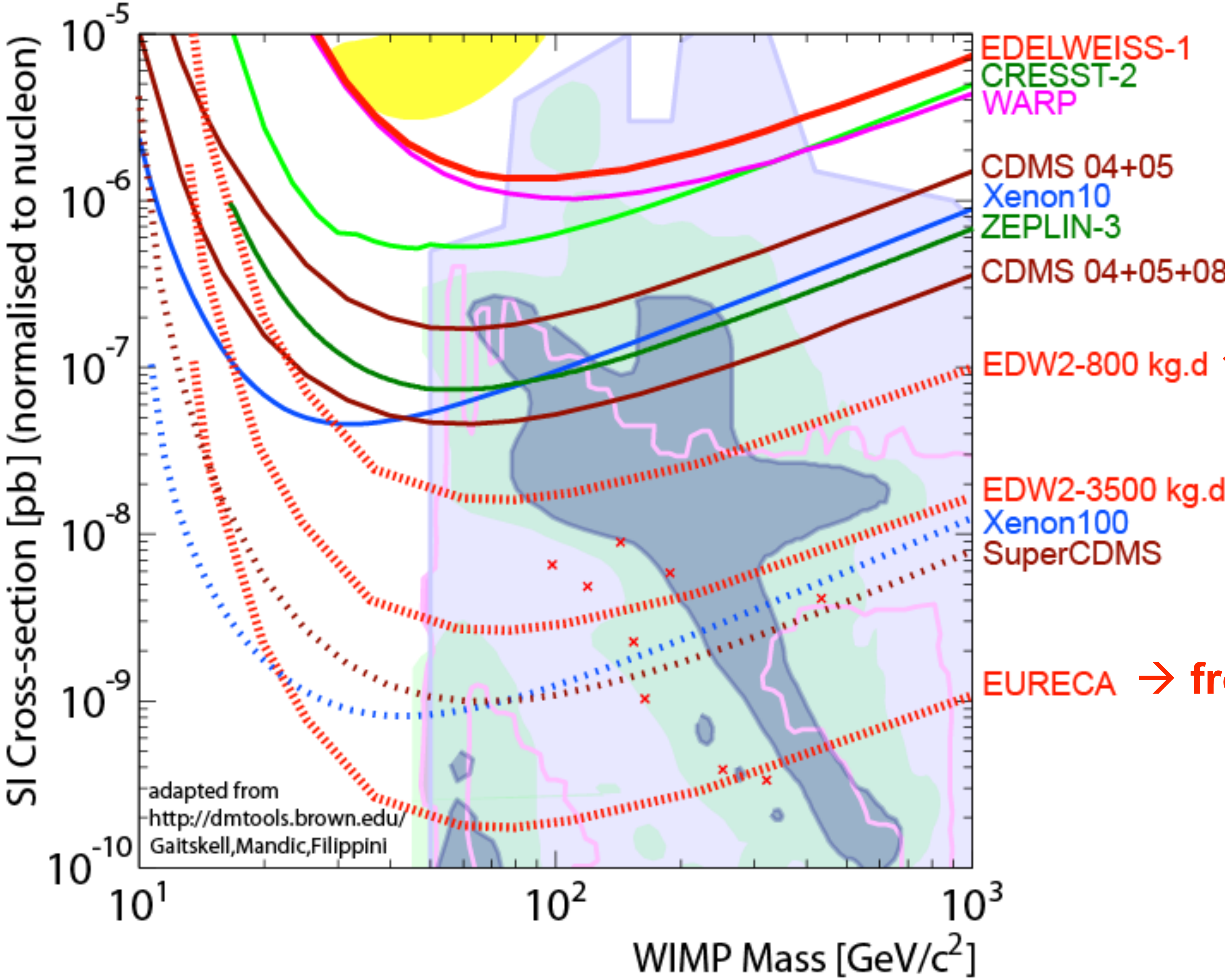
EDELWEISS


μ
n
n


Pointe du Fréjus
2932 m
France
Alt
27 m
Italy
Alt
1296 m
LSM
sine A
Usine B
Usine C
Usine D
Length 12 870 m



