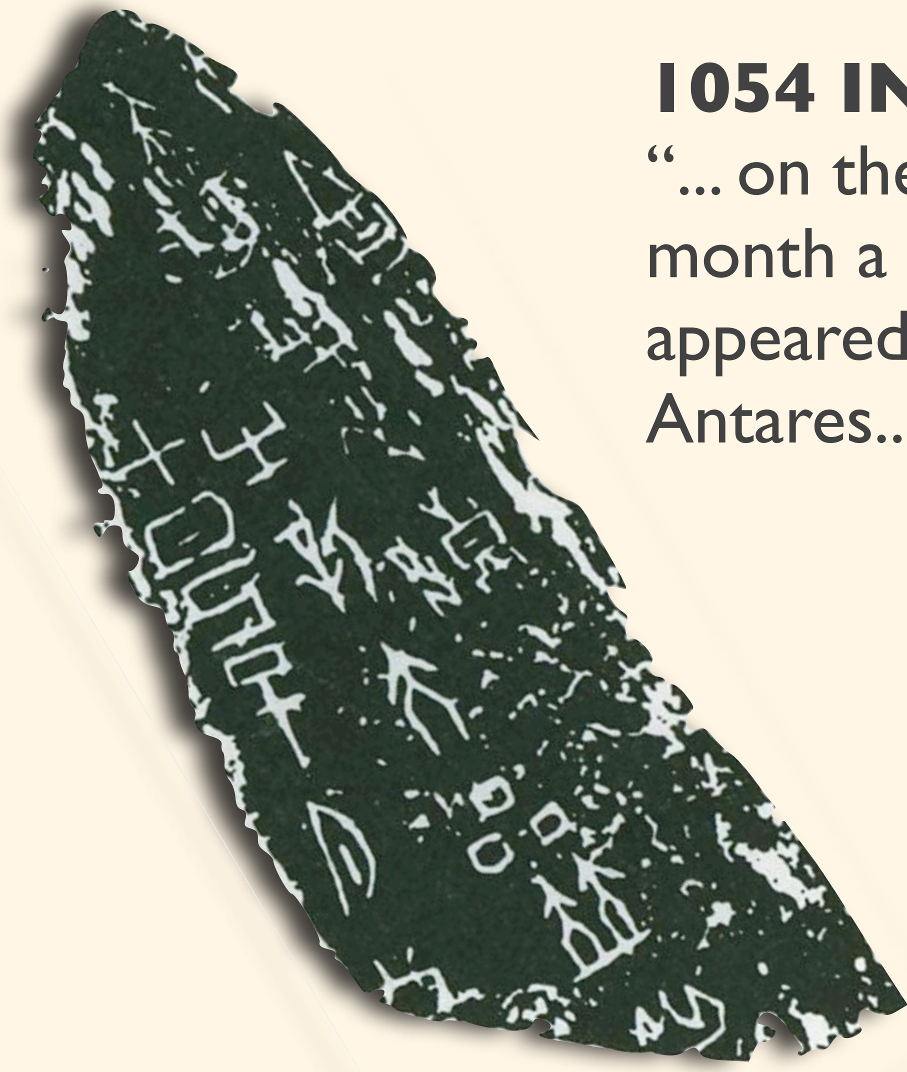
Perspectives and challenges in Astroparticle Physics

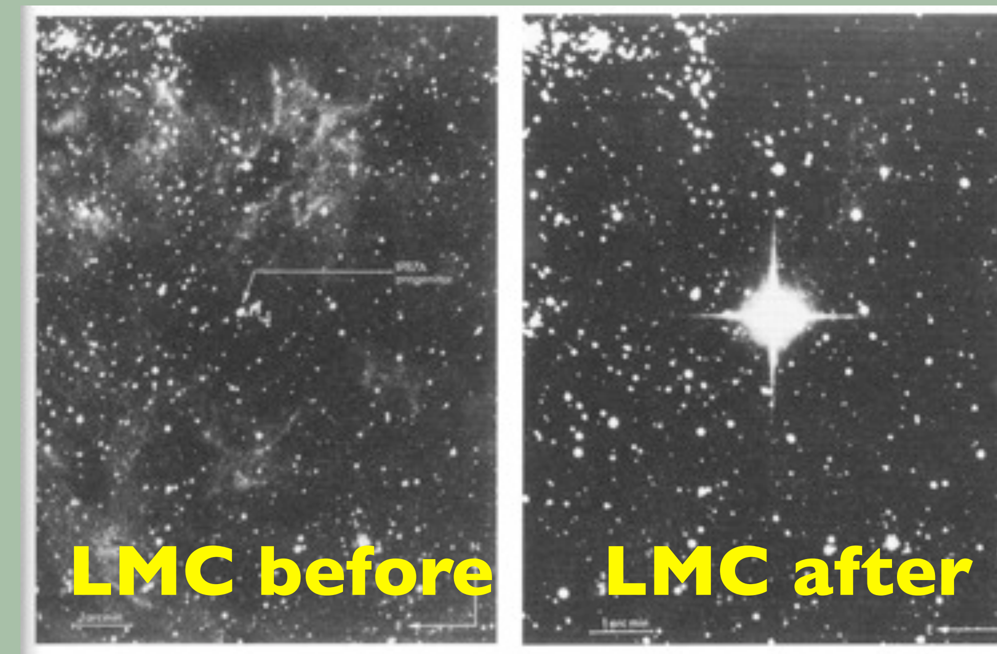
Johannes Blümer, KIT

European Summer Institute 2011
Karlsruhe, July 11, 2011

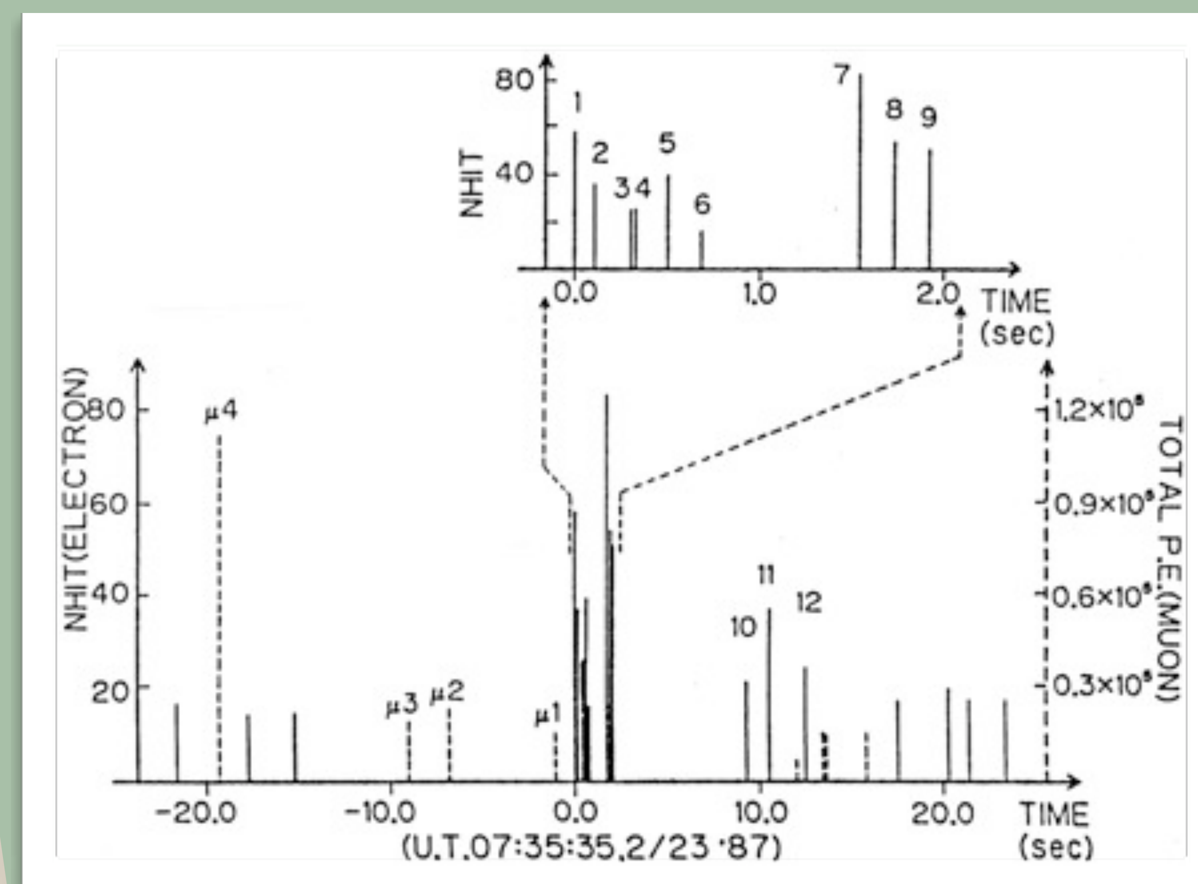
KIT-Center Elementary Particle and Astroparticle Physics KCETA



1054 IN CHINA:
"... on the 11th of the month a new star appeared near Antares..."

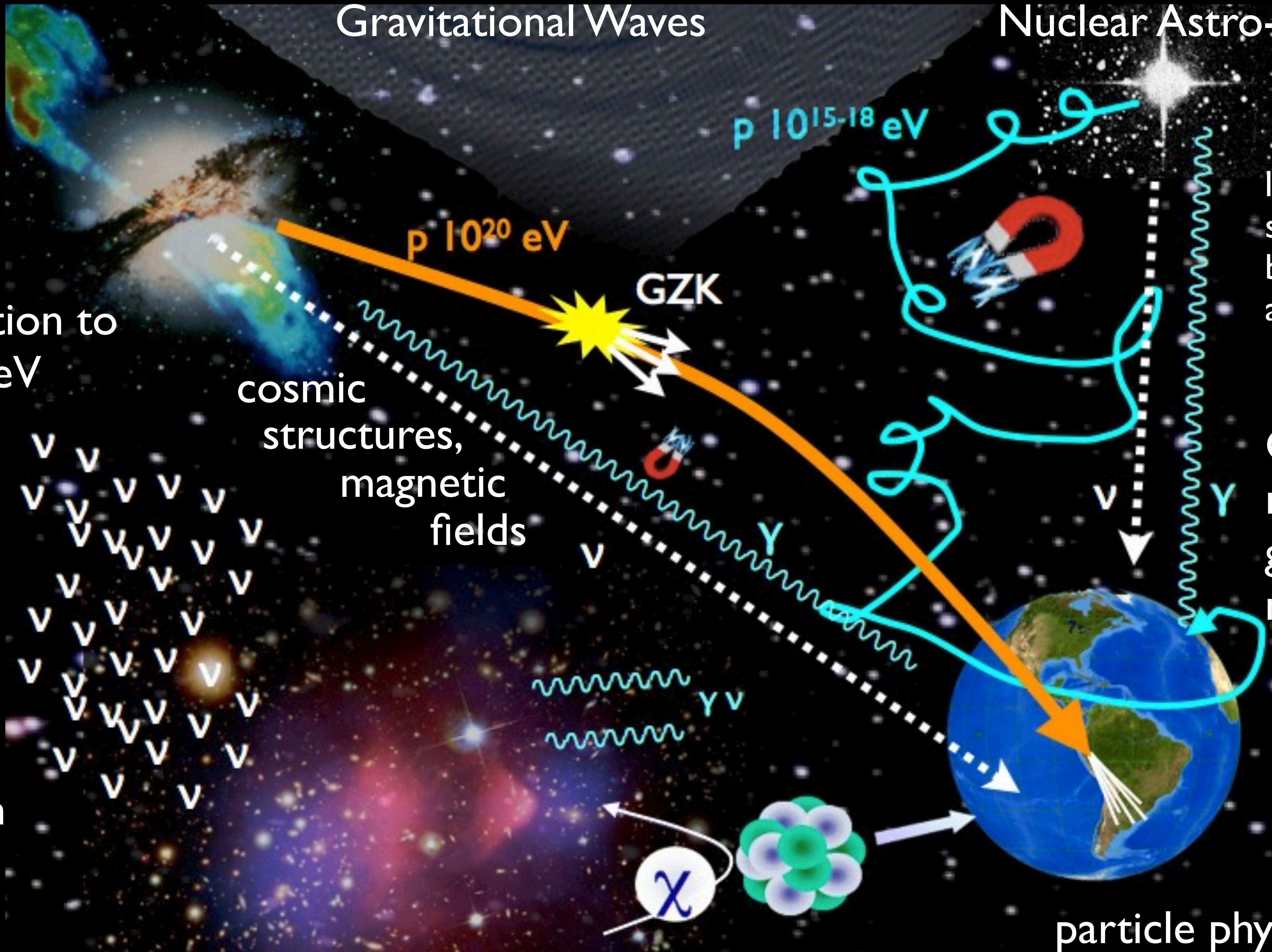


Today: the famous Crab nebulus



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."

This is Astroparticle Physics



Acceleration to 10^{20} eV

low-energy satellite based astrophysics

Cosmic rays, gammas, neutrinos

Relic ν, structure formation ν mass

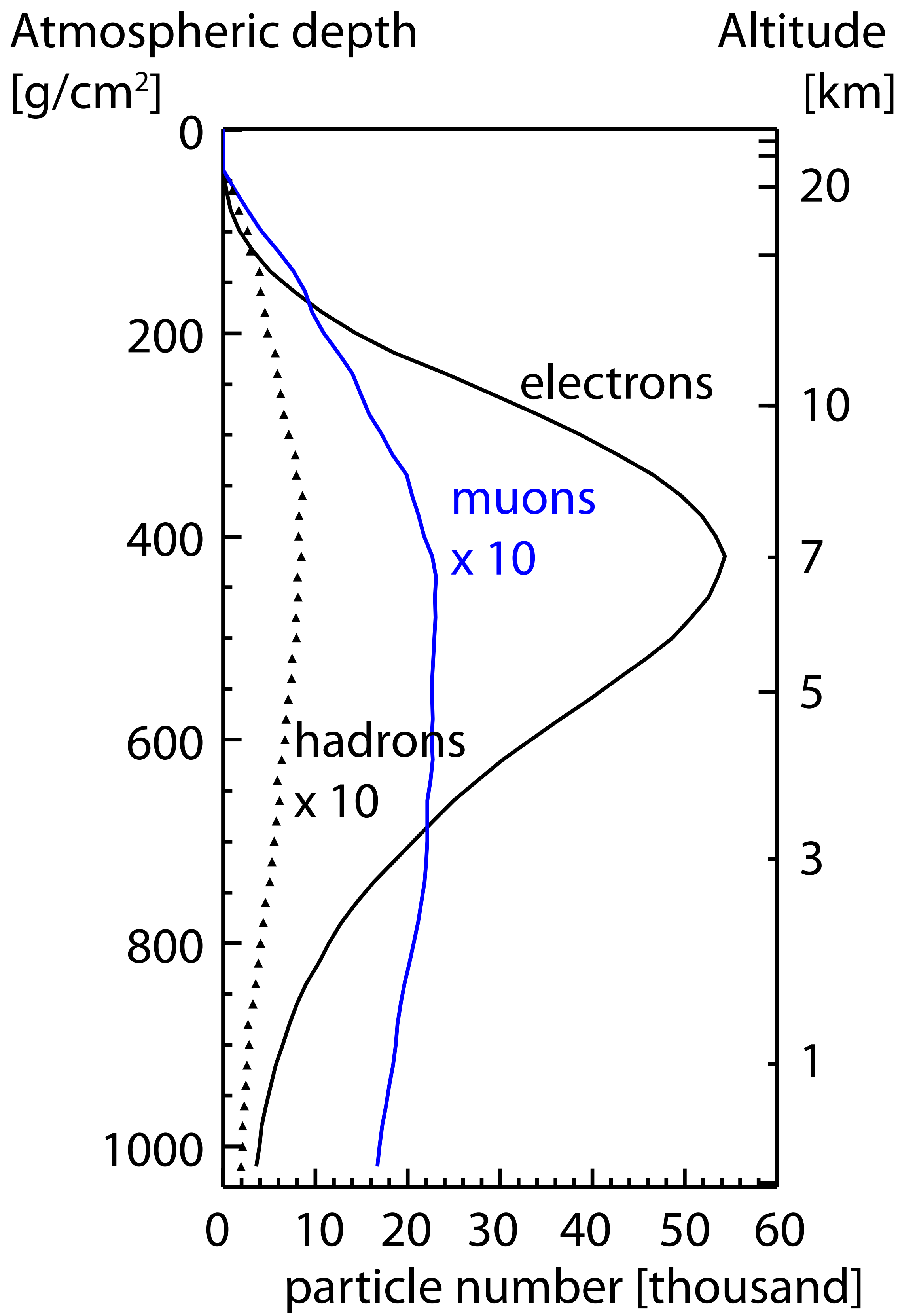
Dark Matter

particle physics at 400 TeV in the c.m.s.

pνγχ: multi-messenger approach

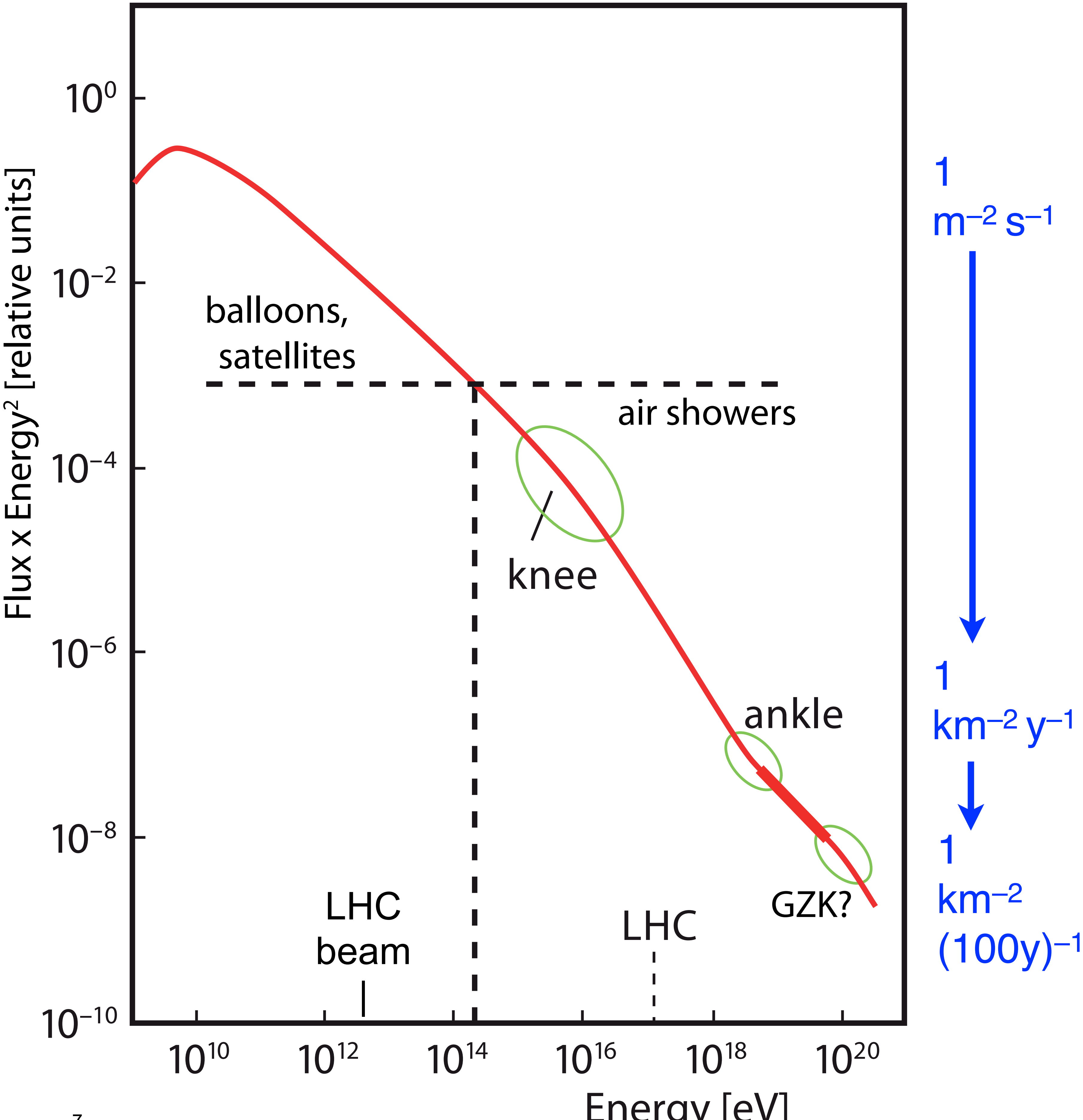
Cosmic radiations: nuclei


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

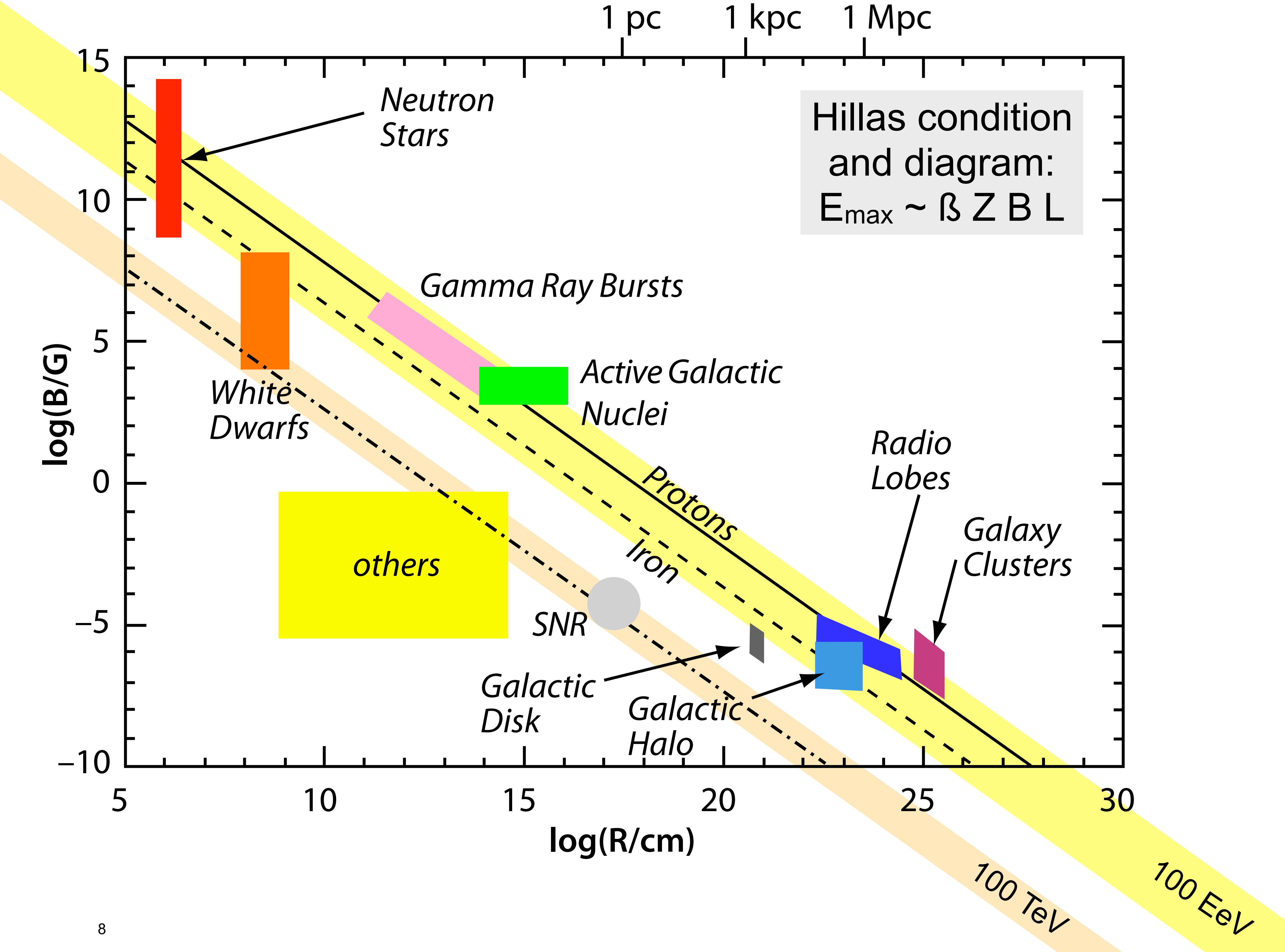
knee: p drop out first; end of SN acceleration?