WIMP sensitivities



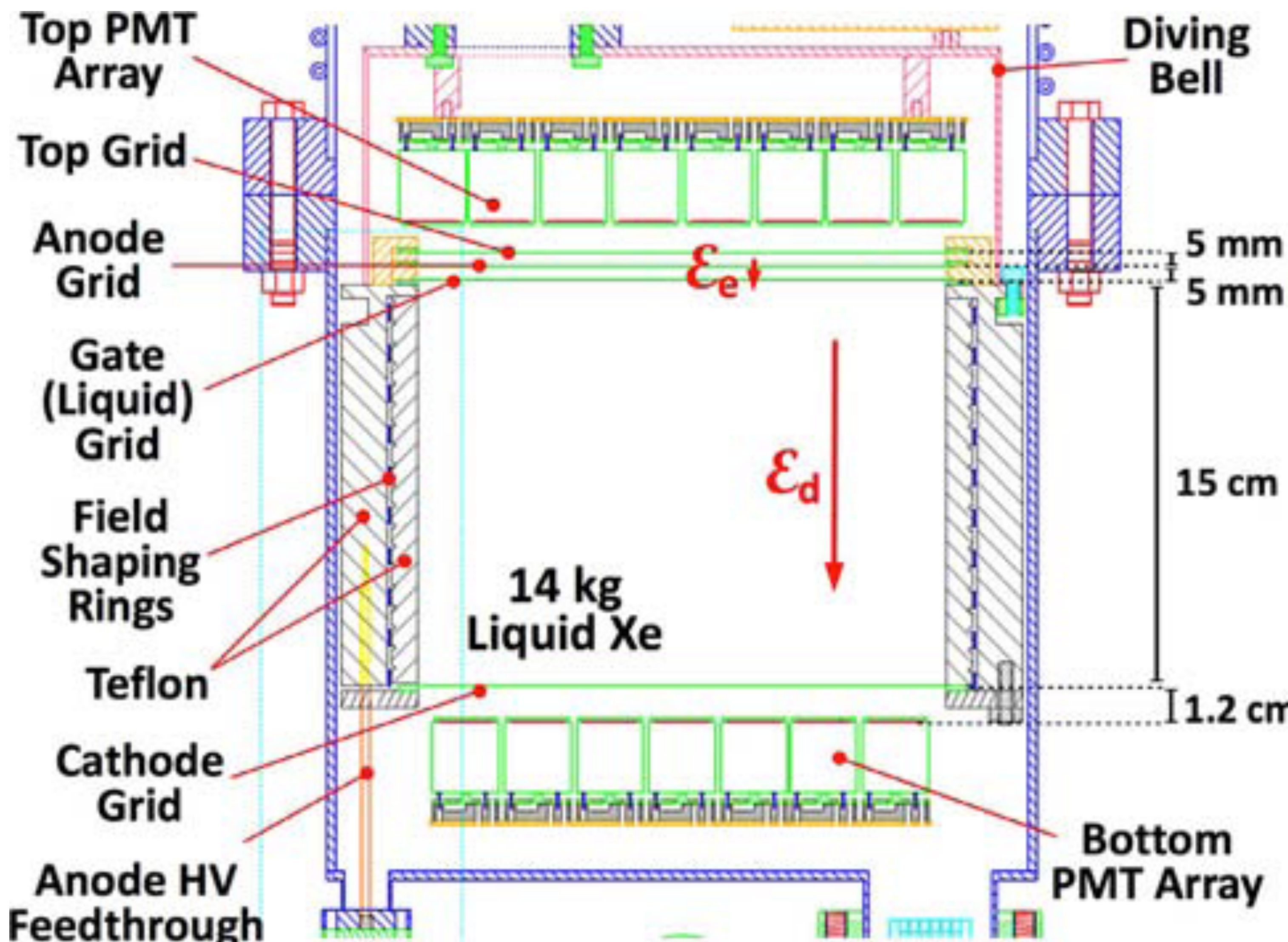
best sensitivity in 2003

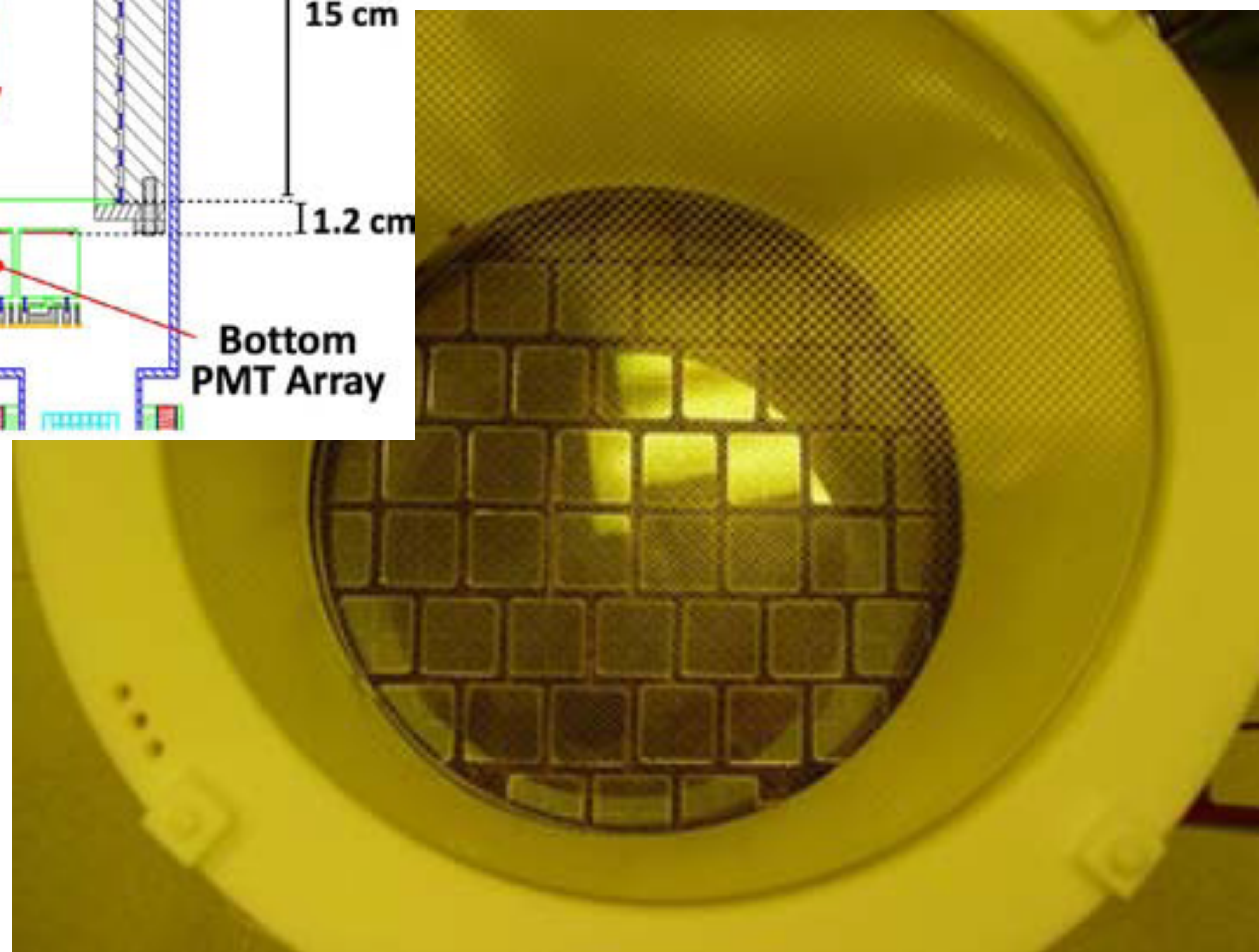
200kg.d$_{fid.}$ → 09/2009

← early 2011

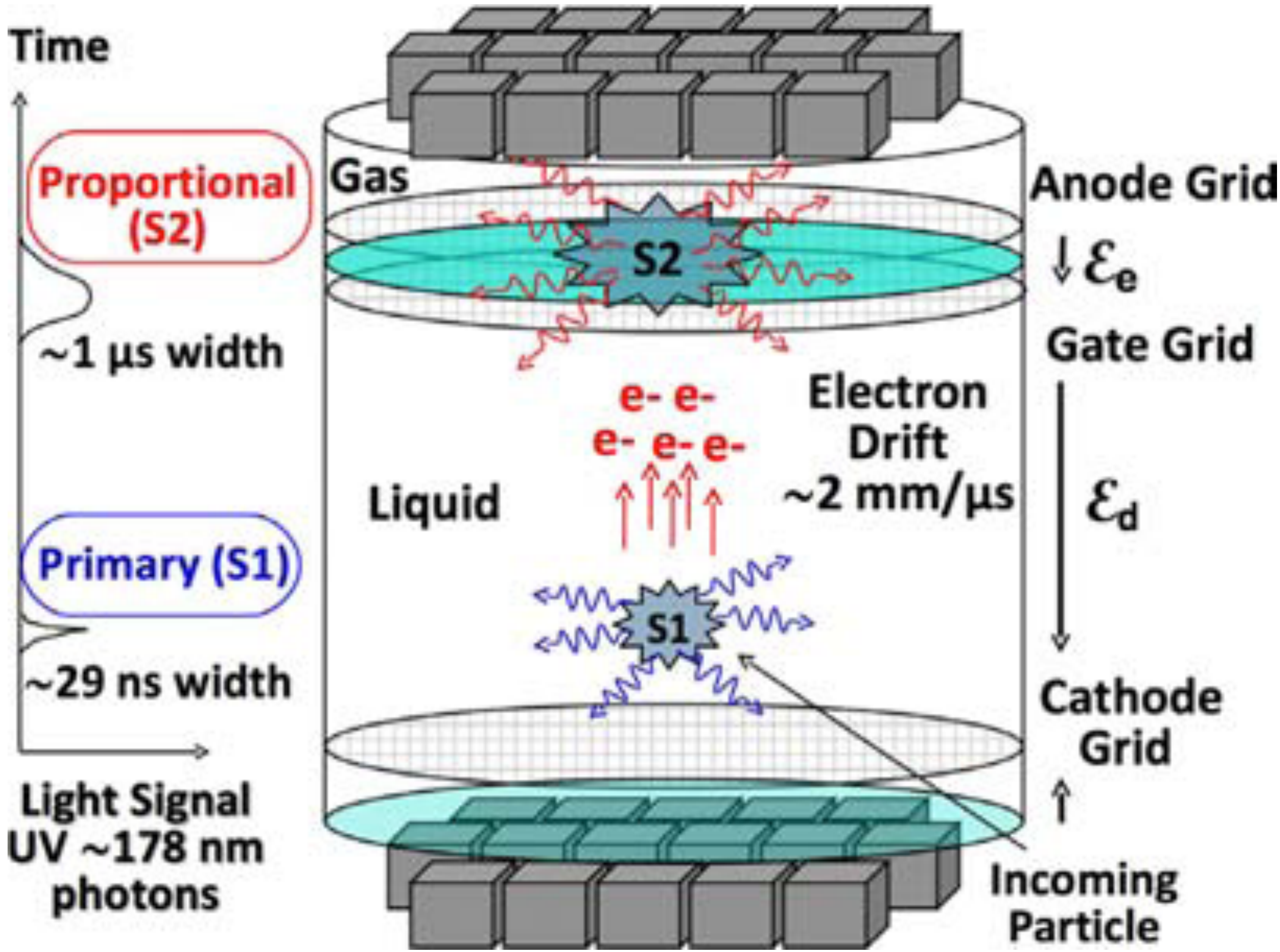
← 2012

→ from 2015 on



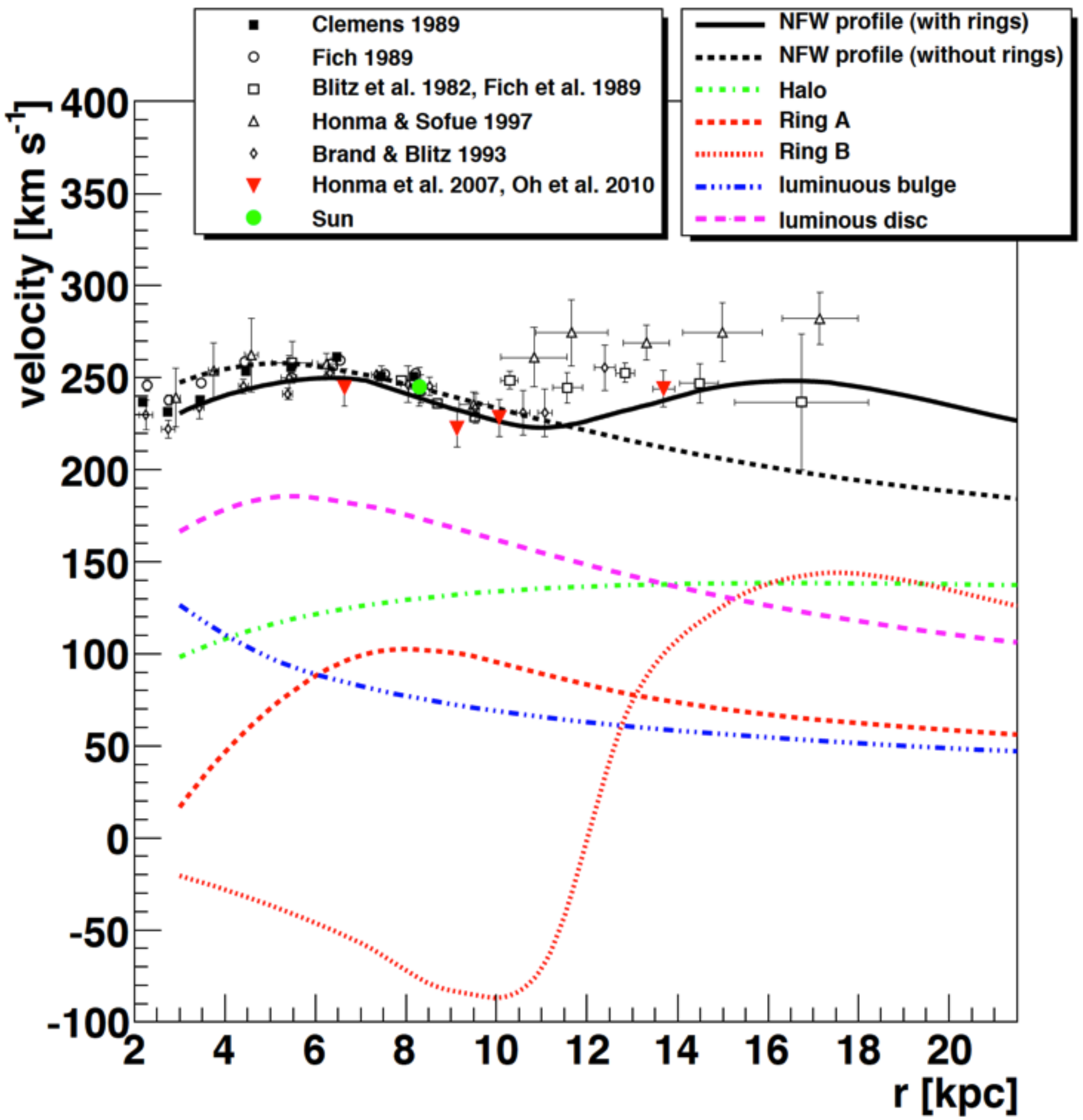


E. Aprile, Astroparticle Physics (2011), doi: 10.1016/j.astropartphys.2011.01.006

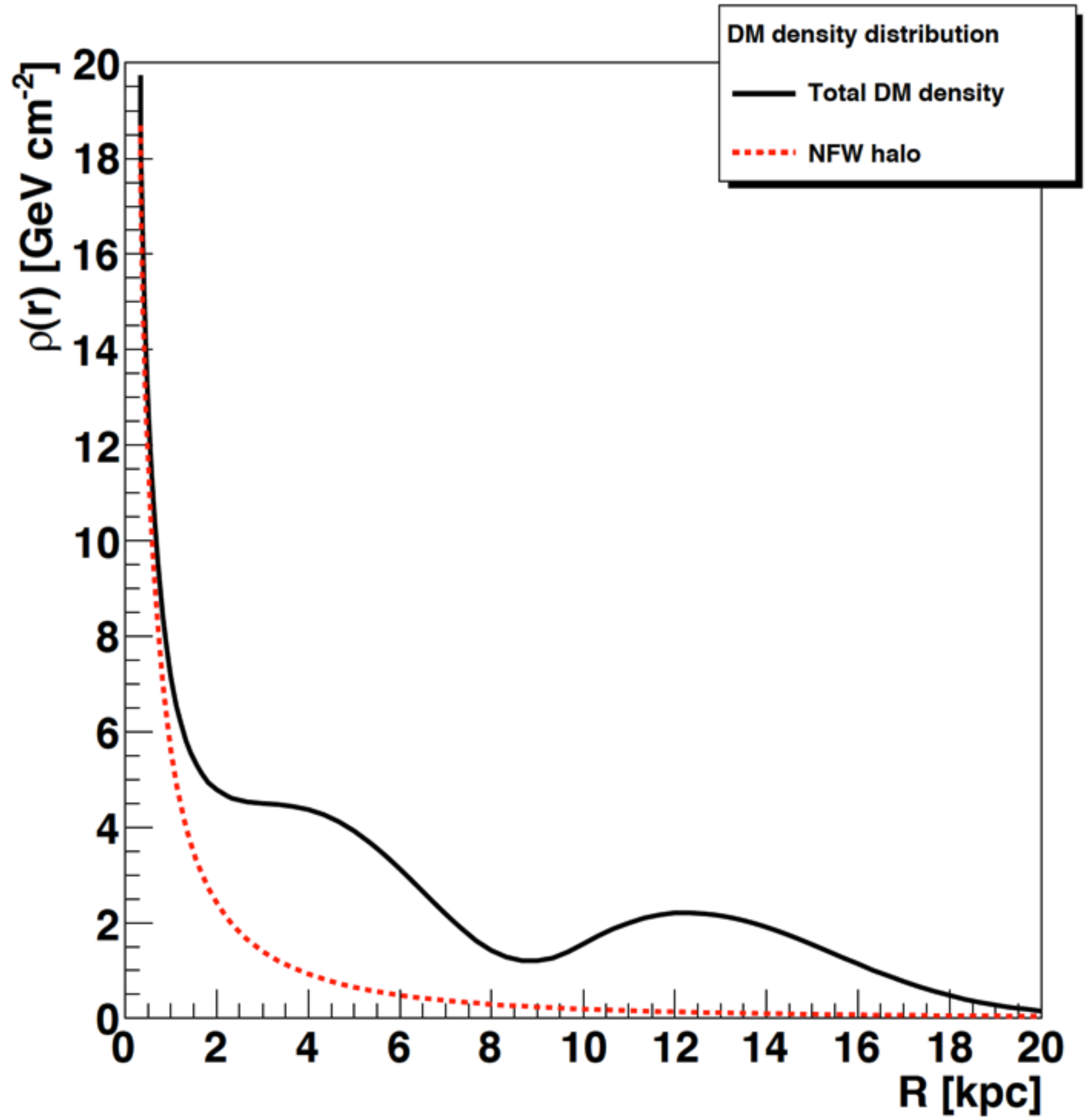


Time
Proportional (S2)
~1 μs width
Primary (S1)
~29 ns width
Light Signal
UV ~178 nm
photons
Gas
S2
Anode Grid
$\mathcal{E}_e$
Gate Grid
e- e-
e- e- e-
Electron
Drift
~2 mm/μs
Liquid
$\mathcal{E}_d$
S1
Cathode
Grid
Incoming
Particle

Rings of Dark Matter in the galaxy?



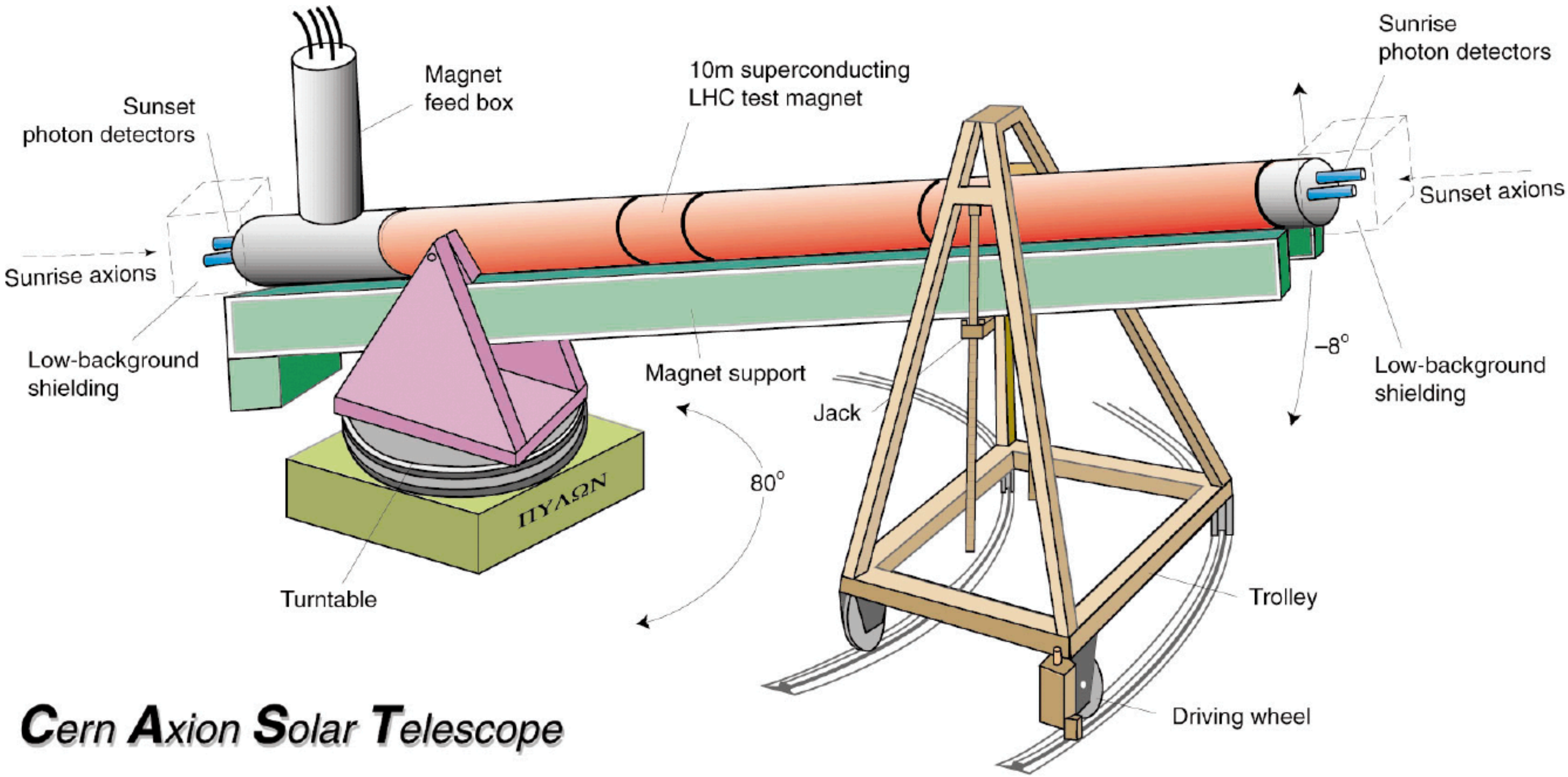
The Galactic rotation curve



The radial dependence of the DM density including the ringlike structures at 4.2 and 12.4 kpc

from W. de Boer, S. Kunz, M. Weber, Progress in Particle and Nuclear Physics (2011), doi:10.1016/j.ppnp.2011.01.006

Dark Matter search at CERN



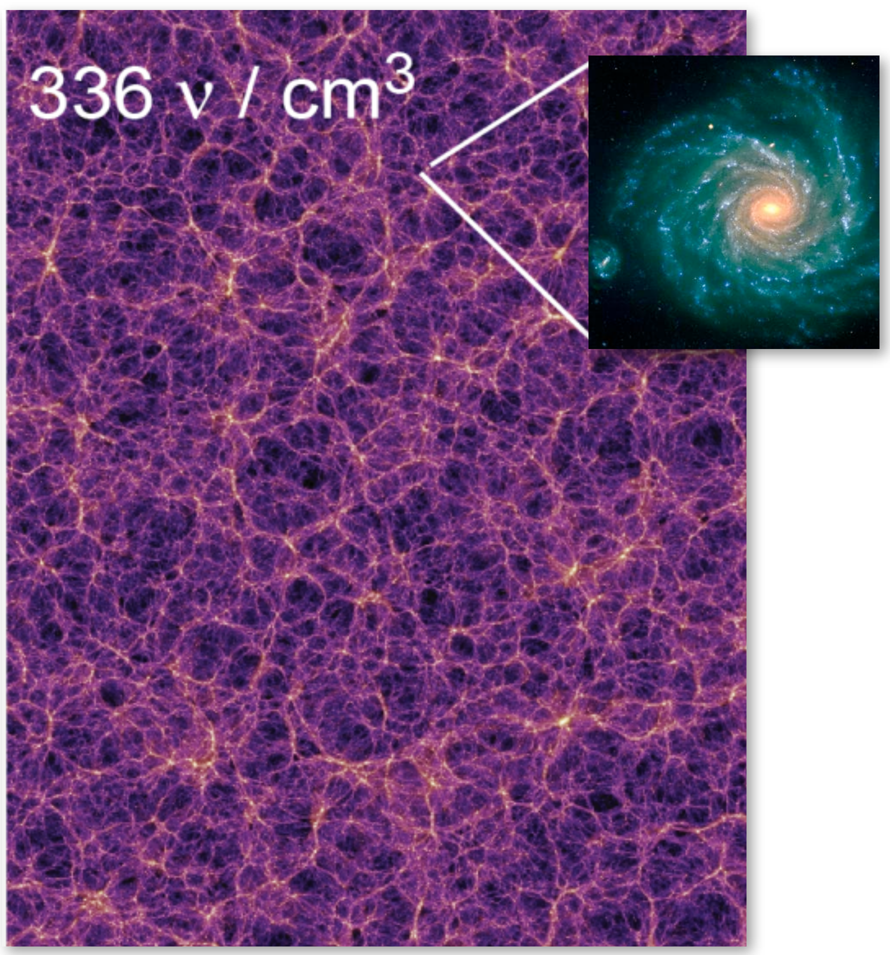
DM search at LHC: look for missing (transverse!) energy that might be due to the escape of a neutral, weakly interacting massive particle... Q: how to relate that with the ones in the universe?