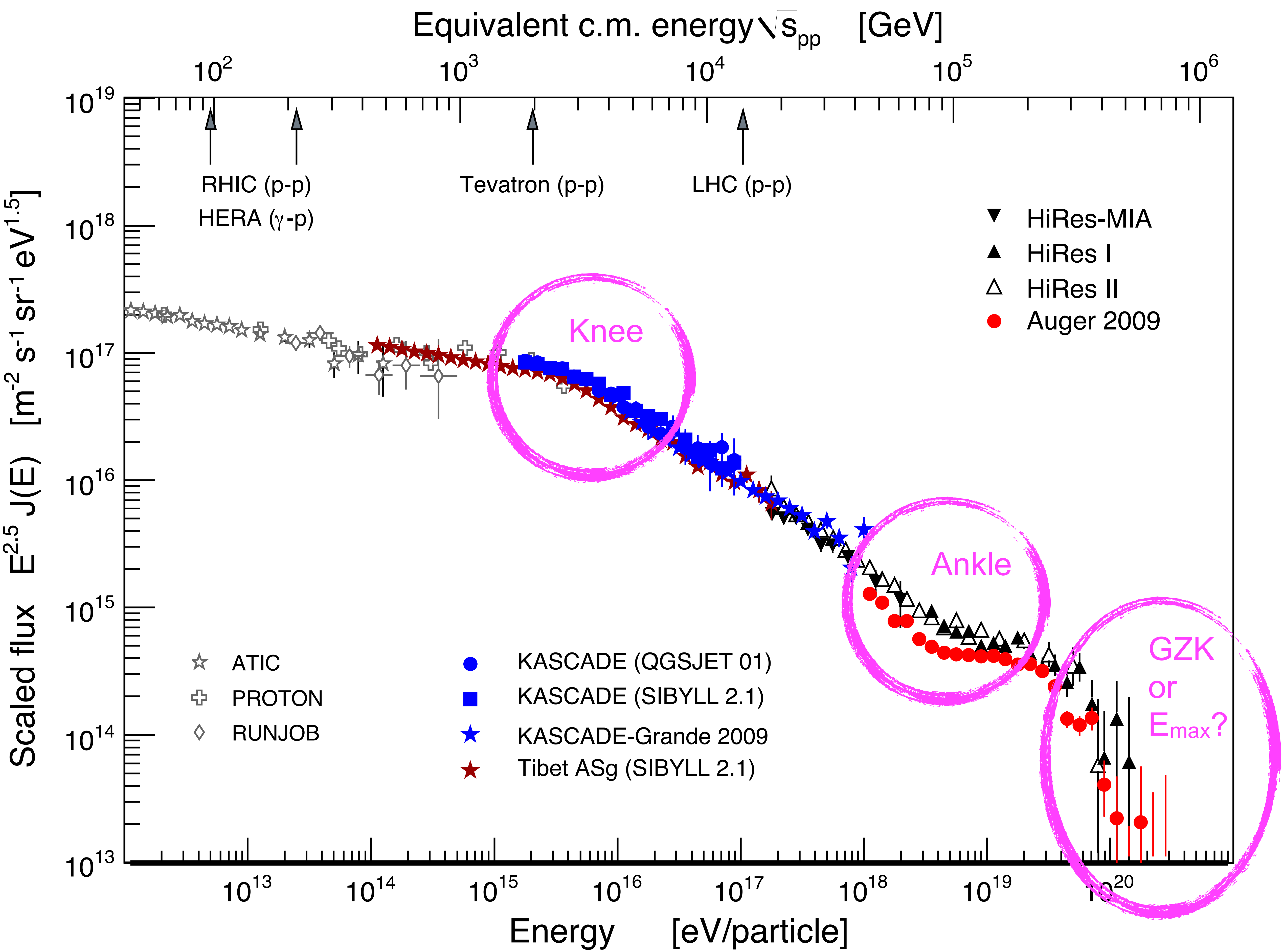
isotropic directions

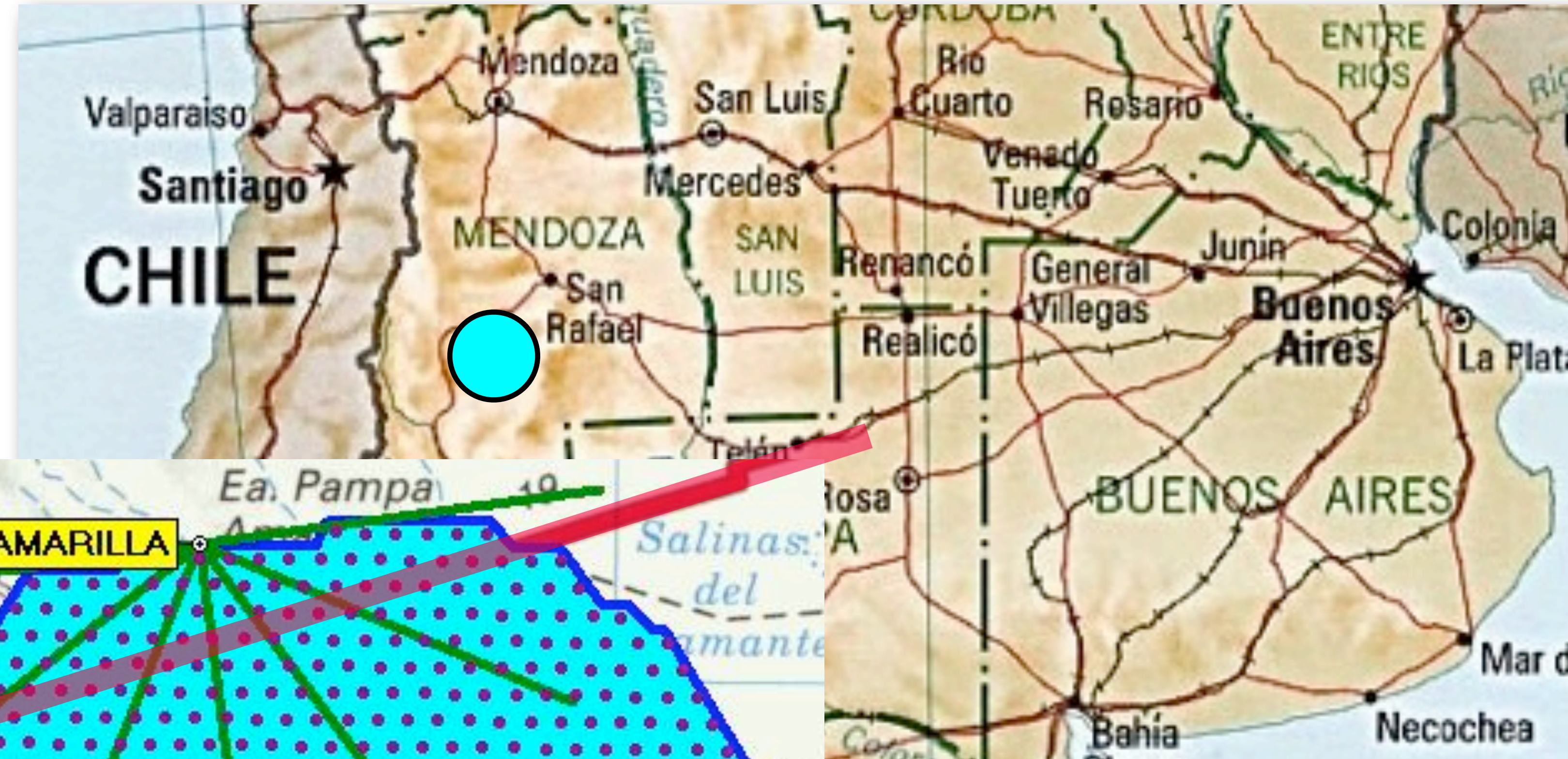
ankle: harder component, extraglactic

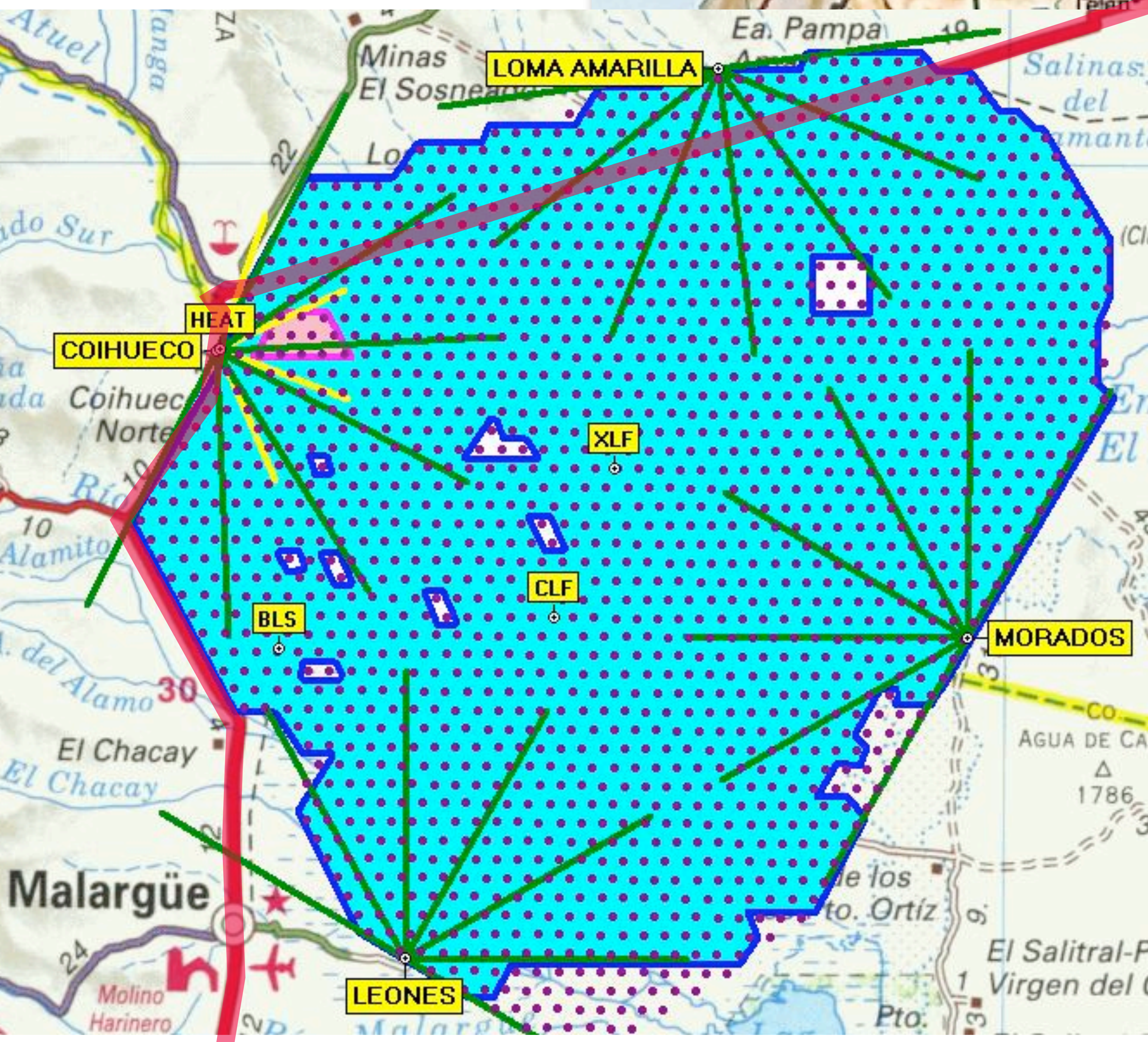
GZK: flux suppression above 60 EeV

composition?
sources?
propagation?
particle physics?


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


Equivalent c.m. energy √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
Emax?
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]

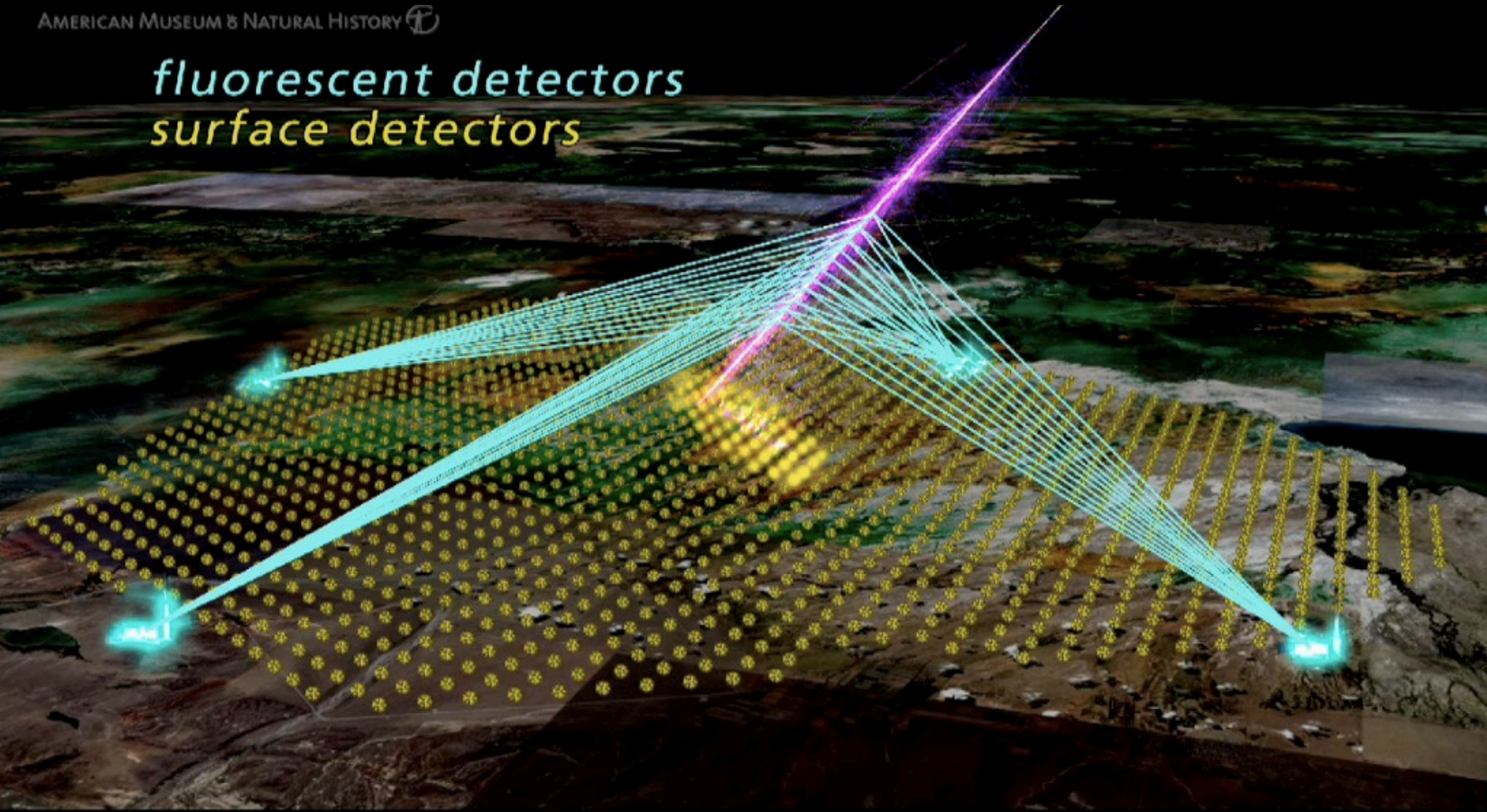




1660 water Cherenkov detectors covering 3000 km^2

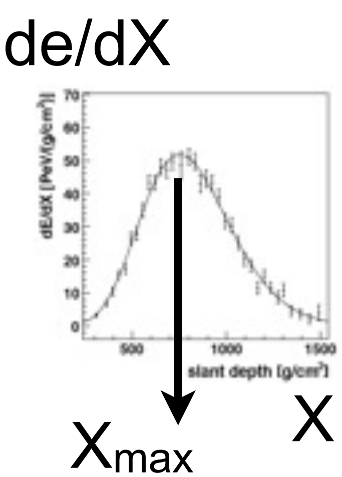
4 x 6 fluorescence telescopes


PIERRE
AUGER
OBSERVATORY

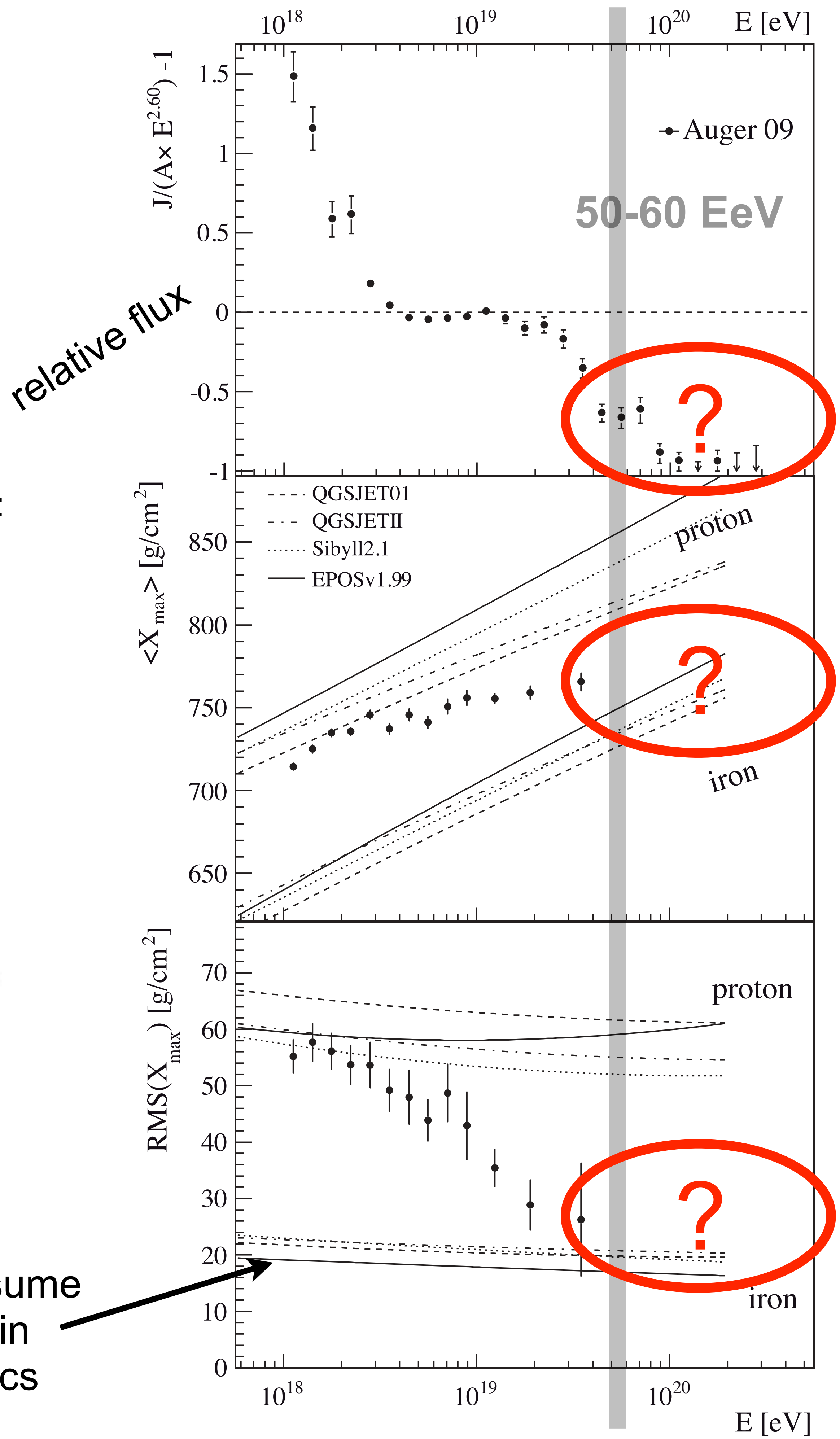

AMERICAN MUSEUM & NATURAL HISTORY
fluorescent detectors
surface detectors

spectrum: convoluted information about sources, particles and propagation

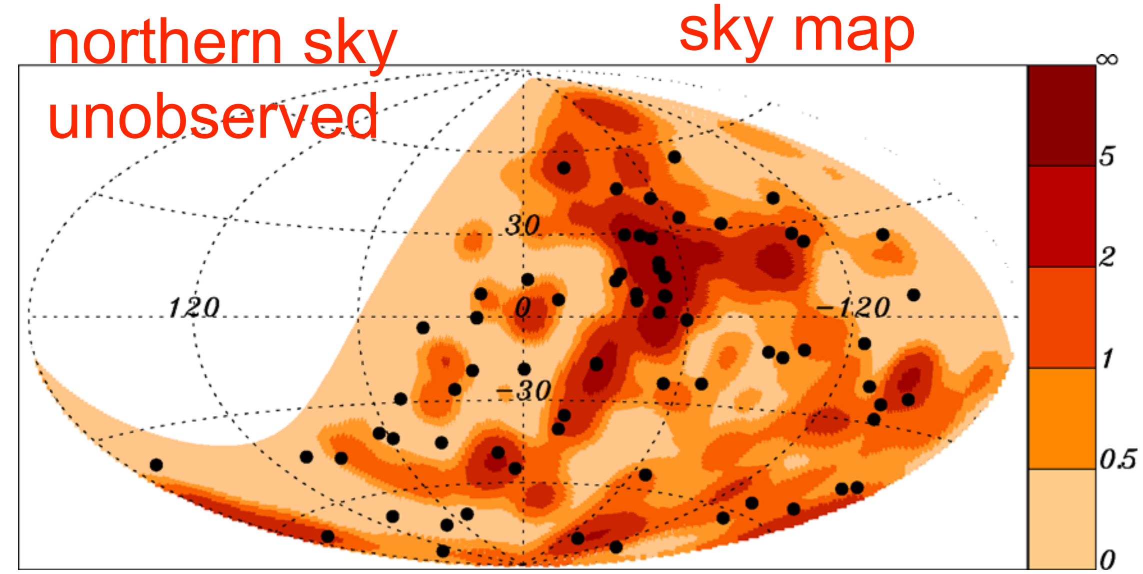
shower profile: independent, best estimator of primary particle mass



models assume no change in basic physics



few events in sky map



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

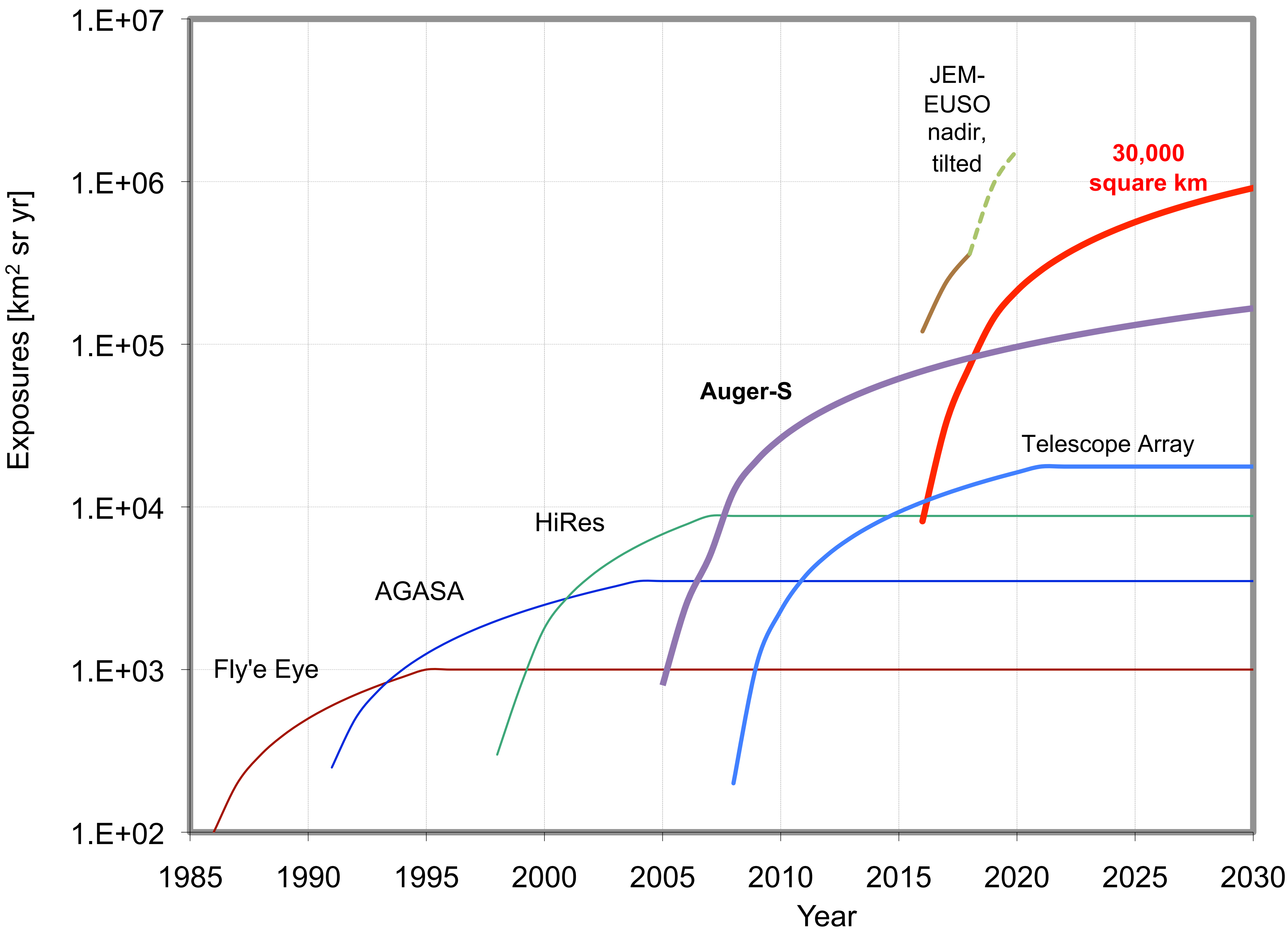
composition at and above the GZK threshold?

alternative explanations like increasing cross section?

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

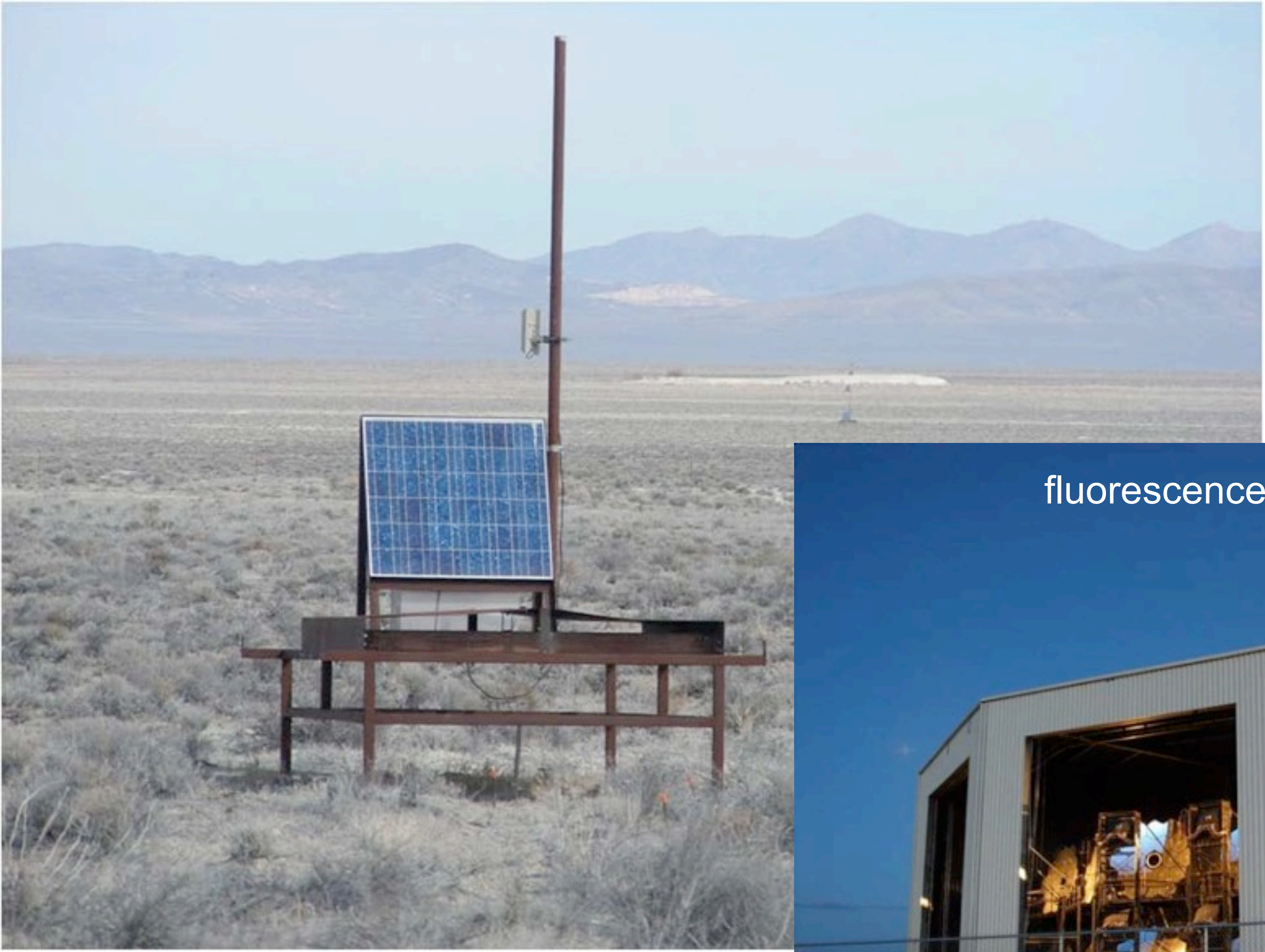
Addressing these questions needs much more statistics at the highest energies, i.e. a much larger area

Exposures

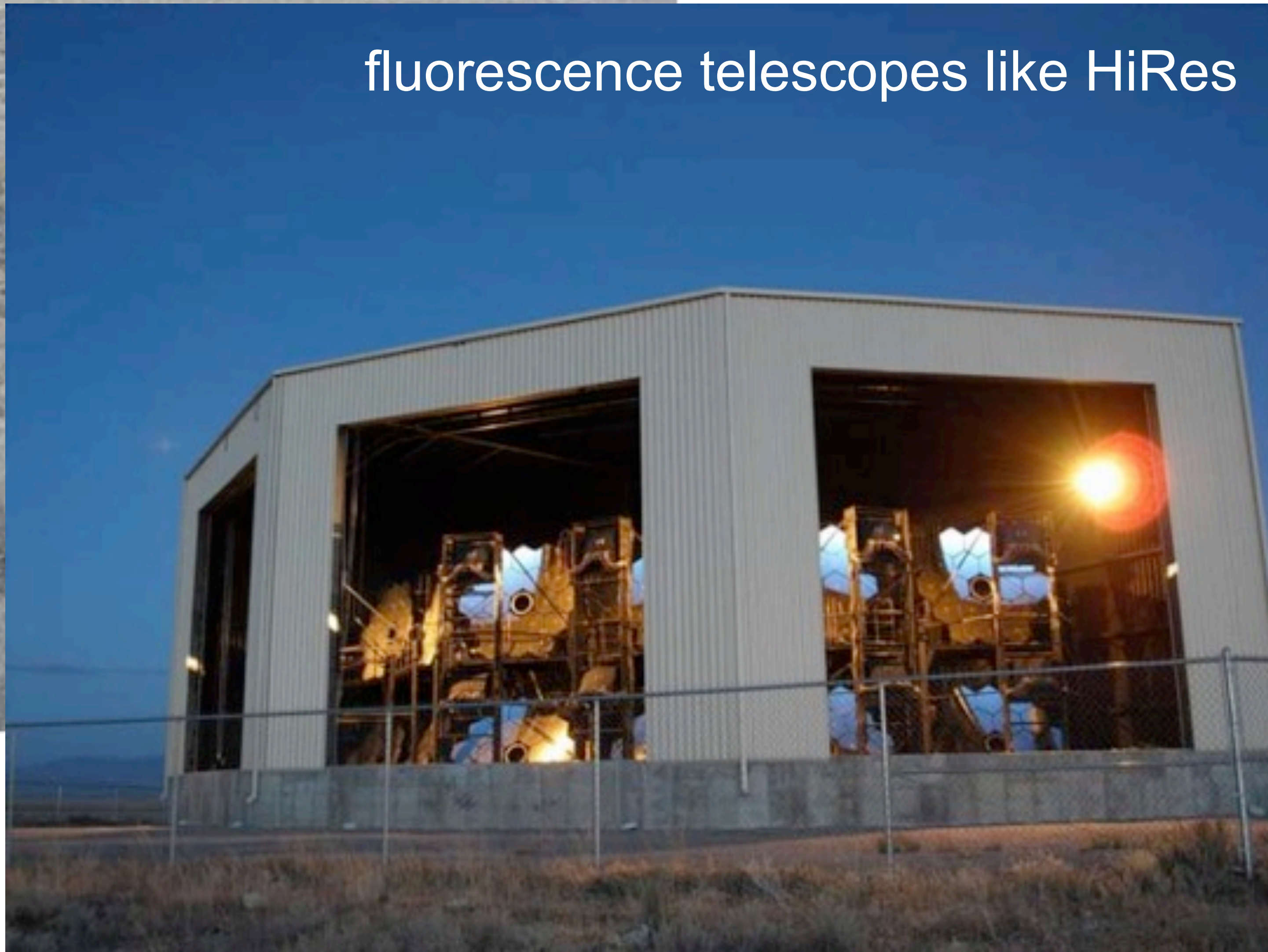


1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
Exposures [km² sr yr]
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
JEM-
EUSO
nadir,
tilted
30,000
square km
Auger-S
Telescope Array
HiRes
AGASA
Fly'e Eye