Neutrino mass

motivation: ν´s in astroparticle physics

cosmic architects: role of relic ν´s as hot dark matter?

cosmology



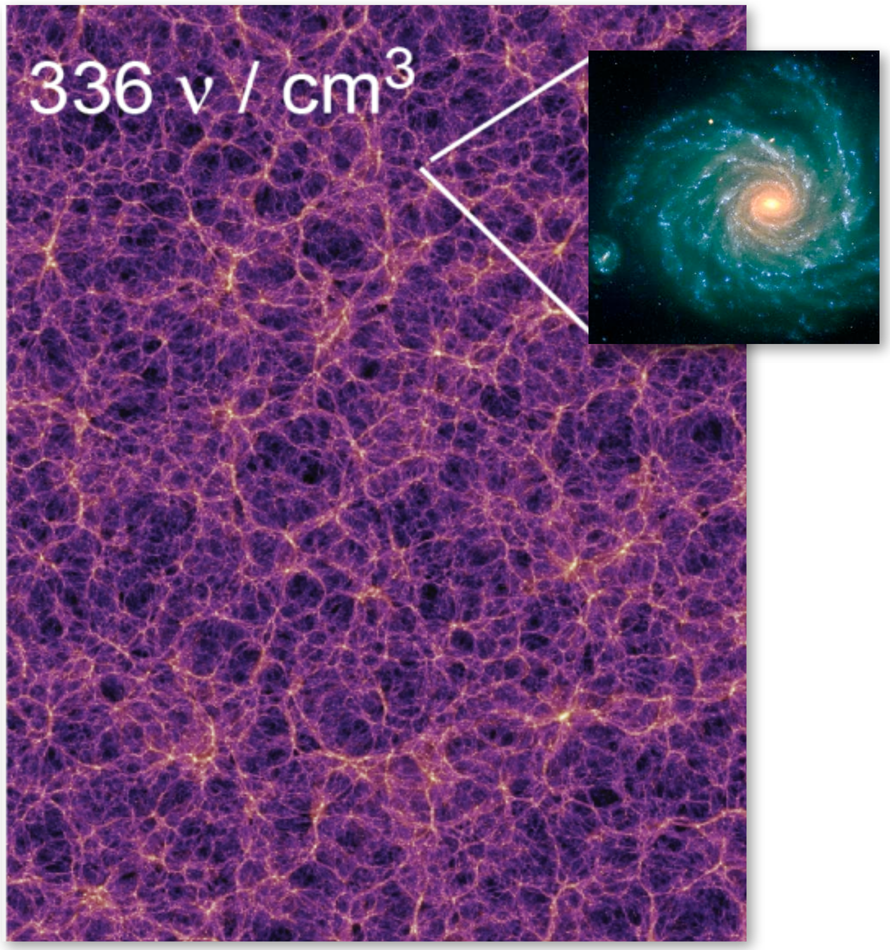
structure of the universe
(Millenium Simulation)

motivation: ν´s in astroparticle physics

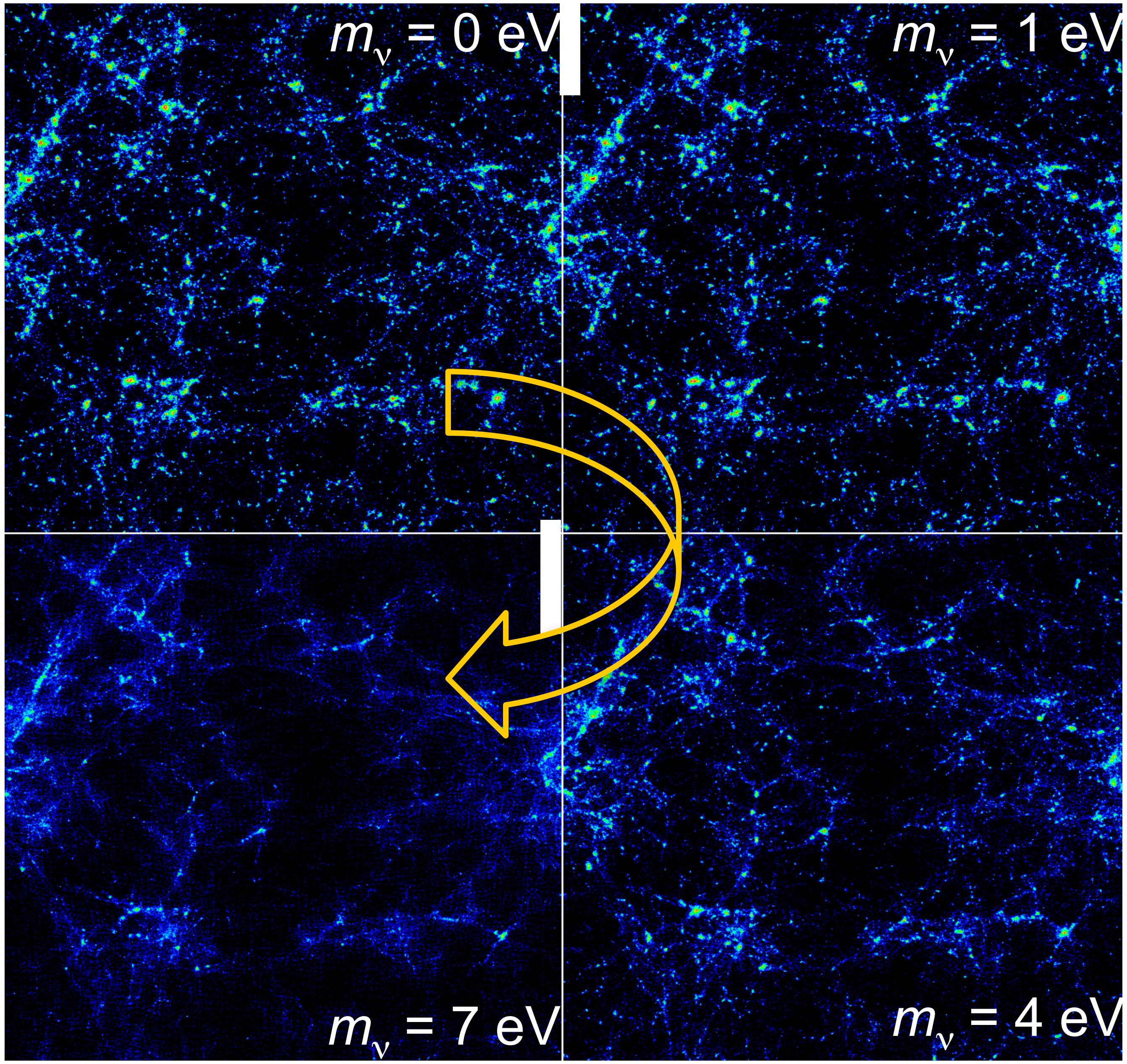
cosmic architects: role of relic ν´s as hot dark matter?

large scale structures: free streaming of ν´s on Gpc scales

cosmology



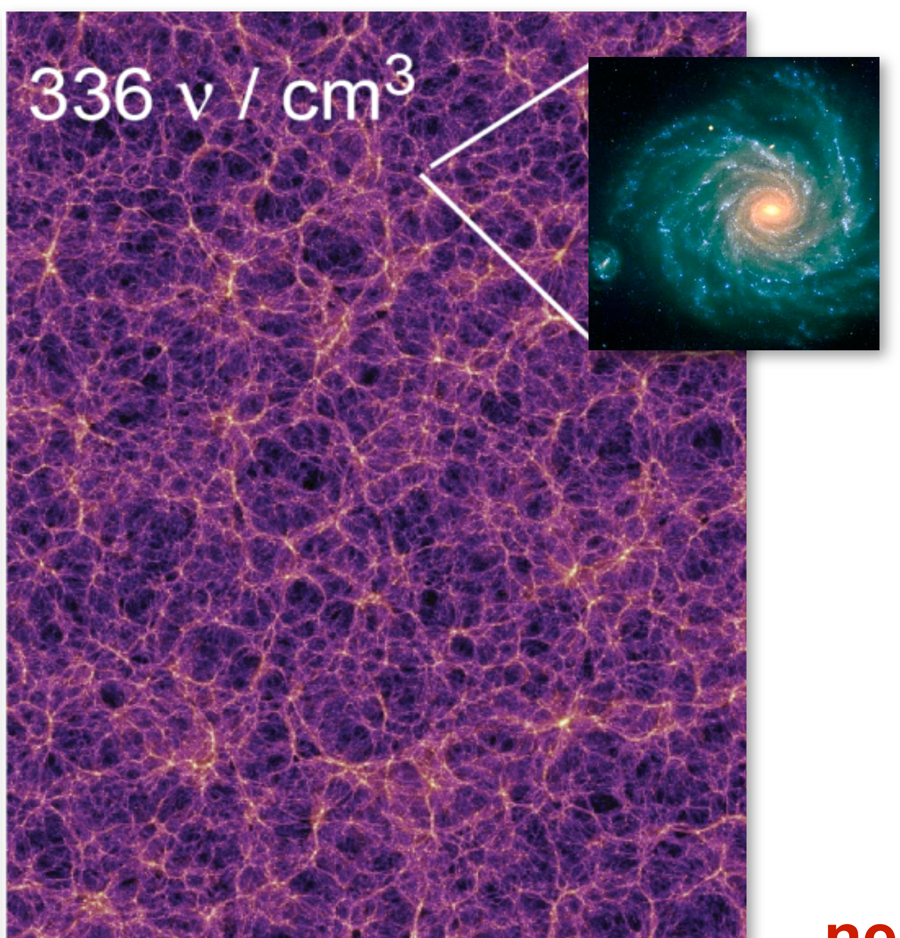
structure of the universe
(Millenium Simulation)



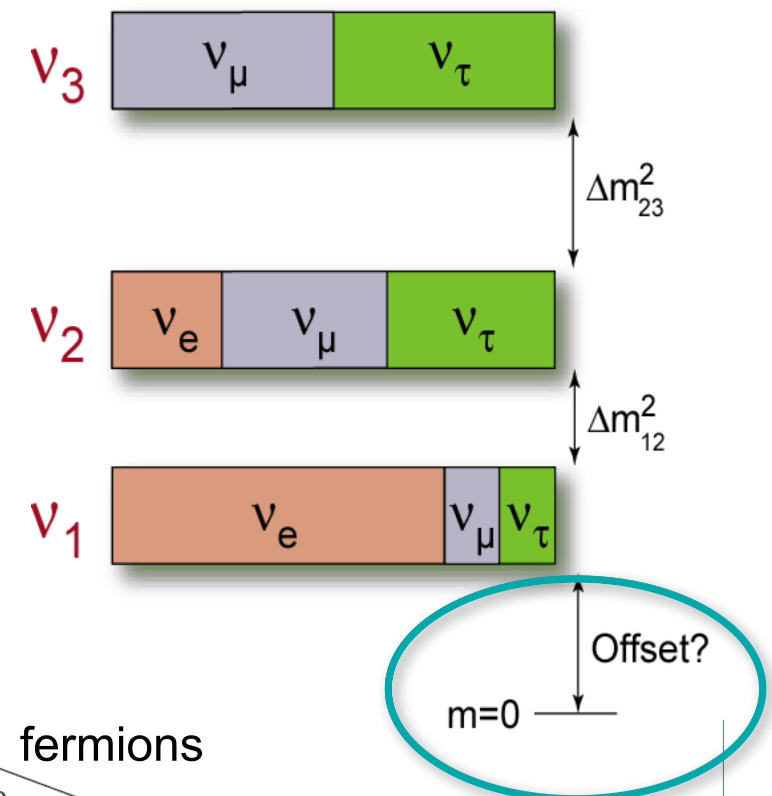
motivation: ν´s in astroparticle physics