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

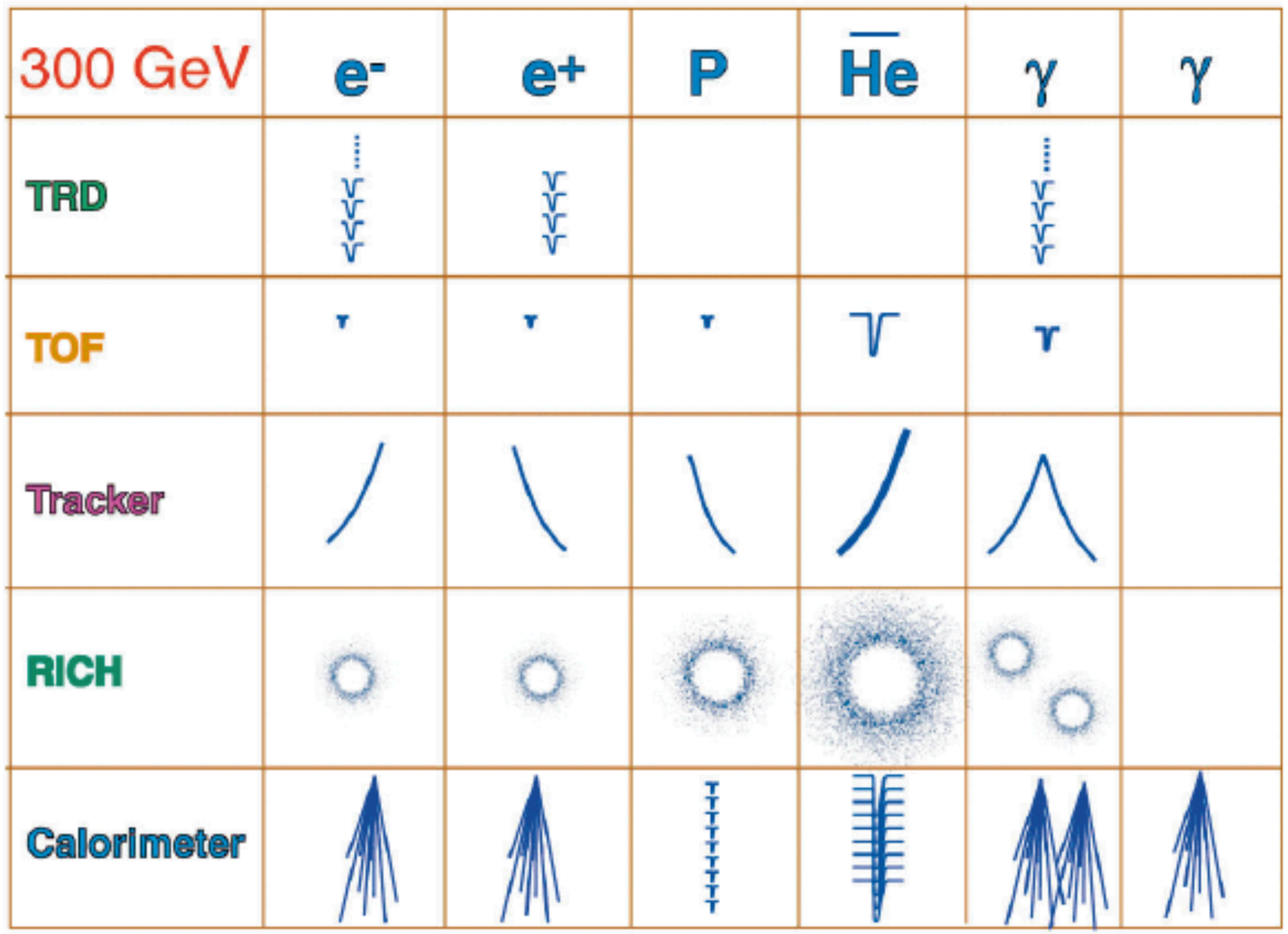


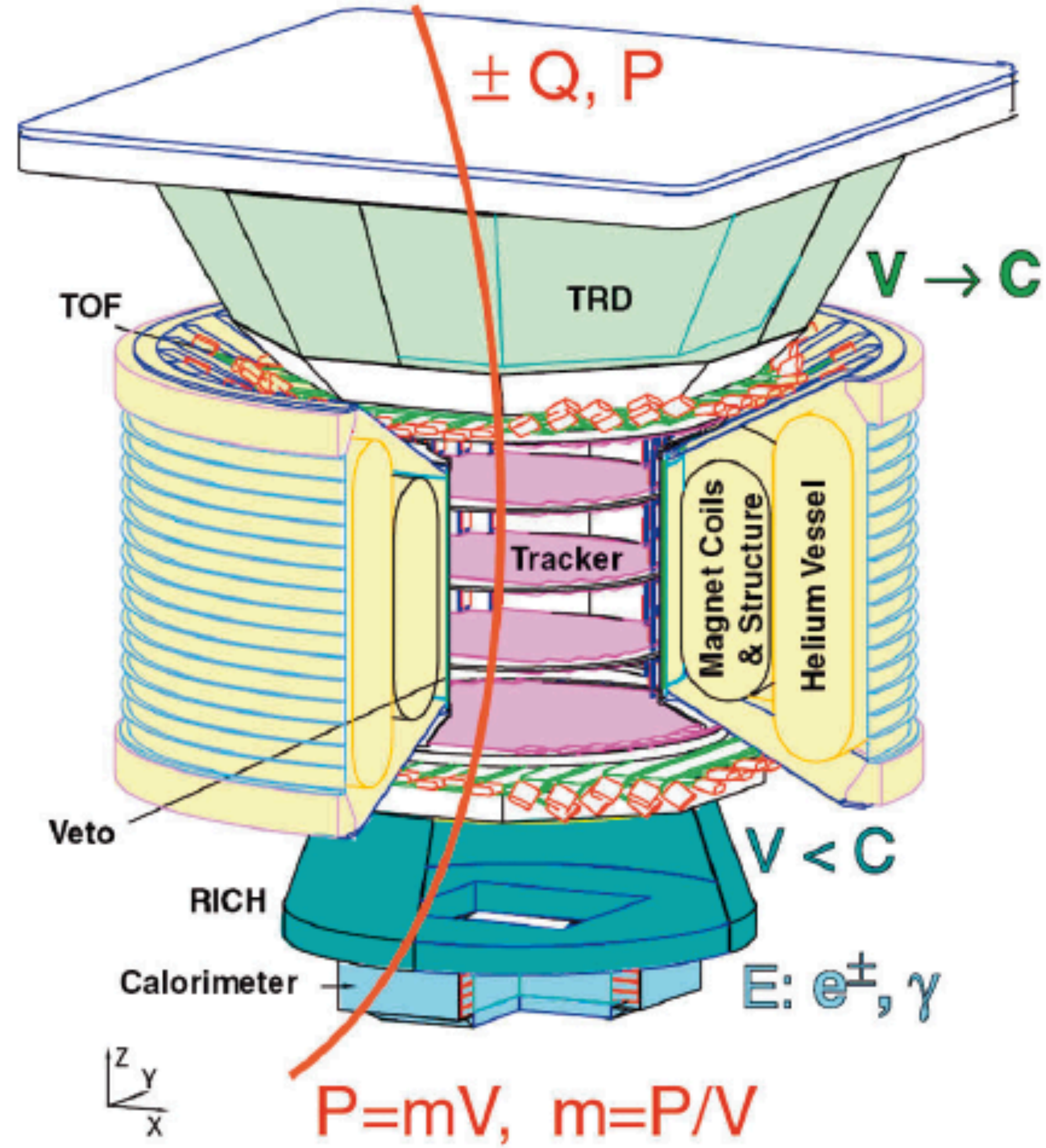
scintillators like AGASA



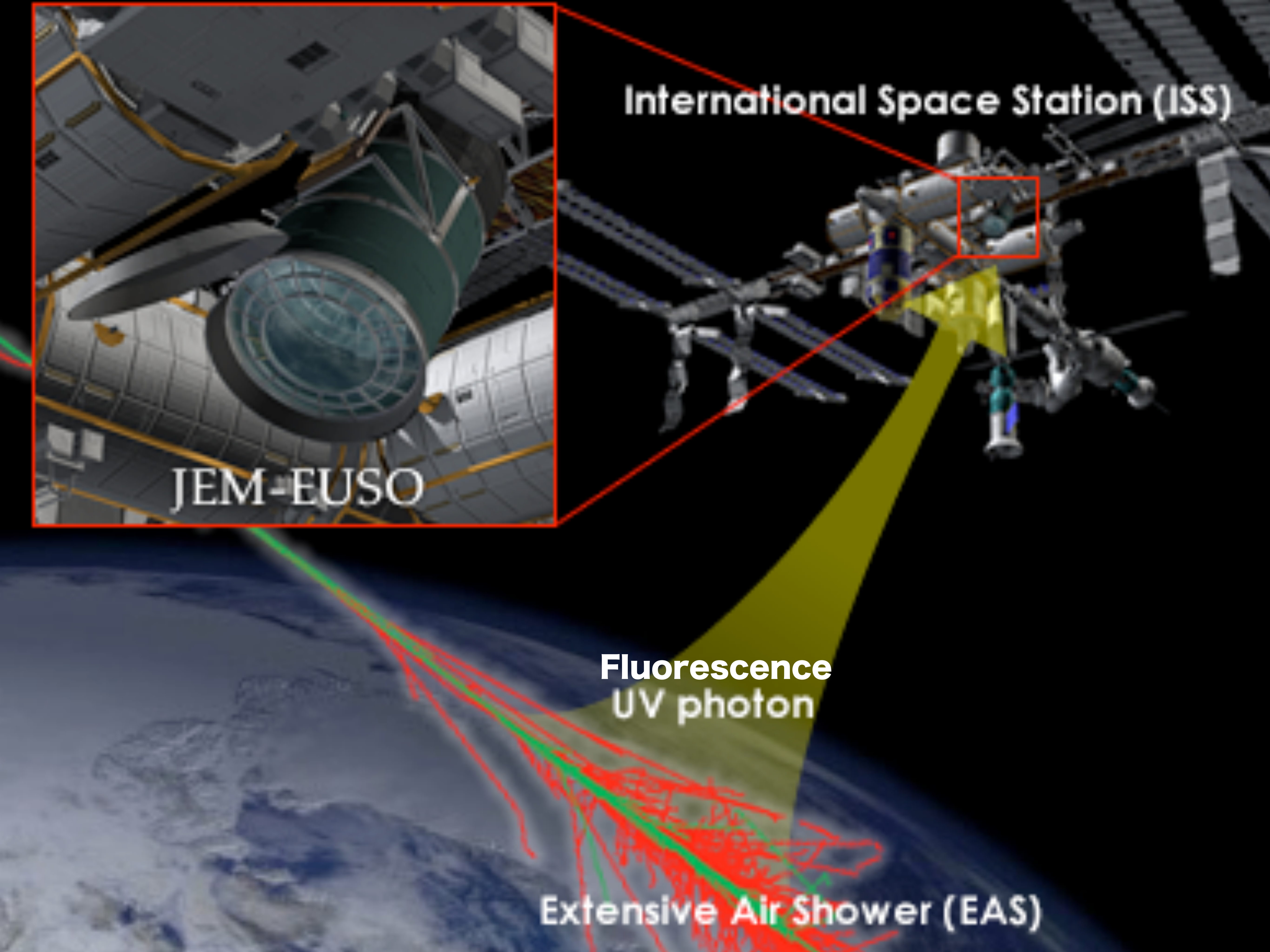
fluorescence telescopes like HiRes

AMS (long at CERN)



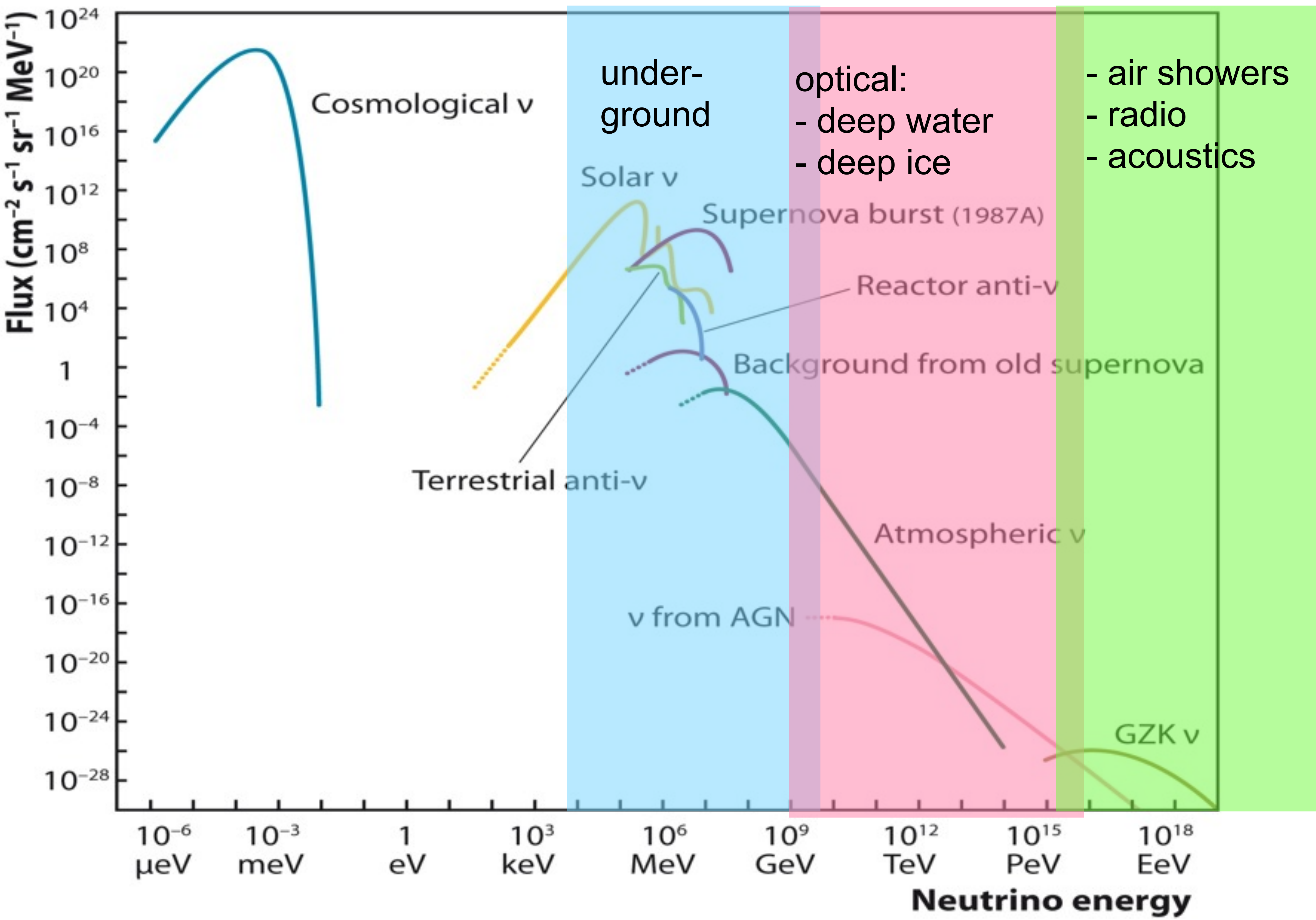


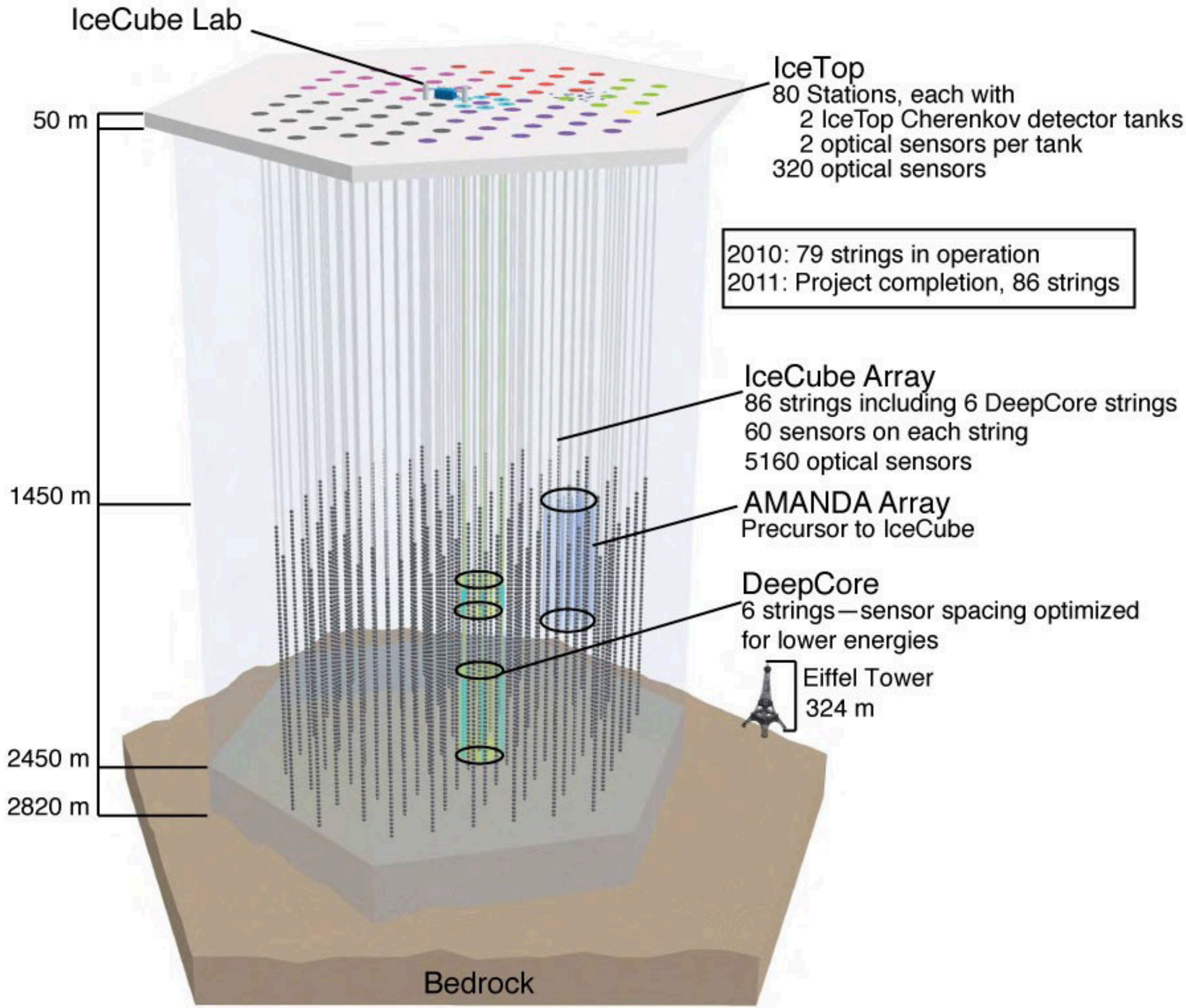
even a single anti-Helium nucleus would be a sensation


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

Cosmic radiations: neutrinos

Fluxes of cosmic neutrinos

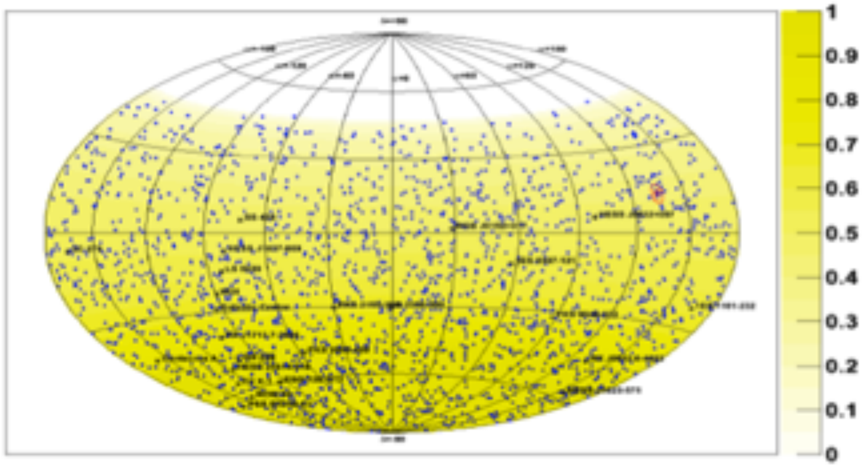




IceCube Lab
IceTop
80 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
320 optical sensors
50 m
2010: 79 strings in operation
2011: Project completion, 86 strings
IceCube Array
86 strings including 6 DeepCore strings
60 sensors on each string
5160 optical sensors
1450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

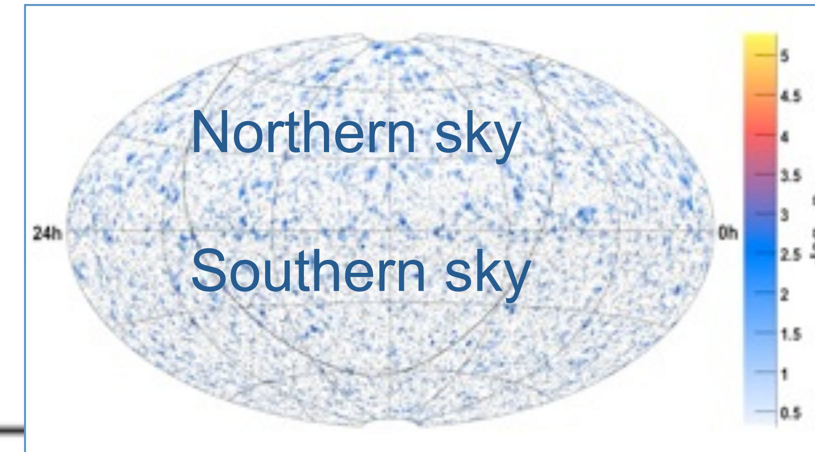
A factor 1000 in 12 years!

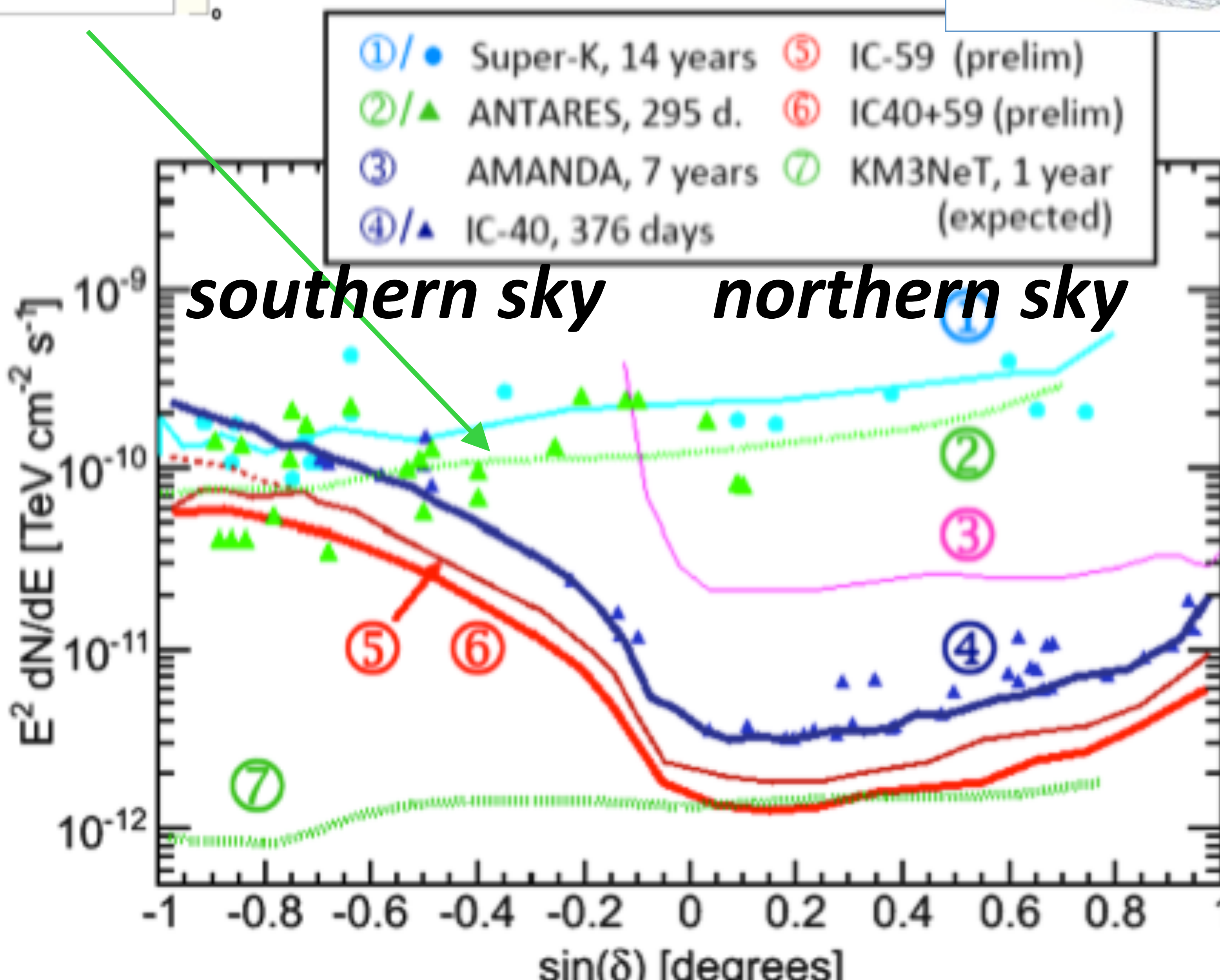
HELMHOLTZ ASSOCIATION
Alliance for Astroparticle Physics

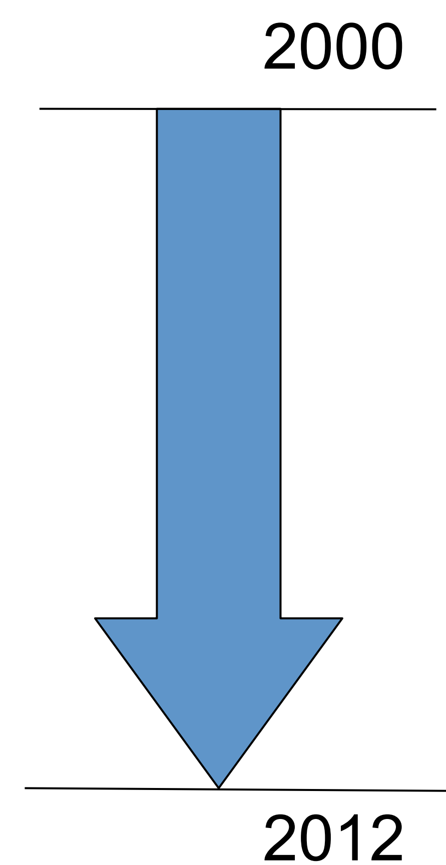


ANTARES

IceCube-40







LENA

- Low Energy Neutrino Astronomy

White Paper to be released in April 2011 !

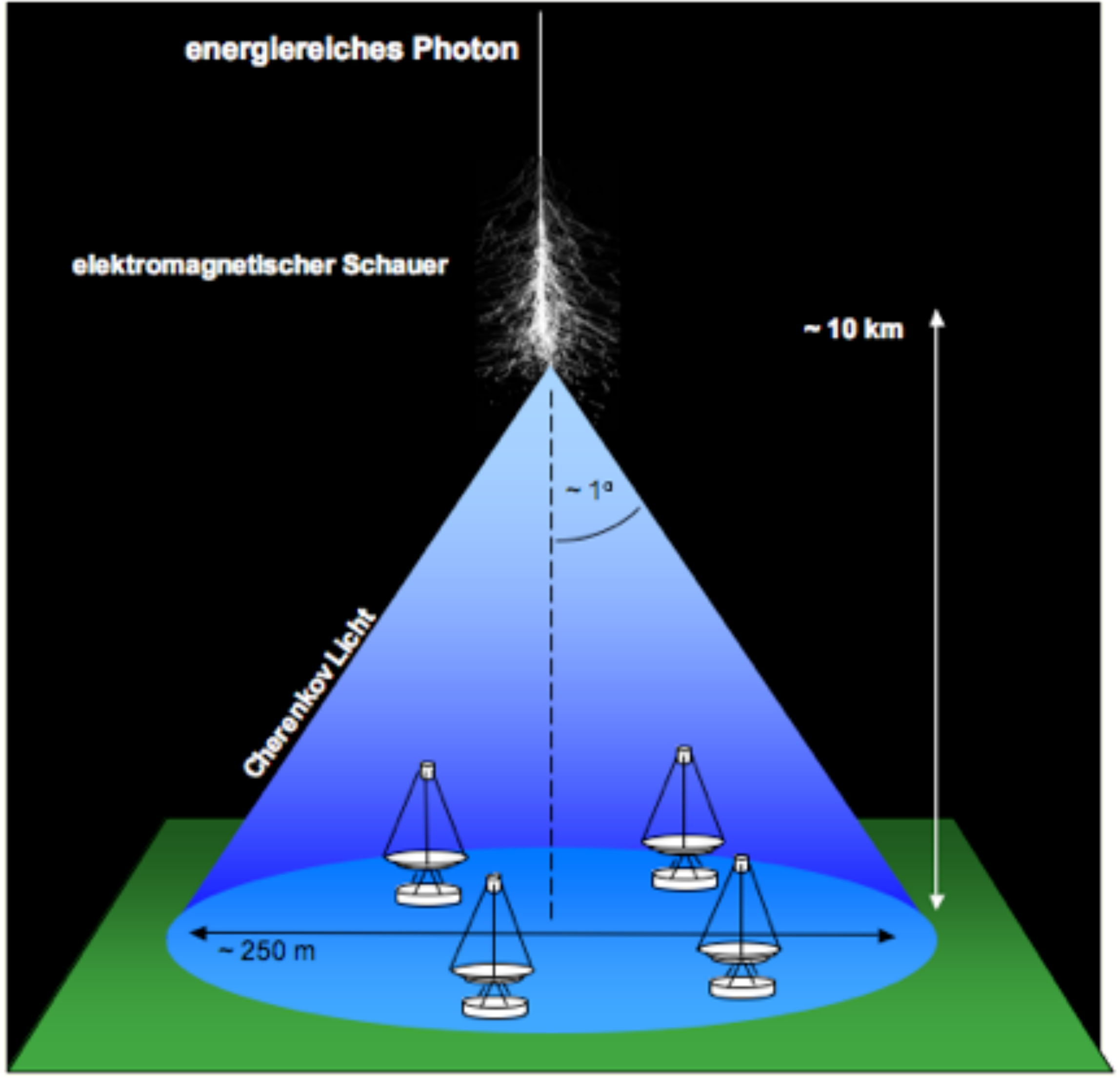
- 50 kt liquid scintillator
- height: 100 m
- Pyhäsalmi mine in Finland (likely)

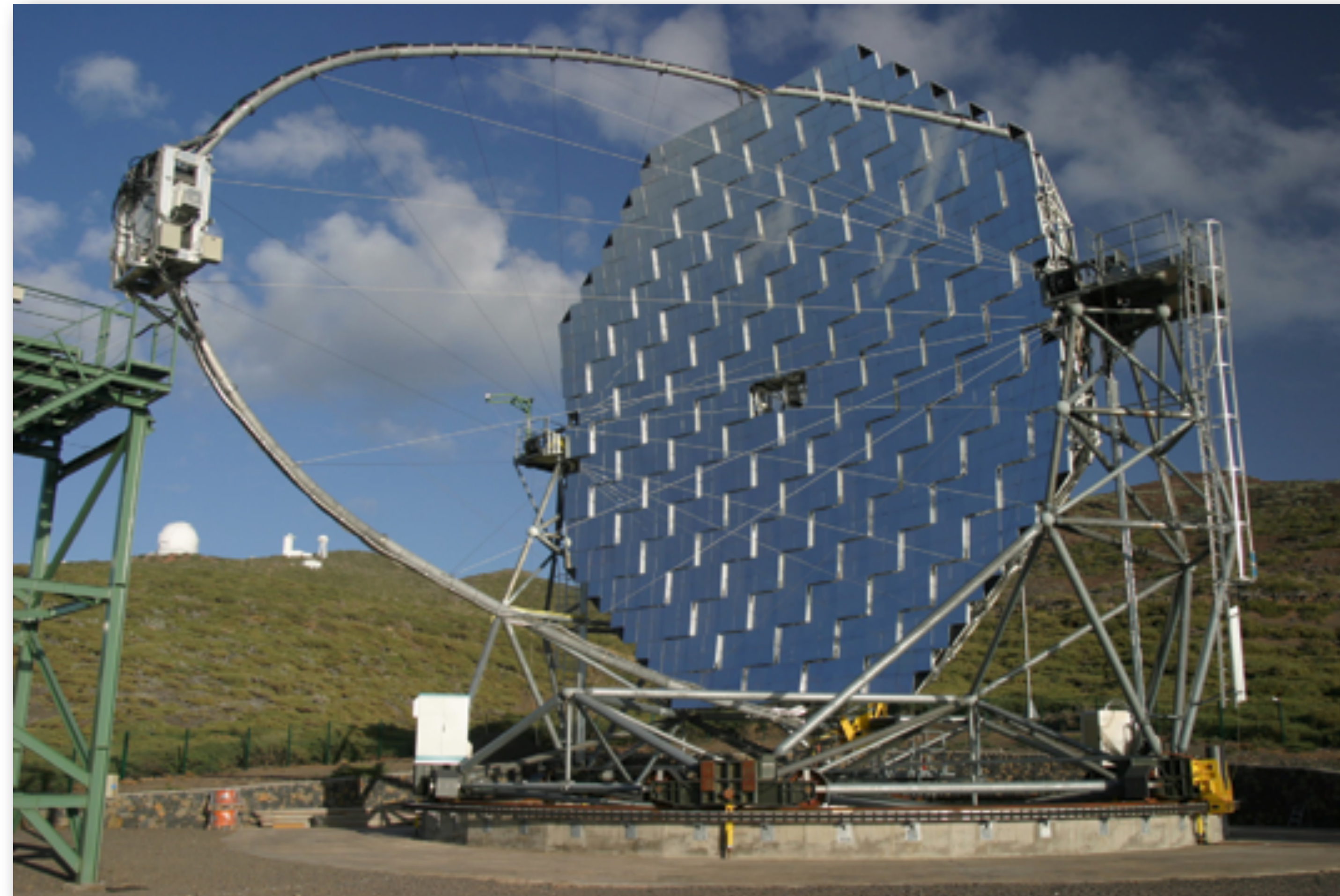
R&D in HAP:
- Readout el.
- PMT

- SN in CG: ~ 20,000 ν
- Solar ν: ~10,000 per year
- p-decay, 10 years: $\tau_p > 4\times10^{34}$ yrs
- SN-relic neutrinos → cosmology
- Geo-neutrinos: thermal regime crust & mantel
- Atmospheric neutrinos