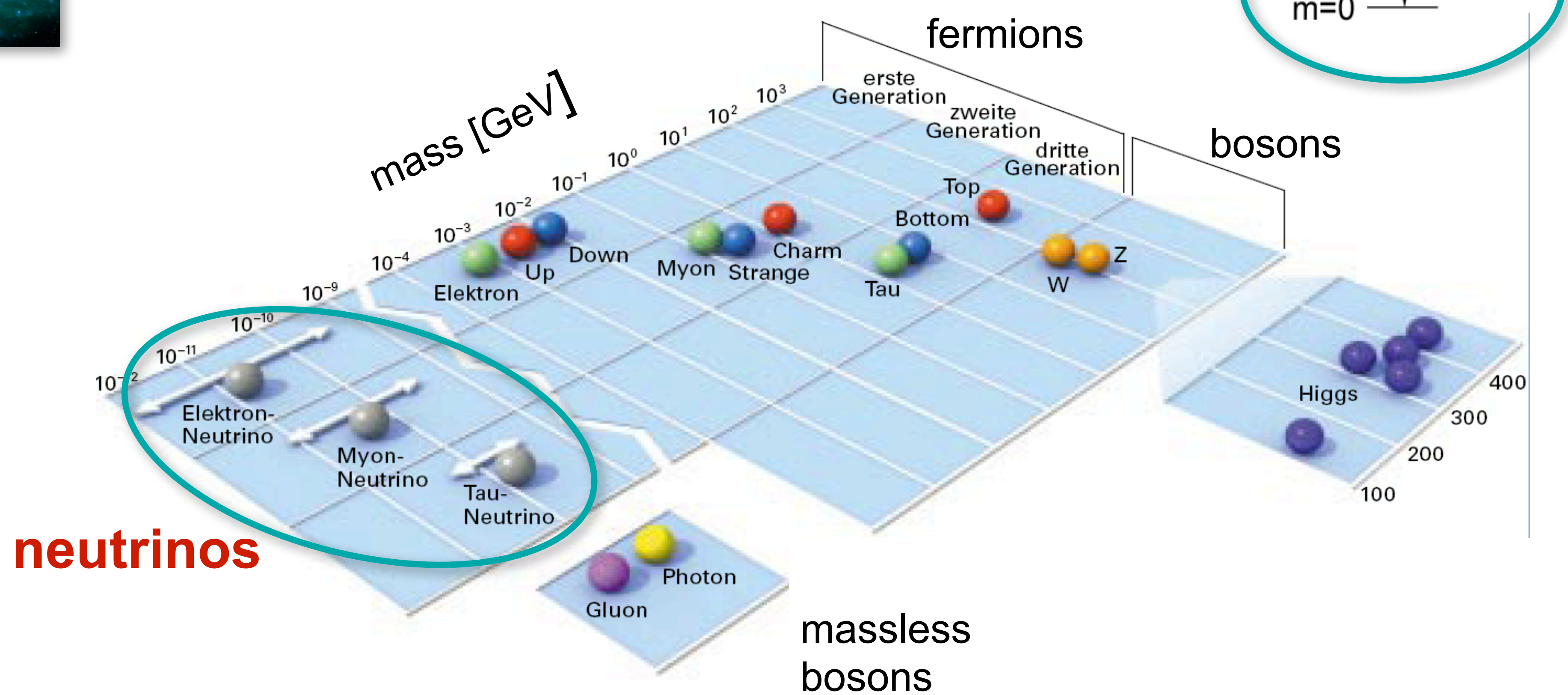
cosmic architects: role of ν´s as hot dark matter?
microscopic keys: origin of the ν-mass?

cosmology ⟺ **particle physics**



structure of the universe
(Millenium Simulation)

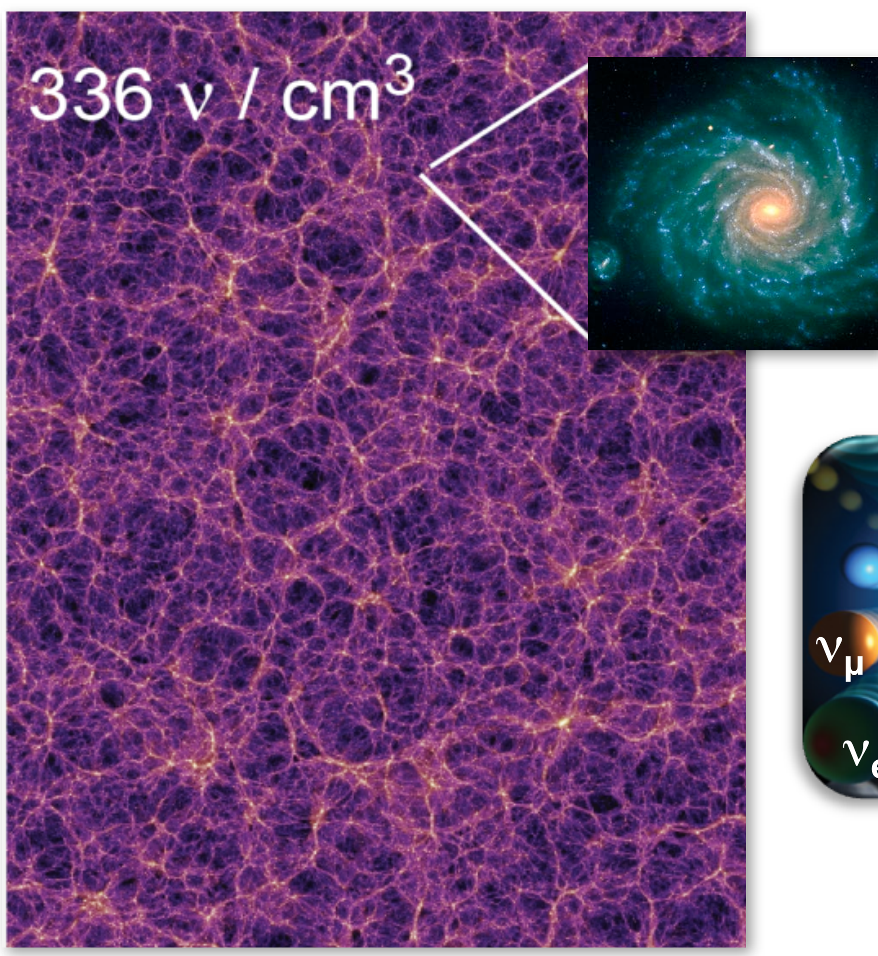




motivation: ν´s in astroparticle physics

cosmic architects: role of relic ν´s as hot dark matter?

$\Omega_\nu h^2 = \Sigma m_\nu / 92$ eV



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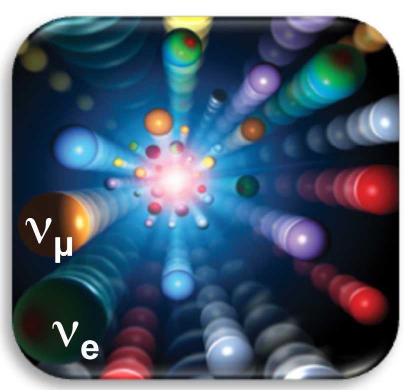

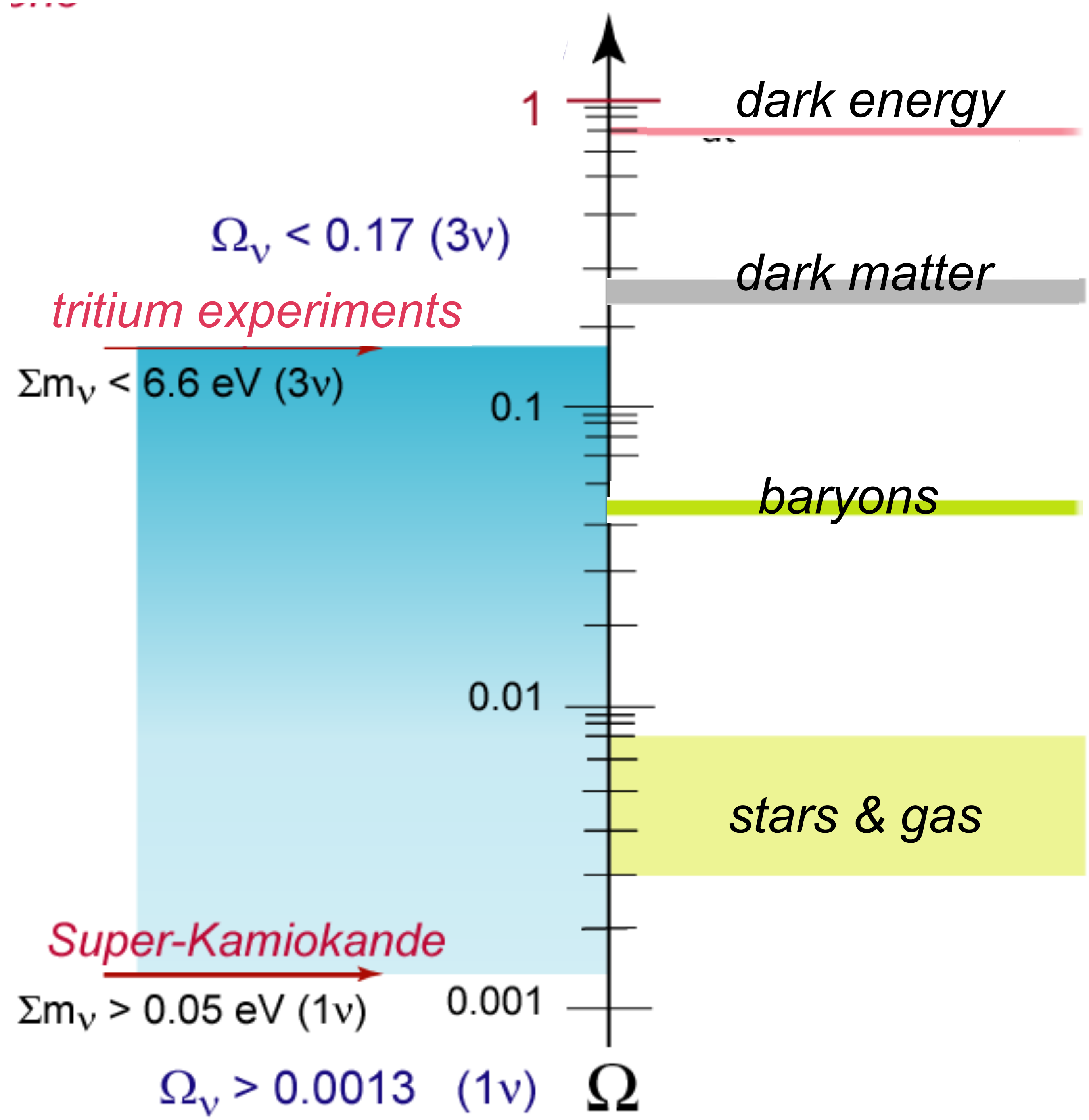

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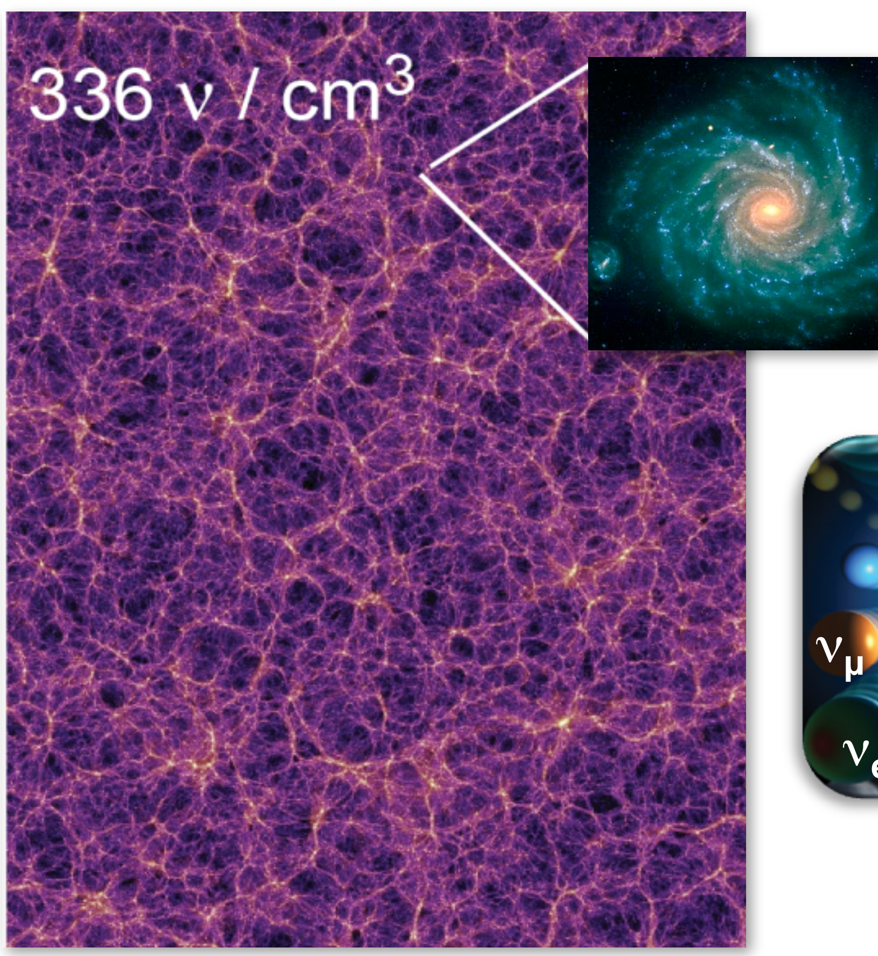

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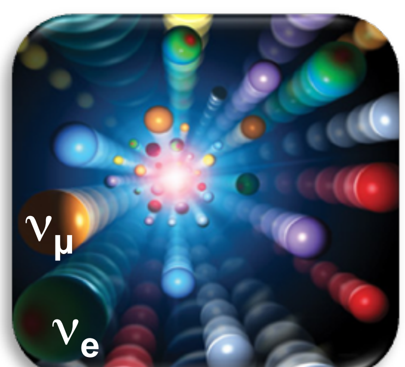