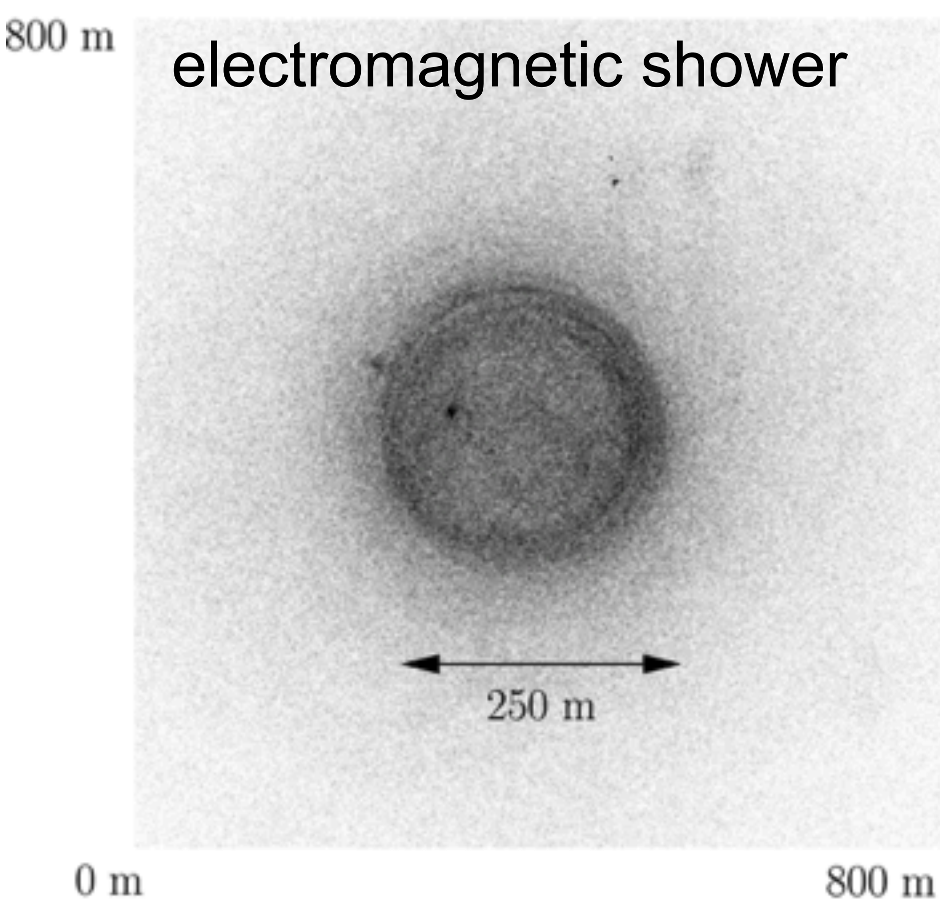
LENA ↔ DeepCore

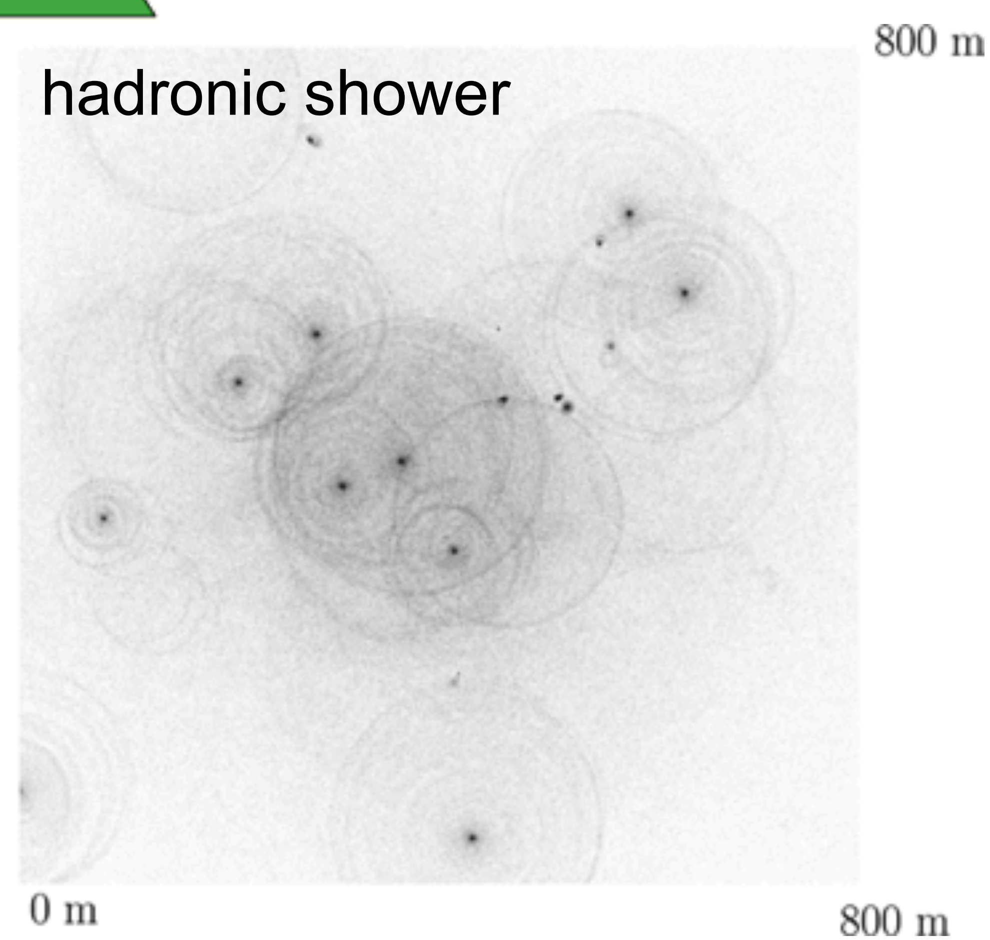
Cosmic radiations: photons





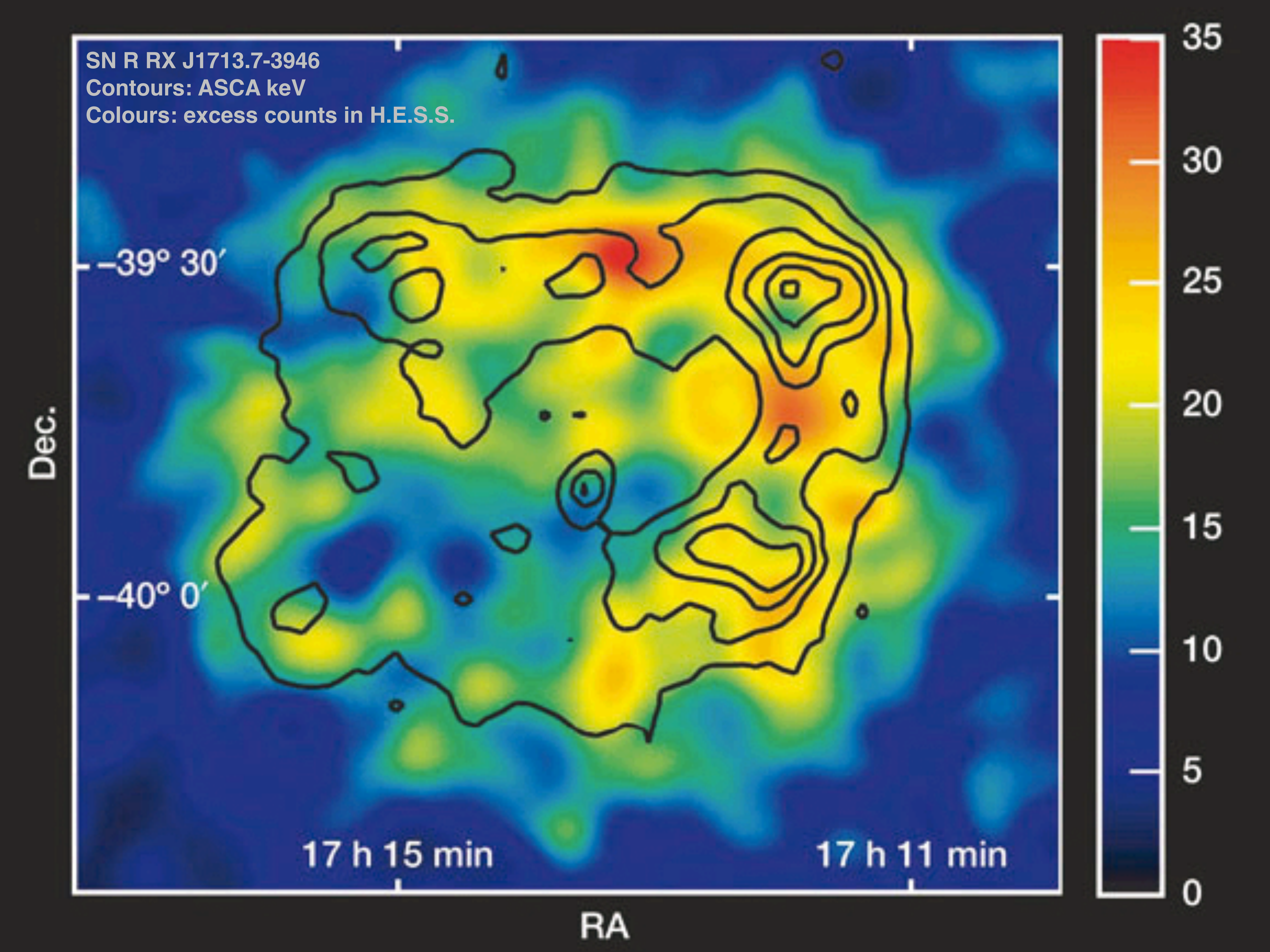
MAGIC telescope, Canary Islands



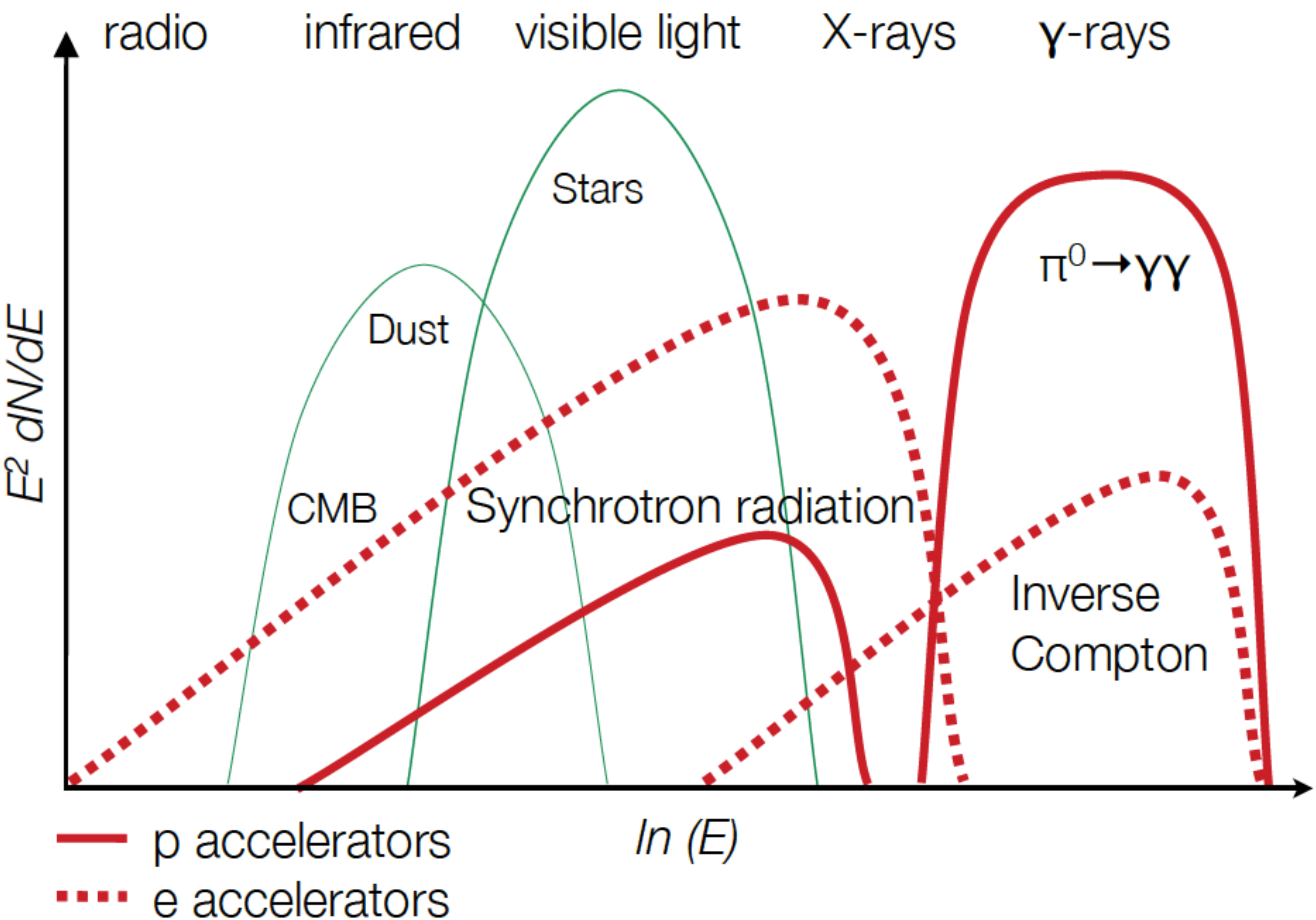



H.E.S.S.