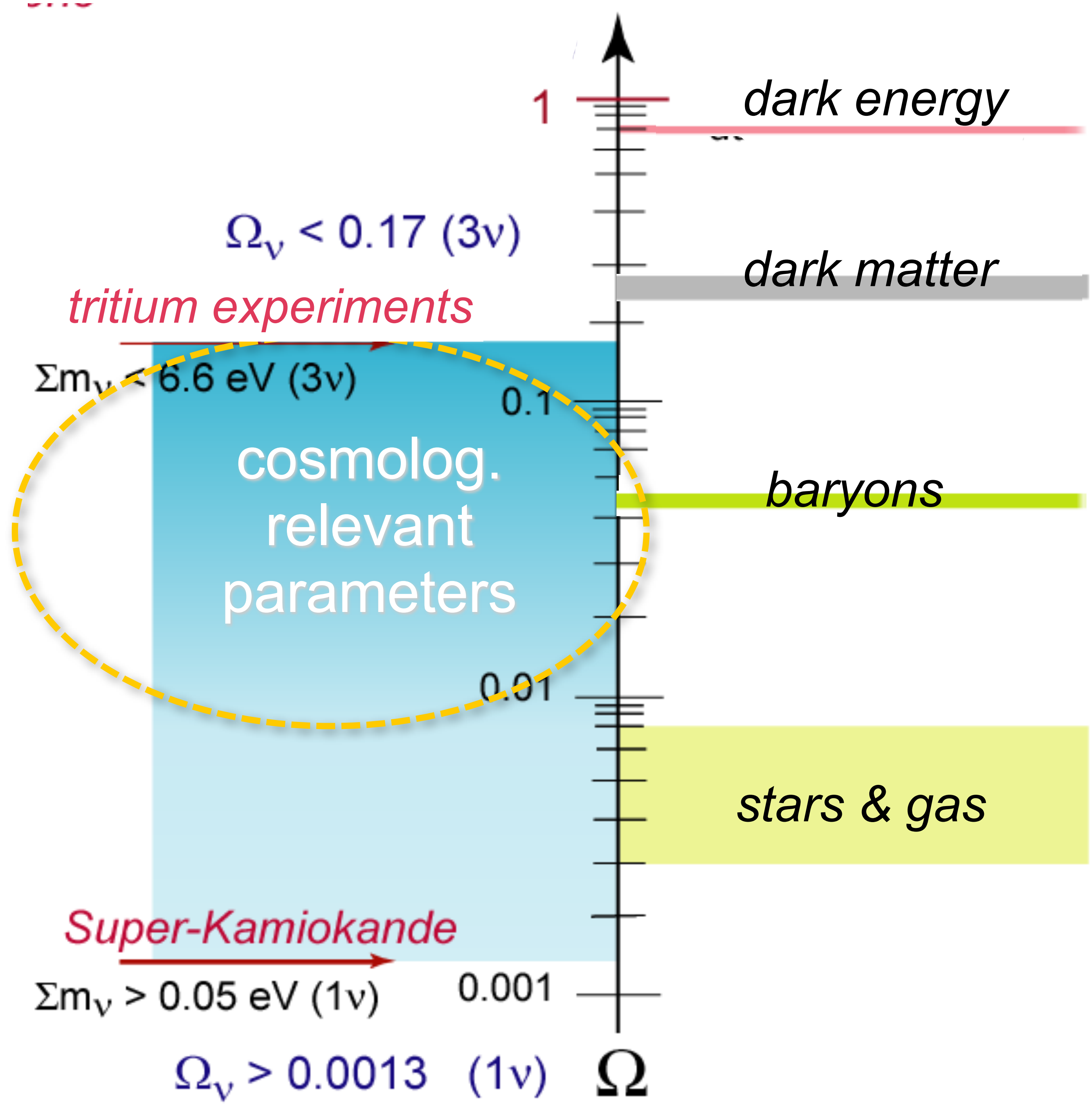

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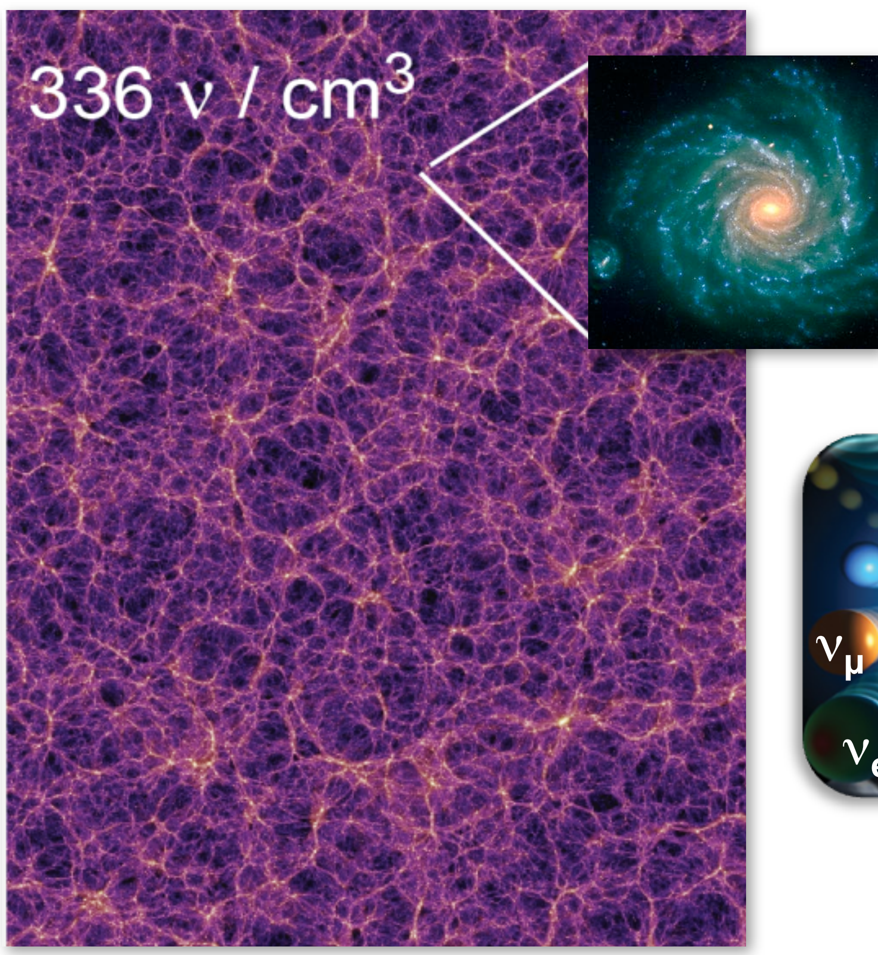

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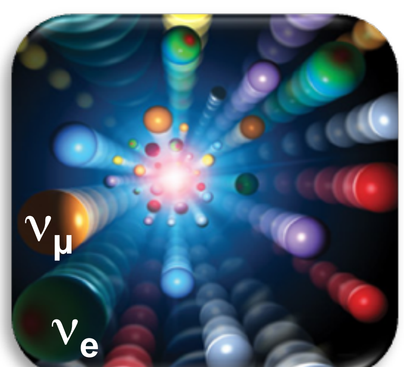
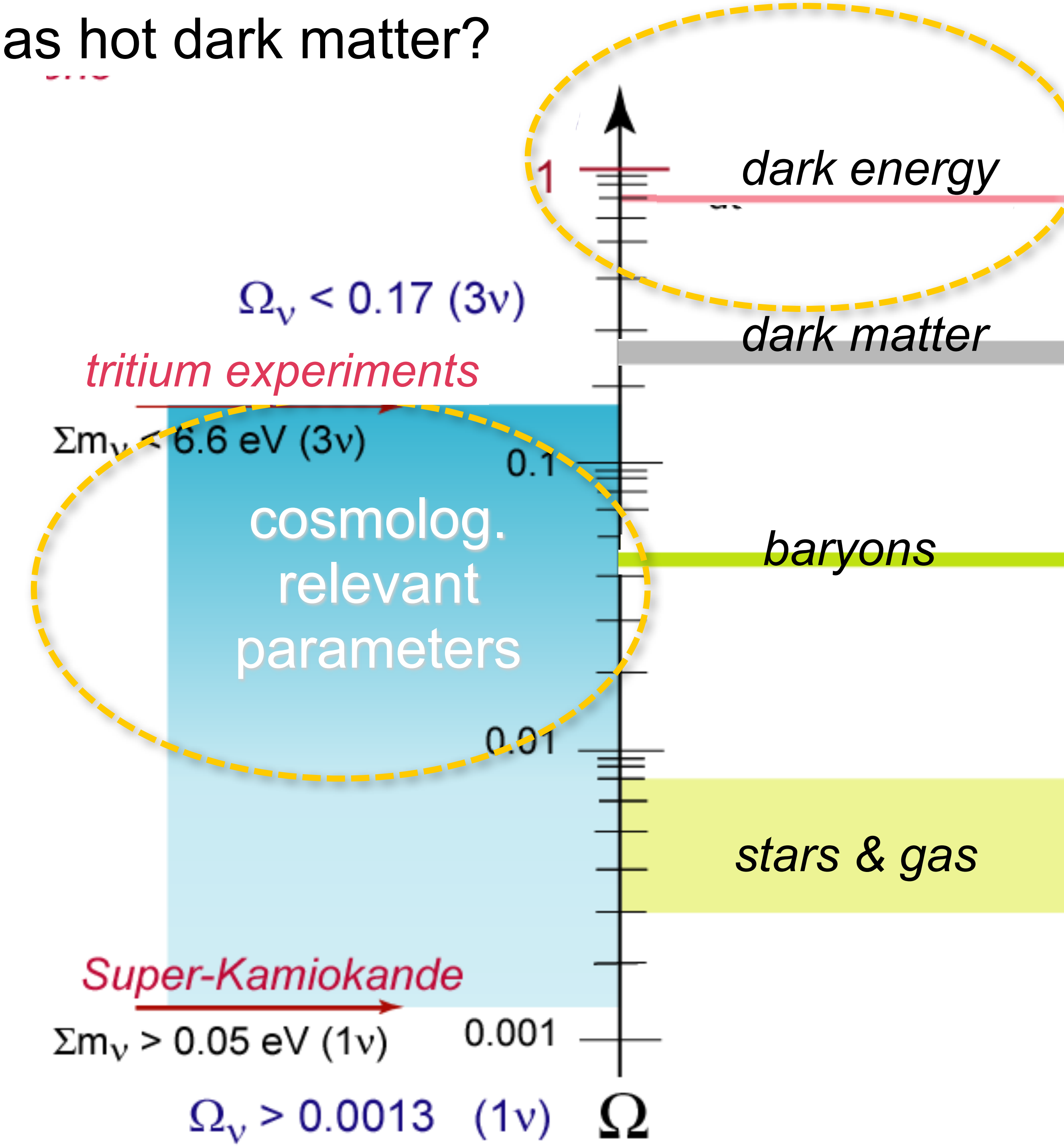
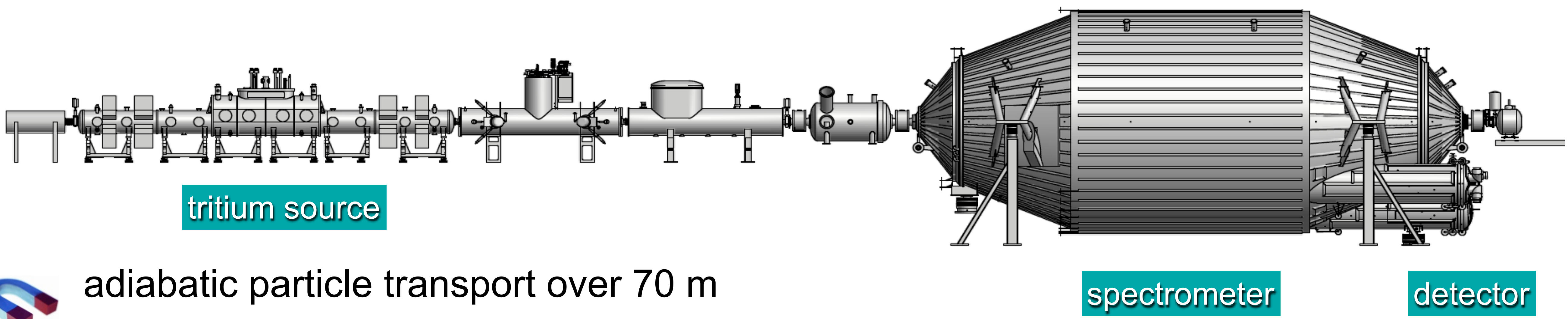


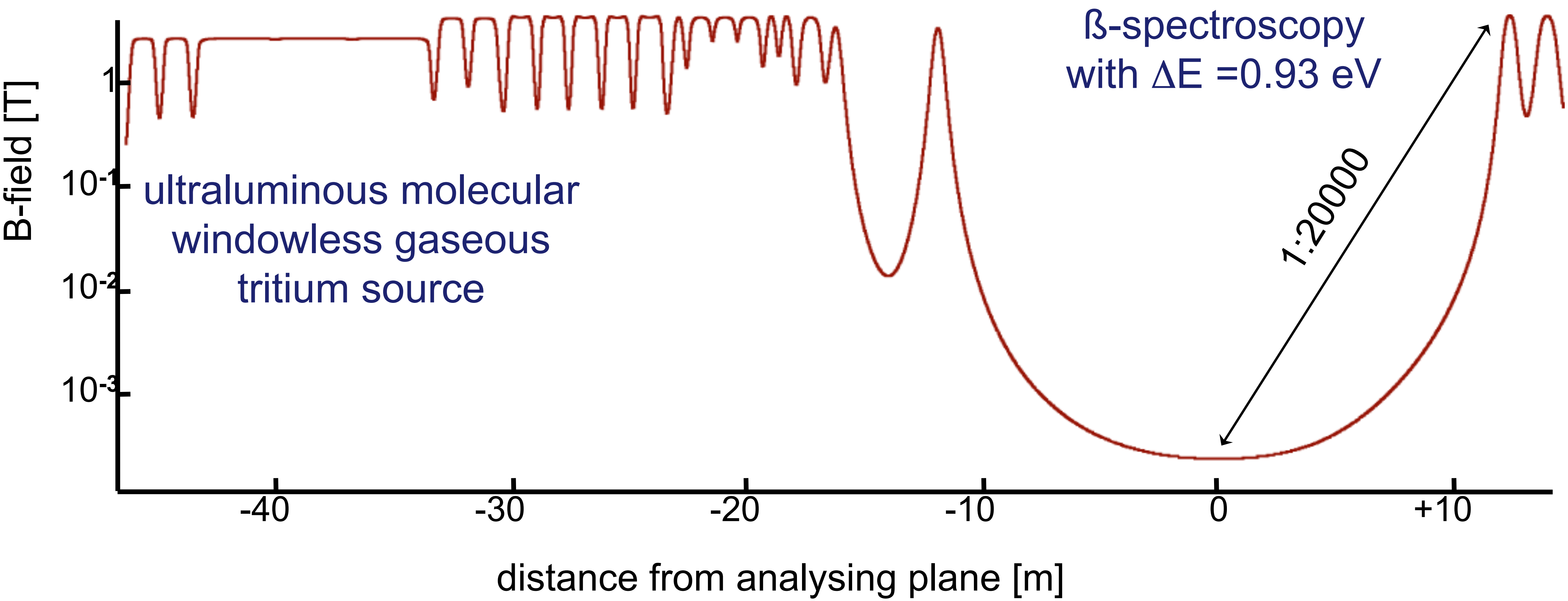


KATRIN – a MAC-E filter system

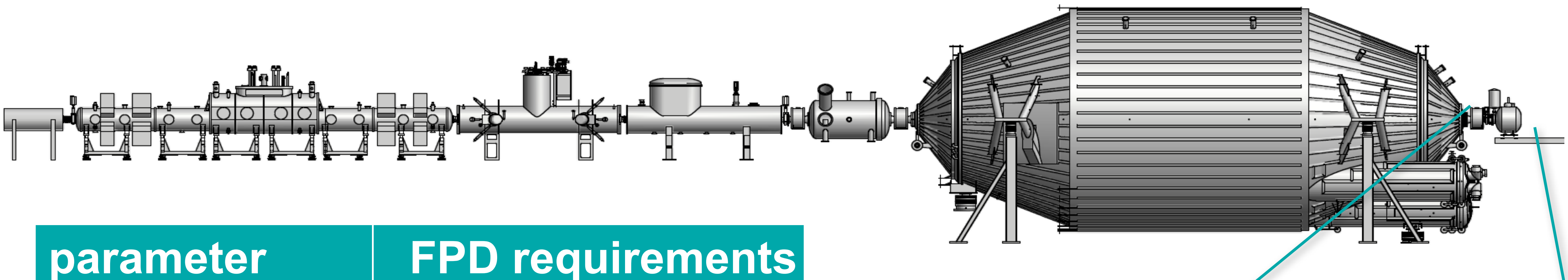
Karlsruhe Institute of Technology



adiabatic particle transport over 70 m

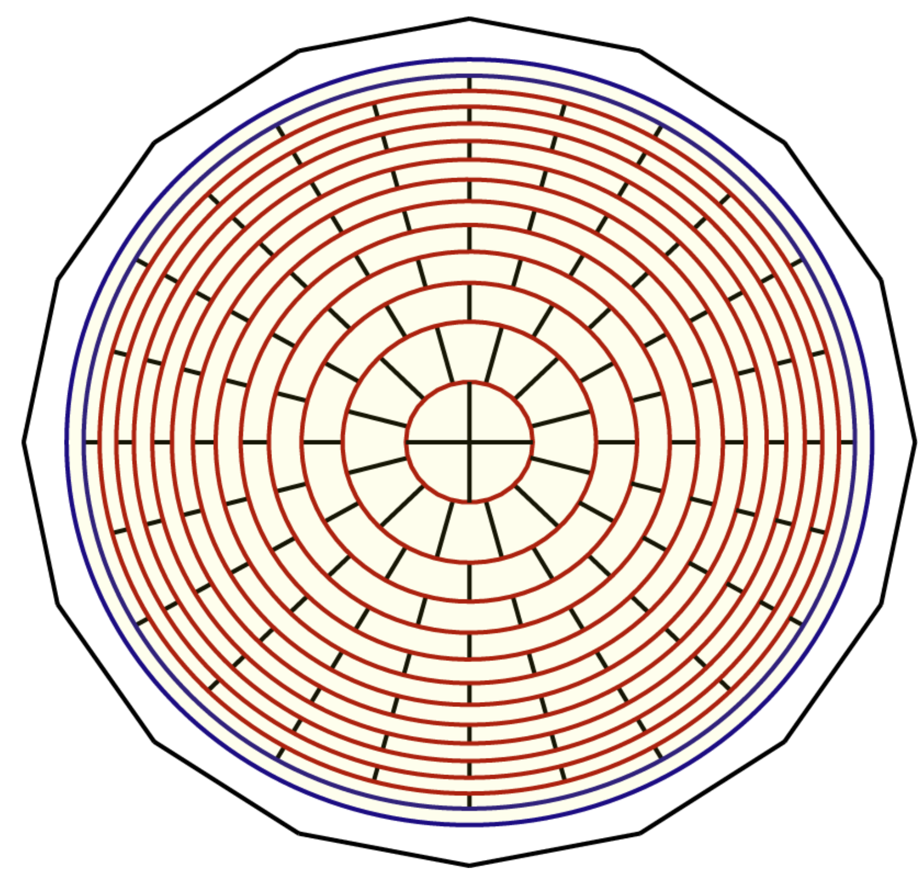


focal plane detector - requirements



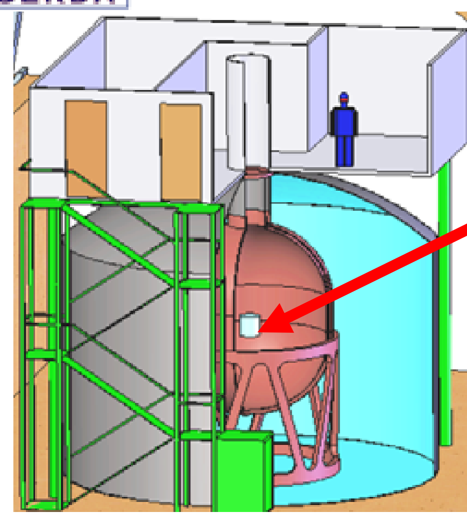
parameter	FPD requirements
electron energy	5 - 100 keV
background rate	< 10^{-3} mHz in RoI
efficiency	>90 % (with veto)
sensitive area	>6300 mm^2 Ø = 10 cm
segmentation	148 pixels
single pixel	~ 50 mm^2
time resolution	$\Delta t < 0.5$ µs
dead layer	< 100 nm
dark currents	< 2 nA / cm^2
magnetic field	3 T → 6 T
temperature	100 K → 250 K

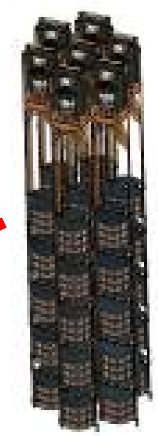
12 rings with 12 pixels
central bull´s eye 4 pixels



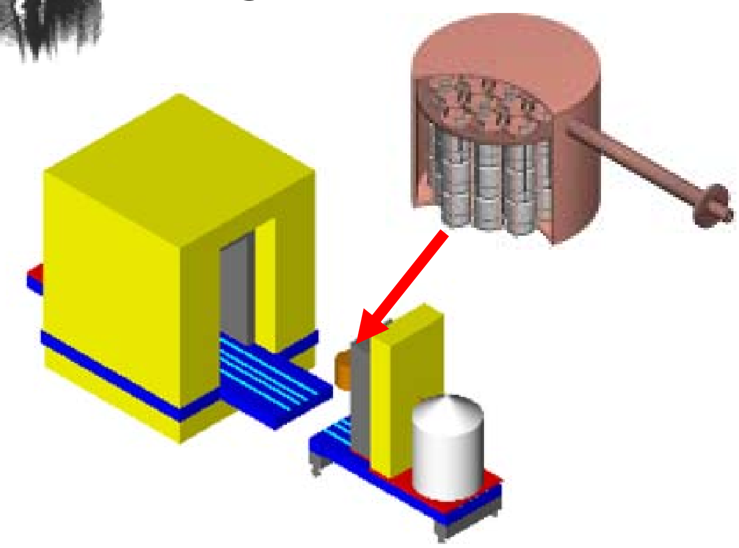
Two new ^{76}Ge Projects:

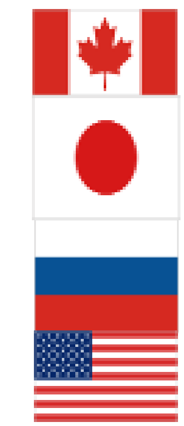
GERDA





Majorana





- ‘Bare’ ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I: 18 kg (HdM/IGEX) / 15 kg nat.
- Phase II: add ~20 kg new enr. Detectors; total ~40 kg

- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D demonstrator module: Total ~60 kg (30 kg enr.)

Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. (inv. Hierarchy) selecting the best technologies tested in GERDA and Majorana

GERDA/Majorana: Phases and physics reach

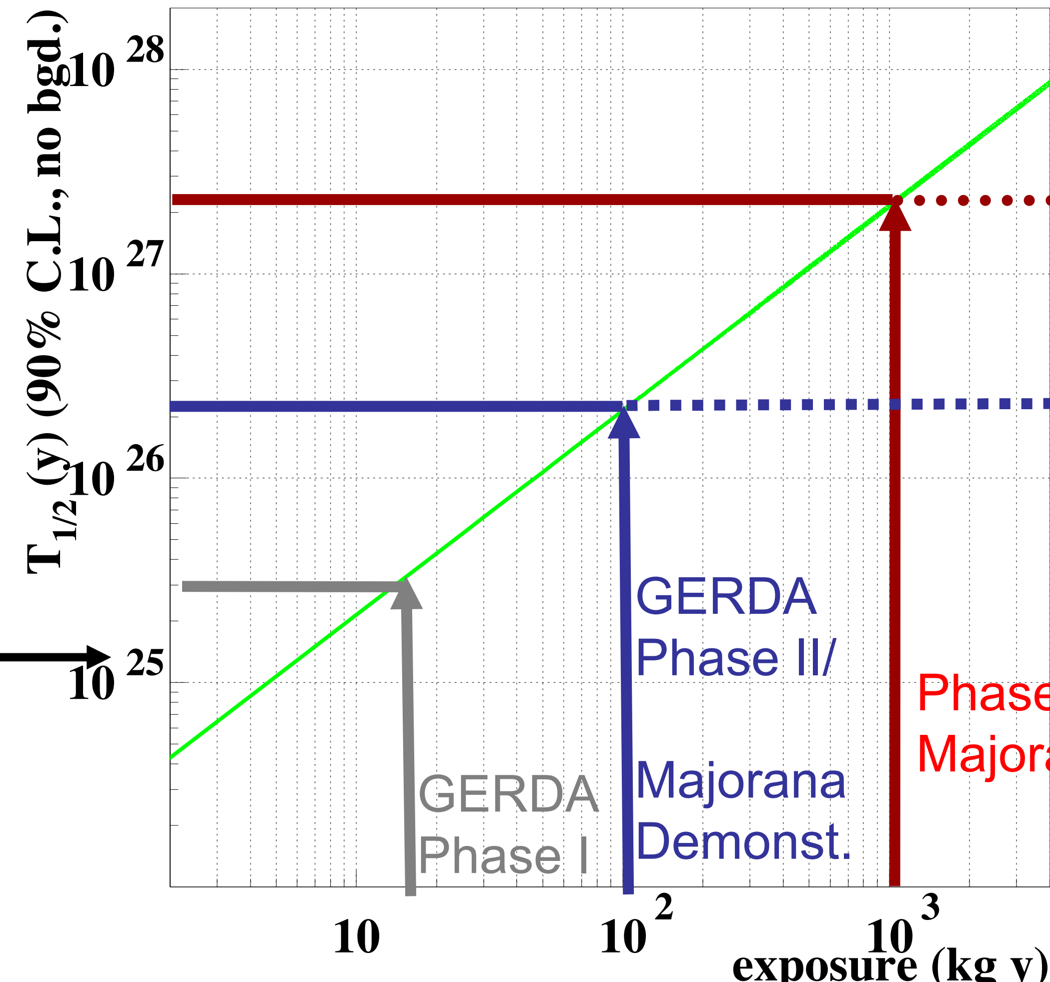
$2 \cdot 10^{27}$ (90 % CL) *

$2 \cdot 10^{26}$ (90 % CL) *

$3 \cdot 10^{25}$ (90 % CL)*

KK

*: no event in ROI



<24 - 41 meV

<75 - 129 meV

assuming
$|M^{0\nu}|$=2.99-8.99
[Smol&Grab PRC'10]
and 89% enrichment

required for 'background free'
exp. with ΔE~3.3 keV (FWHM): **$O(10^{-3})$** **$O(10^{-4})$** counts/(kg·y·keV)

Background requirement for GERDA/Majorana:

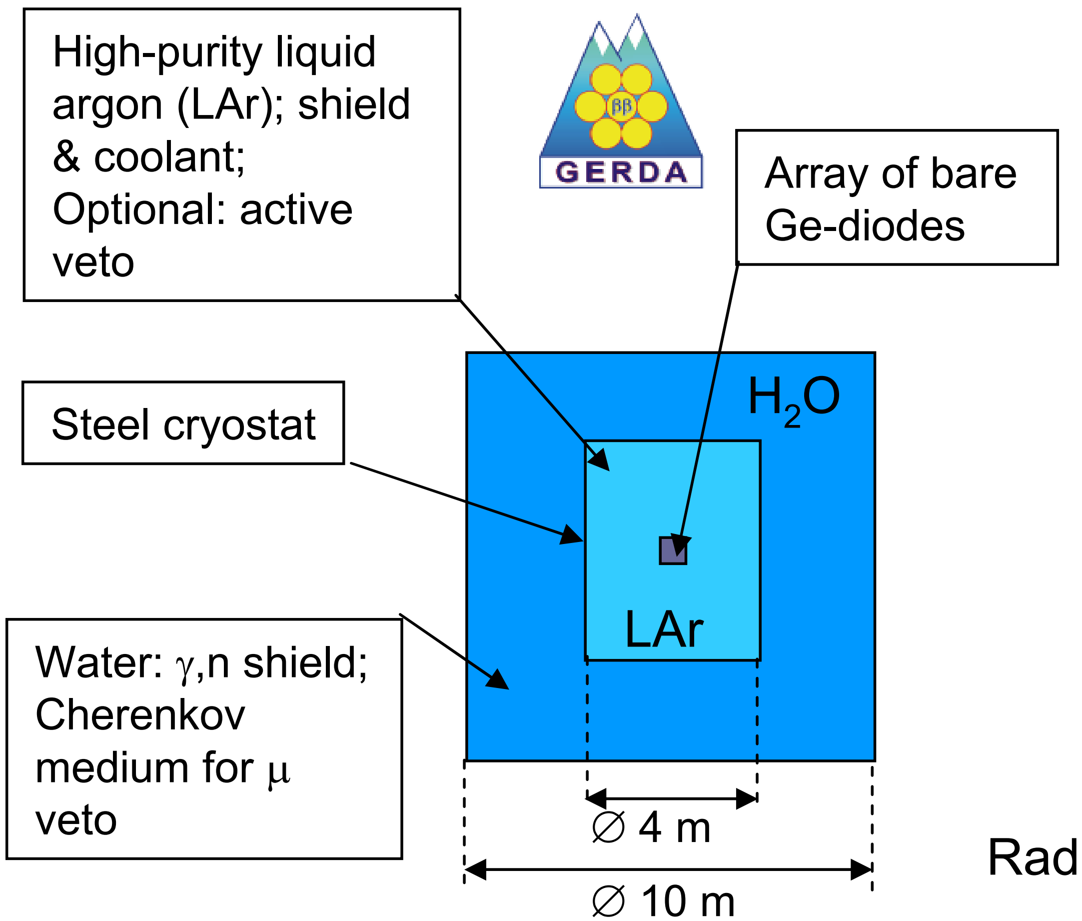
⇒Background reduction by factor **10^2 - 10^3** required w.r.t. to precursor exps.

⇒Degenerate mass scale **$O(10^2$ kg·y)** ⇒ Inverted mass scale **$O(10^3$ kg·y)**

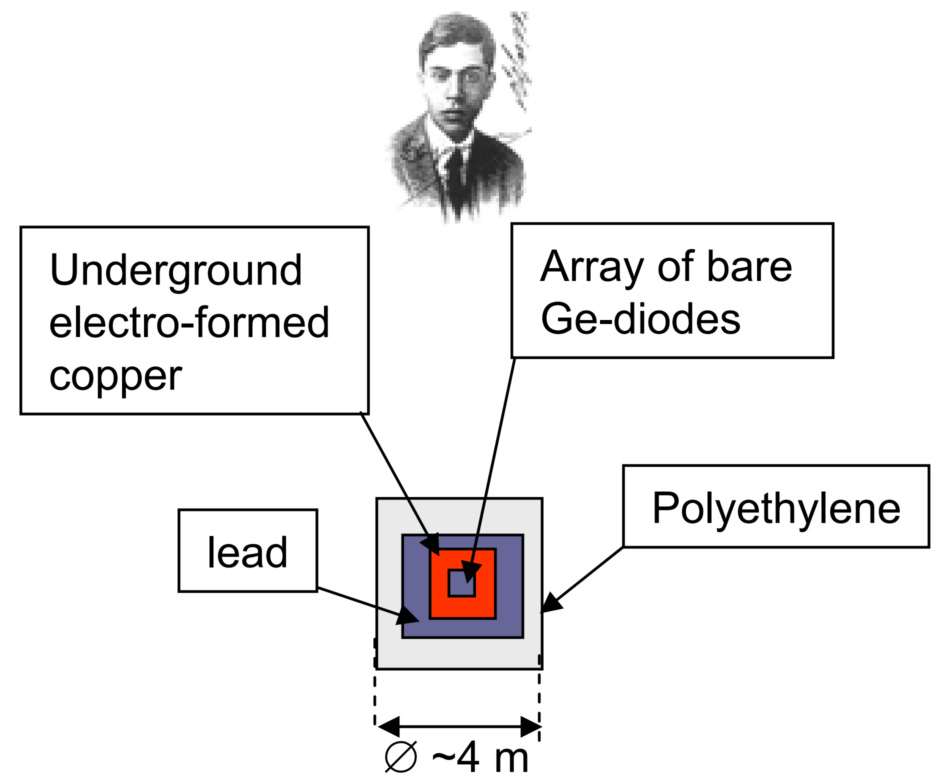
Background reduction:

external bgds: γ, n, residual-μ

GERDA shielding



Majorana shielding

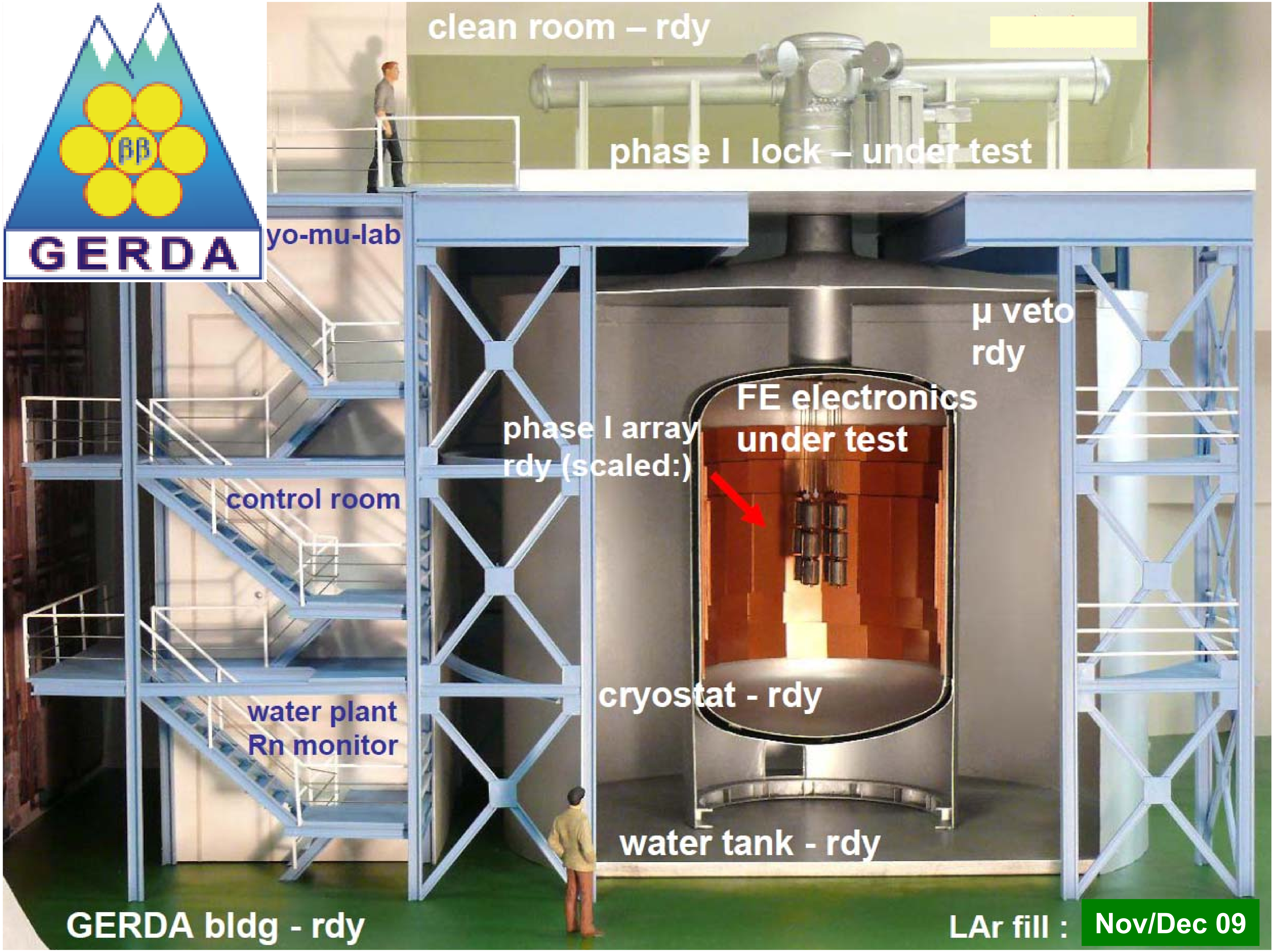


Radio purity of shield <0.1 μBq ^{222}Rn (^{226}Ra)/kg !

N.B.: shield design has impact on μ induced backgrounds

Low-Z shield ⇒LNGS 3400 mwe ok with water Cherenkov μ-veto

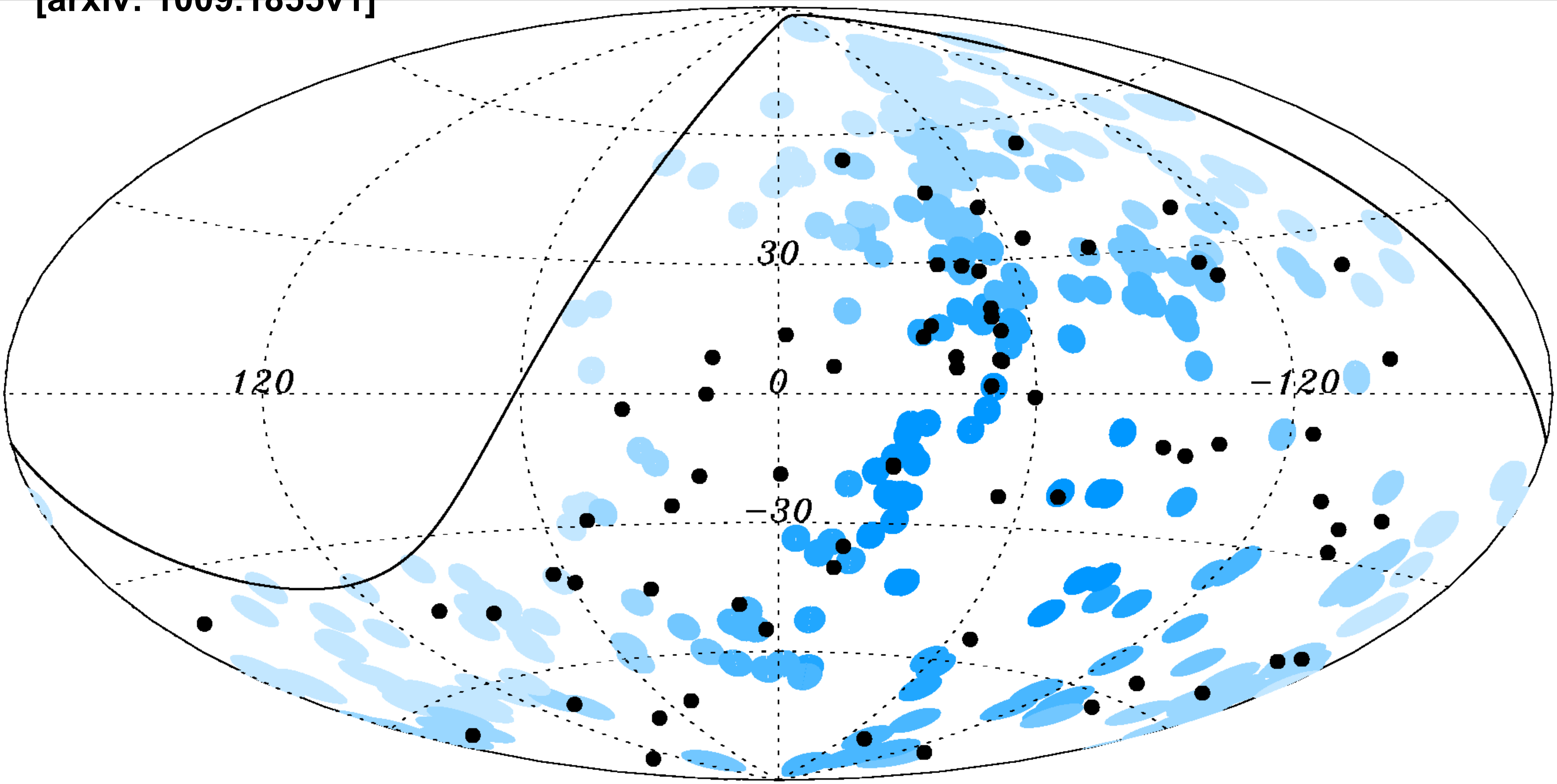
Pb/Cu shield requires depth >4500 mwe ⇒SNOlab, DUSEL


GERDA
ββ
clean room – rdy
phase I lock – under test
yo-mu-lab
μ veto
rdy
FE electronics
under test
phase I array
rdy (scaled:)
control room
cryostat - rdy
water plant
Rn monitor
water tank - rdy
GERDA bldg - rdy
LAr fill :
Nov/Dec 09

Multi-messenger astroparticle physics

the sky in cosmic nuclei

AGN correlation: update; 69 events E>55 EeV
[arxiv: 1009.1855v1]

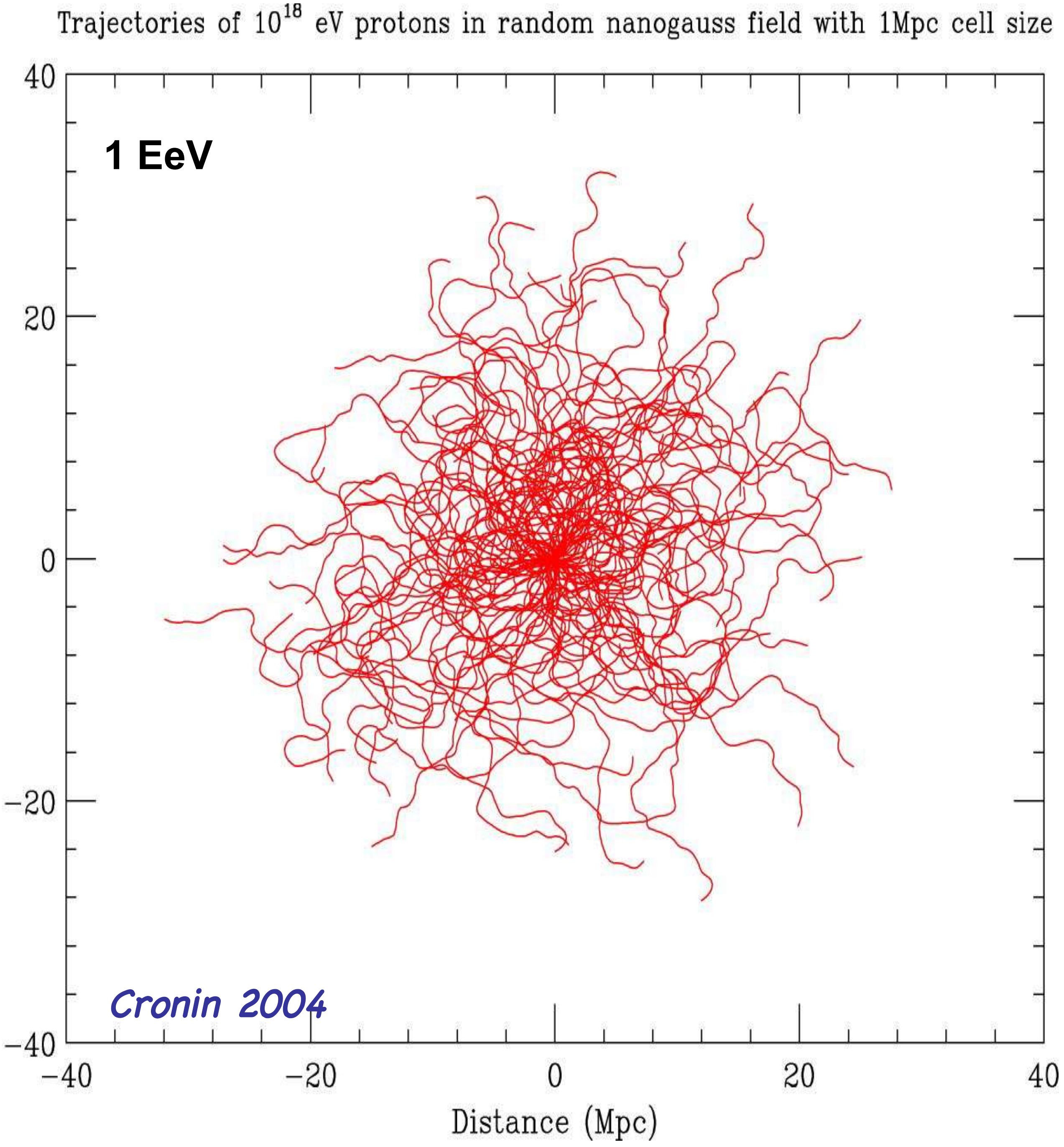


blue: VCV AGNs + 3.1° weighted with exposure, distance less than 75 Mpc
black: 69 events, E>55 EeV, <60° zenith, angular resolution ≤ 0.9°; available as list

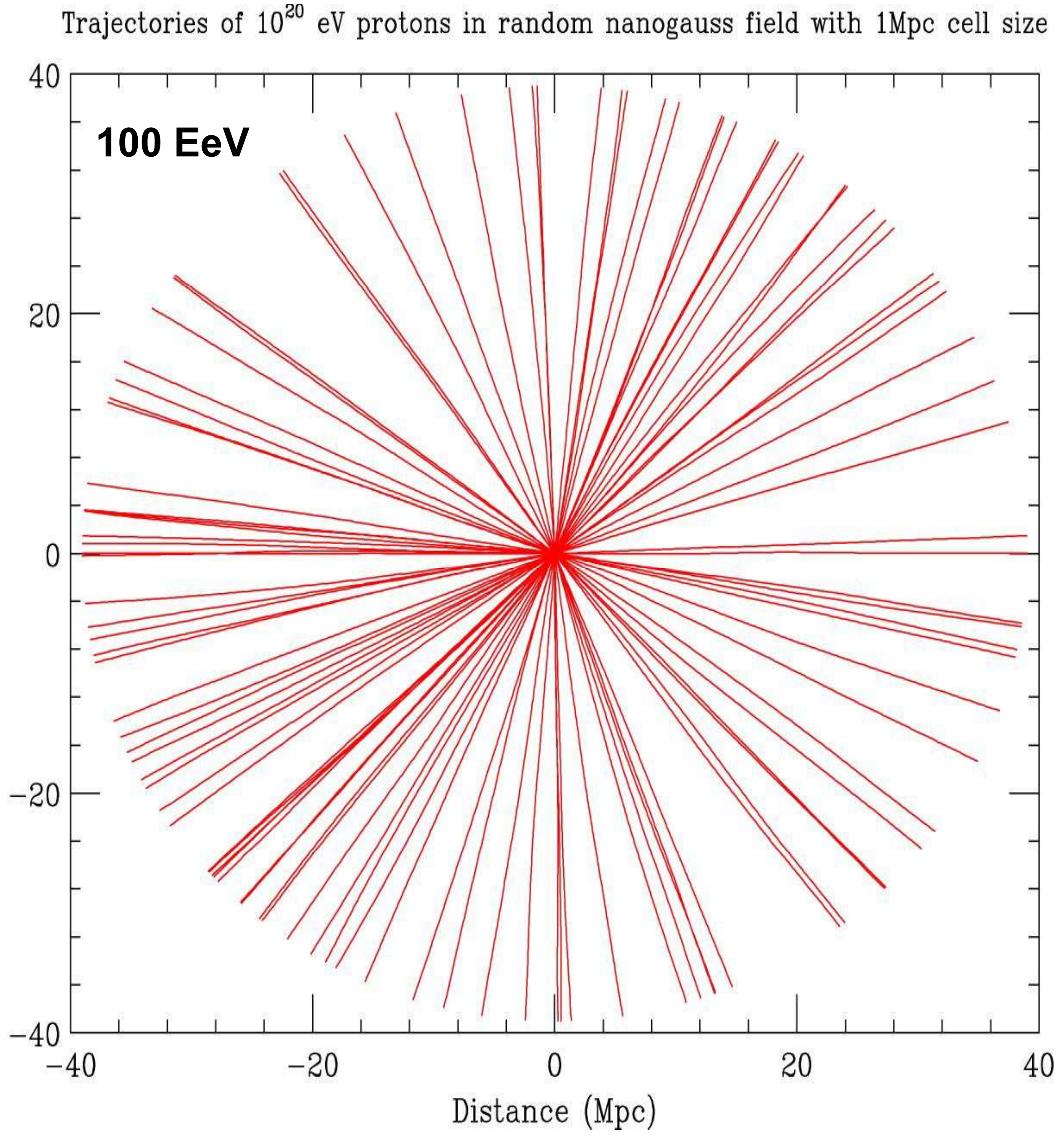
looking far ./. seeing well

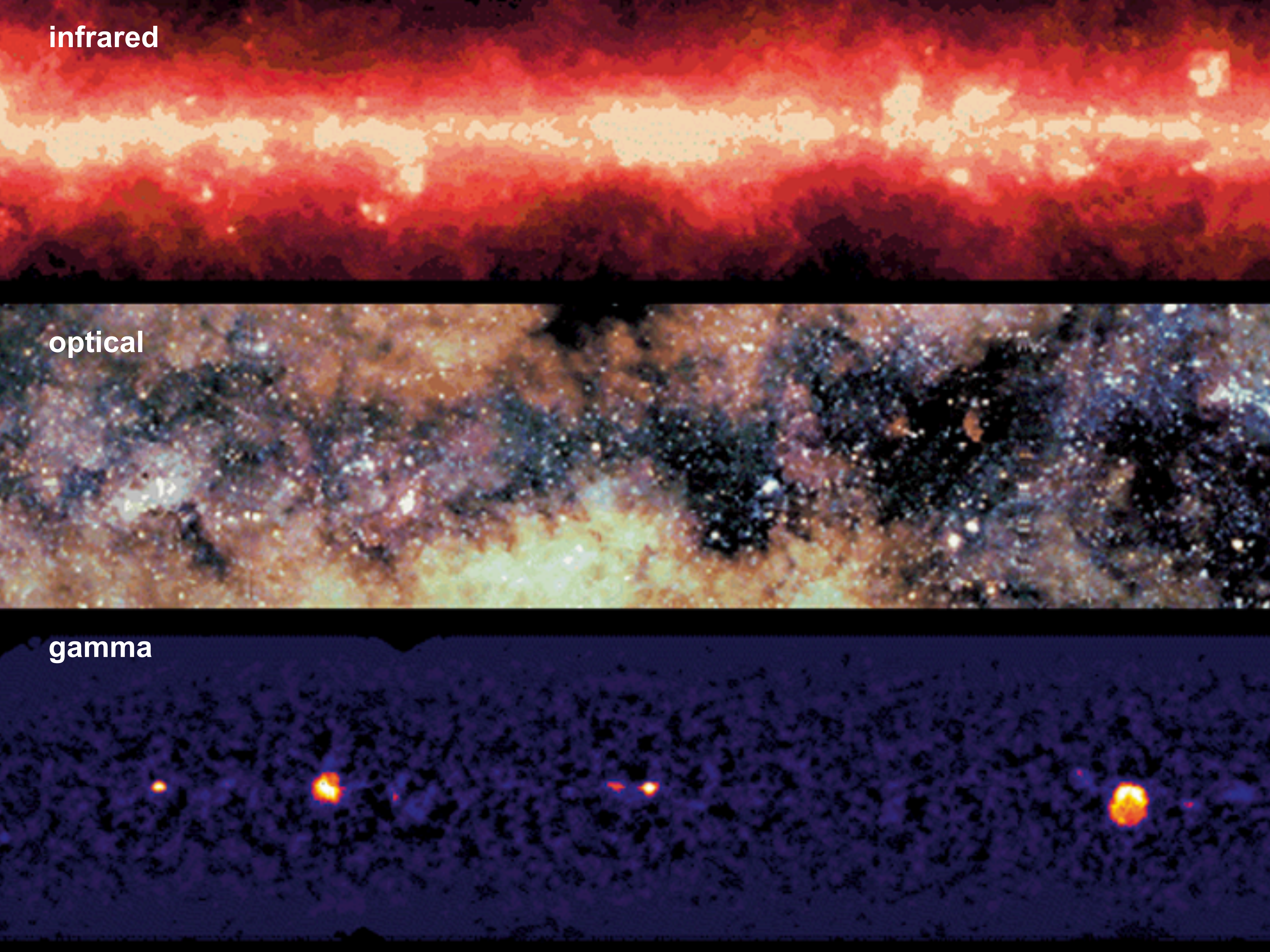
PIERRE AUGER OBSERVATORY

att. length 10,000 Mpc

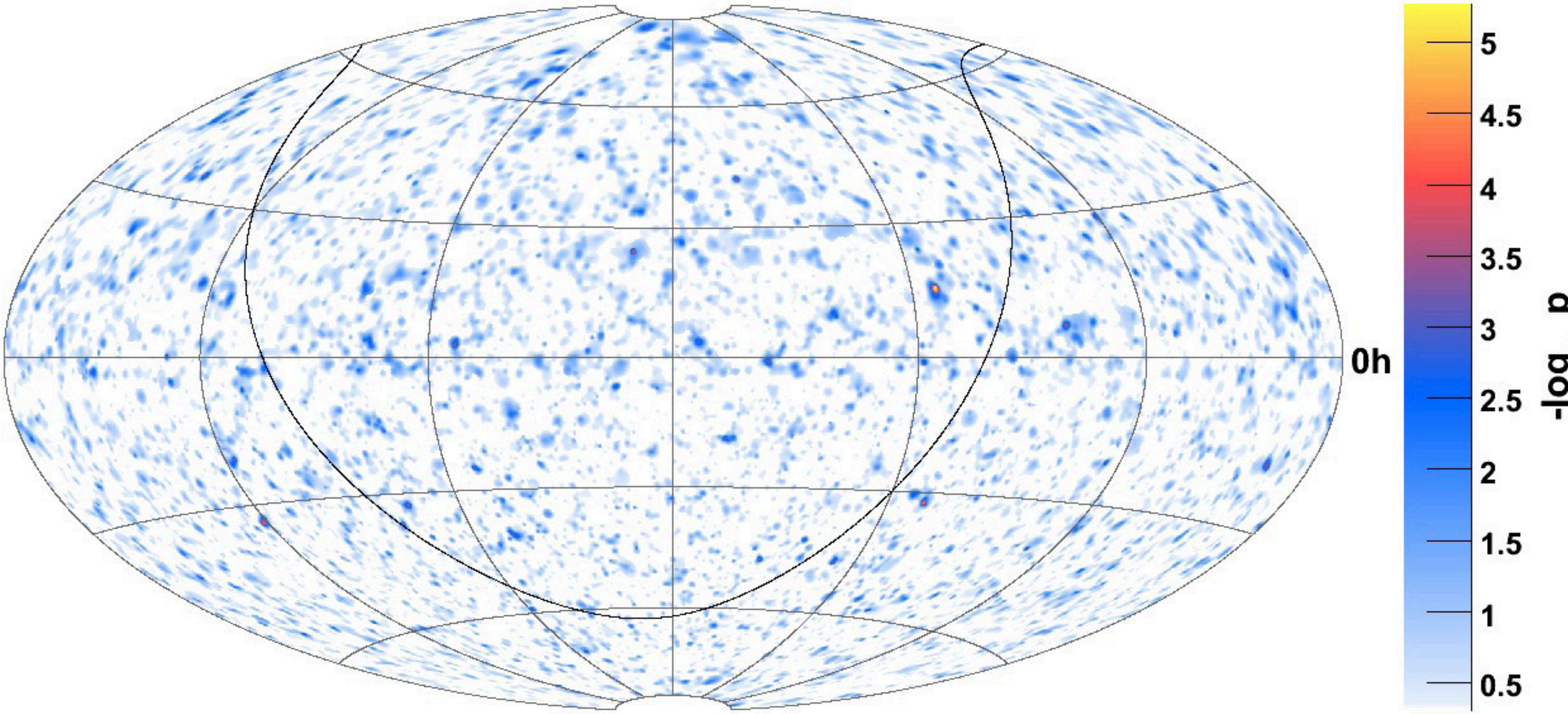


att. length 50 Mpc




infrared
optical
gamma

the neutrino sky -- still all background



particles from the cosmos

messenger	instrument	message
photons	telescopes	sources mostly known not all understood
cosmic rays	particle detectors	sources unknown propagation unknown composition unknown
neutrinos	neutrino telescopes	3 known sources: atmosphere, sun, SN1987a
gravitational waves	resonators, interferometer	not yet detected
Dark Matter	particle detectors	multiple evidence no detection yet

Very interesting but not covered today

- Element synthesis in Big Bang, stars, supernovae, nuclear astrophysics
- Solar neutrino spectroscopy: BOREXINO, LAGUNA, ...
- Neutrino oscillations to pin down the MNS-matrix
- Satellite projects for x-ray and gamma astronomy
- Supernovae, universe expansion, Dark Energy, ...
- Cosmology and astroparticle physics
- "Forward physics" at colliders to improve air shower models
- Anything else

Synthesis

- Astroparticle physics is a great integration effort
- We have gained much deeper insights into the connections between quarks and cosmos
  - More will follow
- Many large projects are conducted outside established laboratories...; important aspect for daily life!
- The role of detectors is – of course – of utmost importance.
  - At least three extremes: extremely harsh operating conditions - extremely large systems - extremely high precision
- You/we have exciting times ahead!