VERITAS



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


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

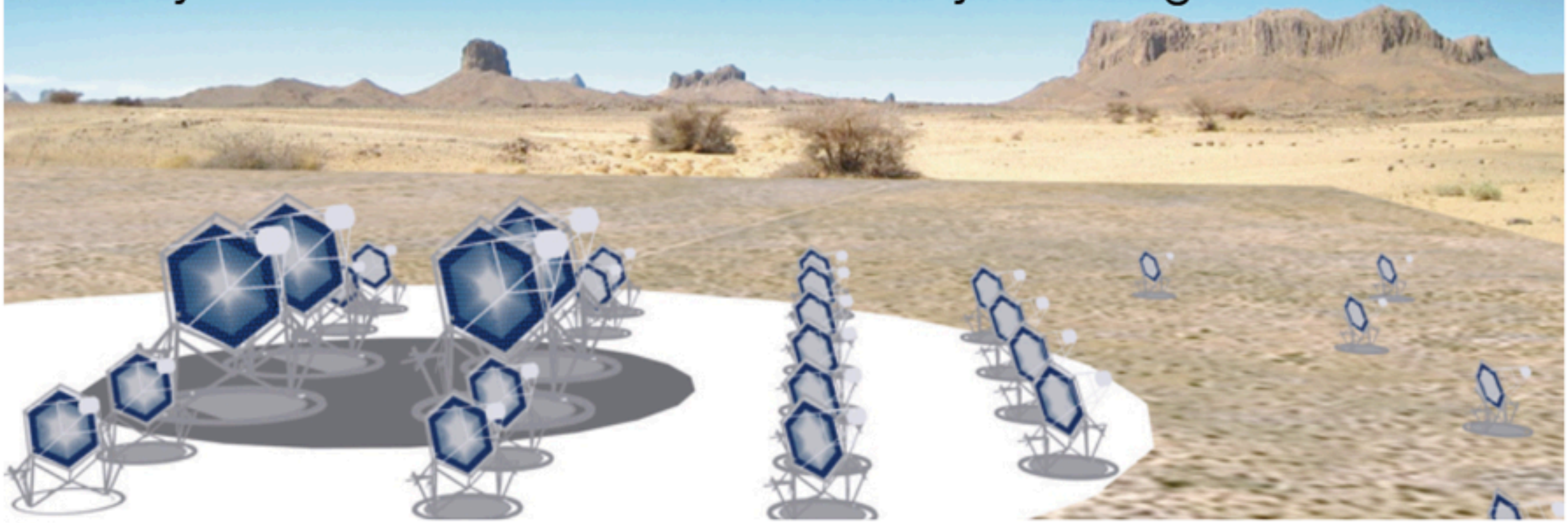
The Cherenkov Telescope Array

- Increase sensitivity
- Extend energy range
- Improve angular resolution

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

- Observatory with flexible and robotic operation
- Arrays in North and South for full sky coverage

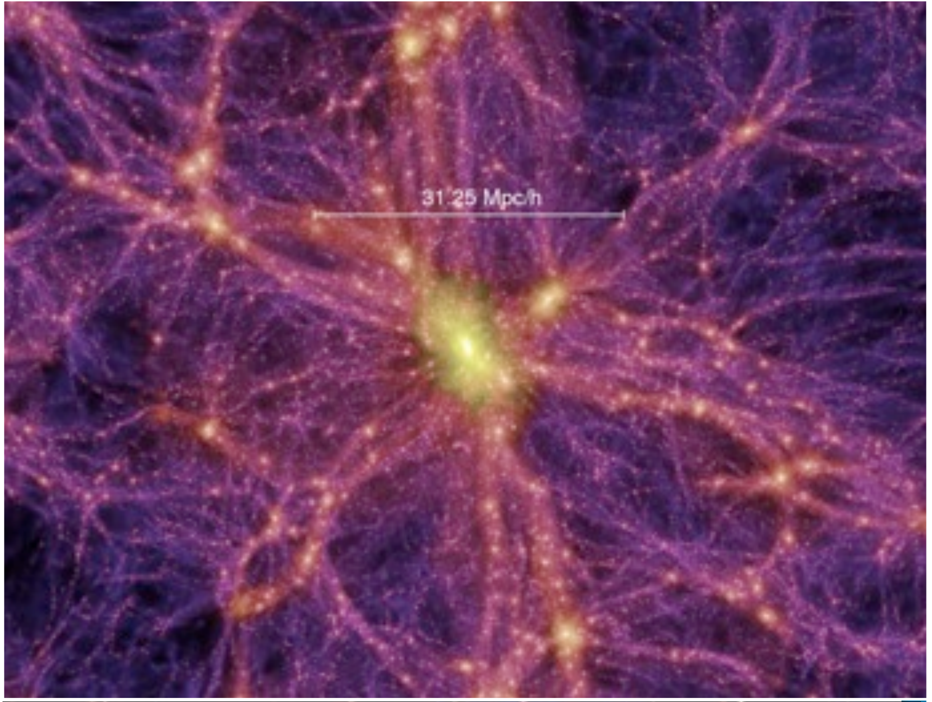
taken from Schlenstedt 2009

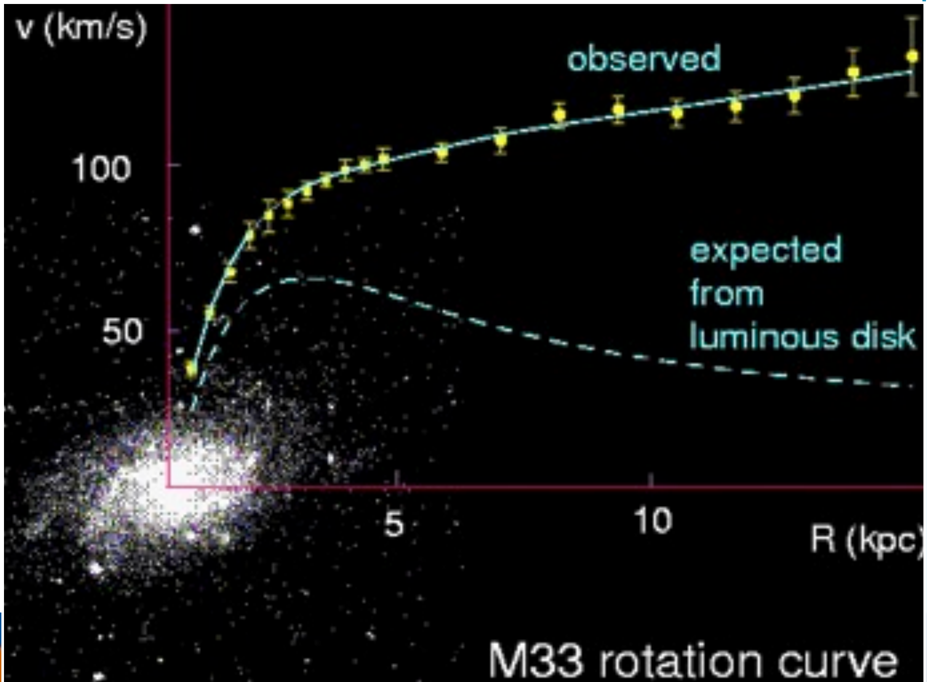


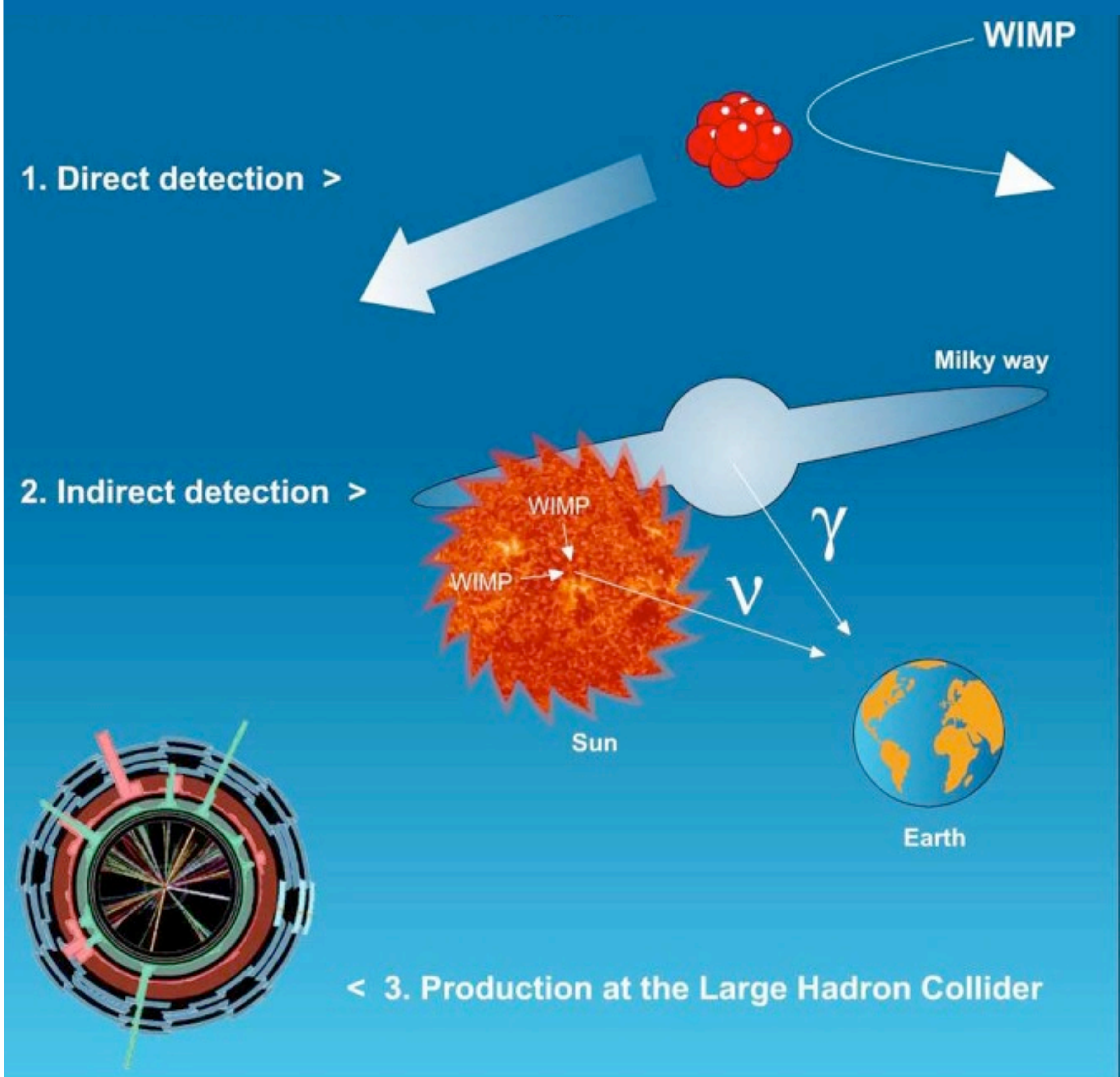
50 to 100 large, medium and small telescopes

Where and what is the Dark Matter?

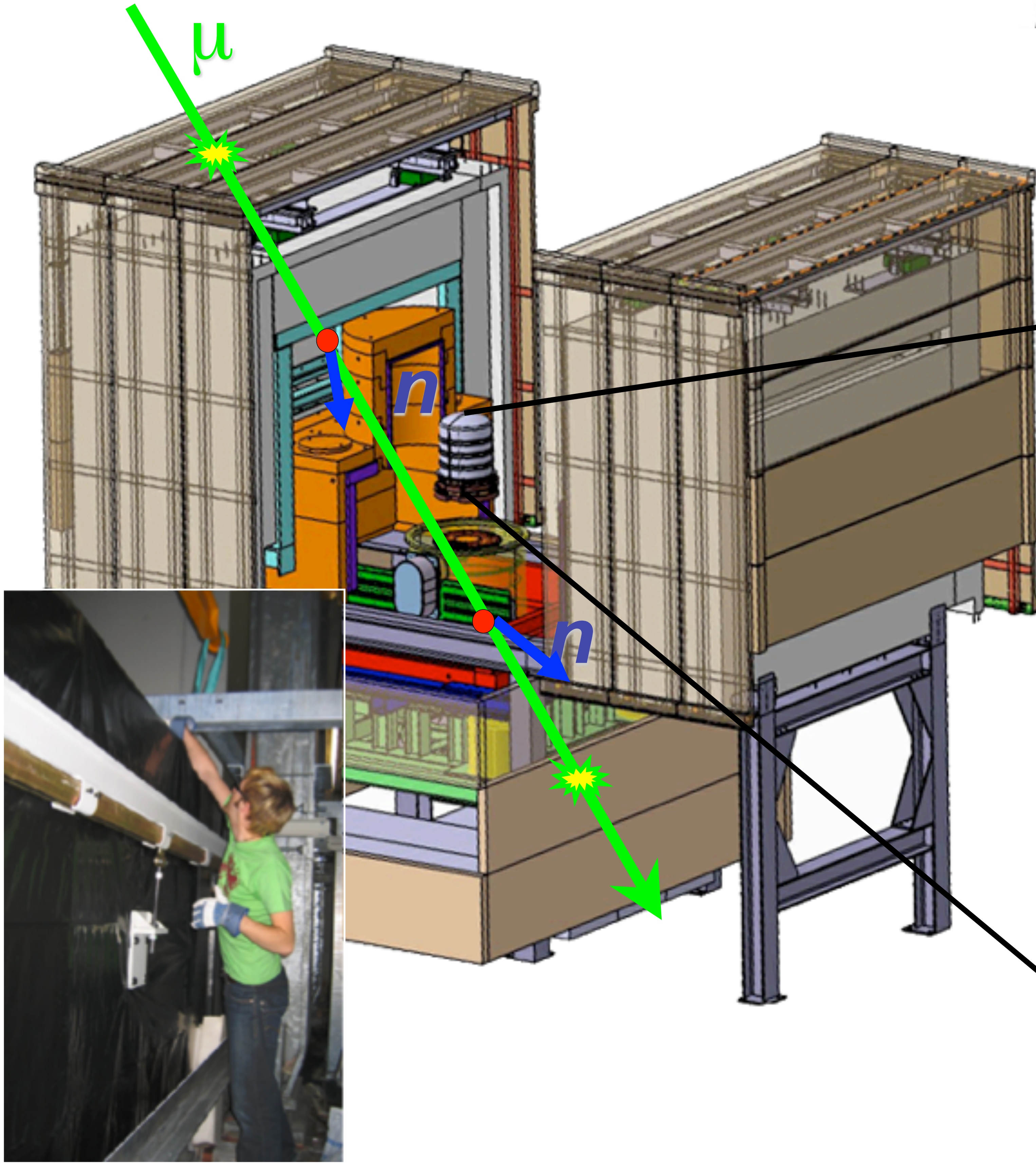
The quest for Dark Matter

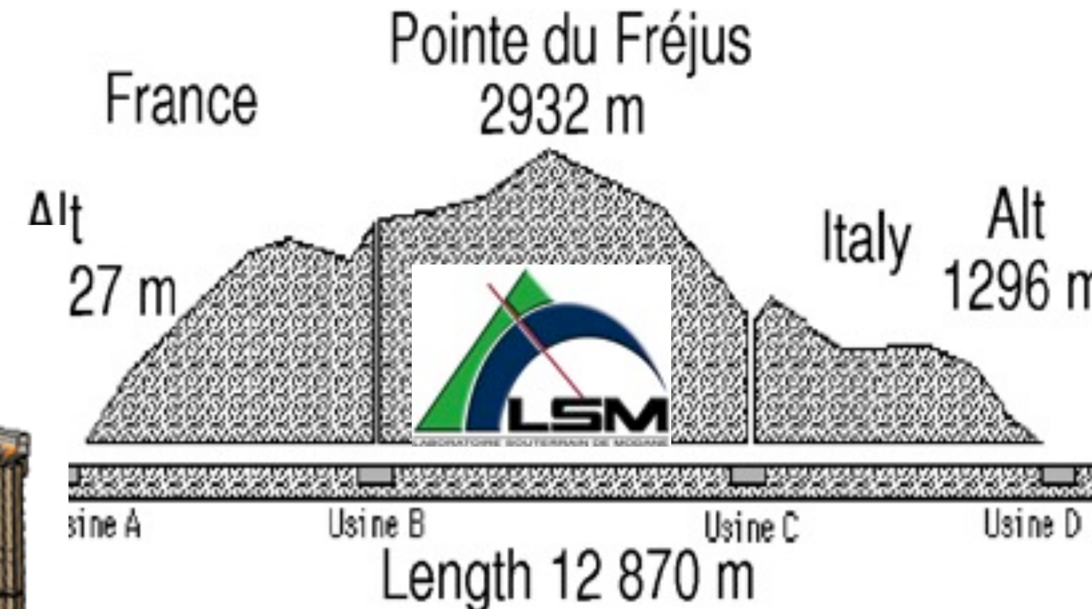


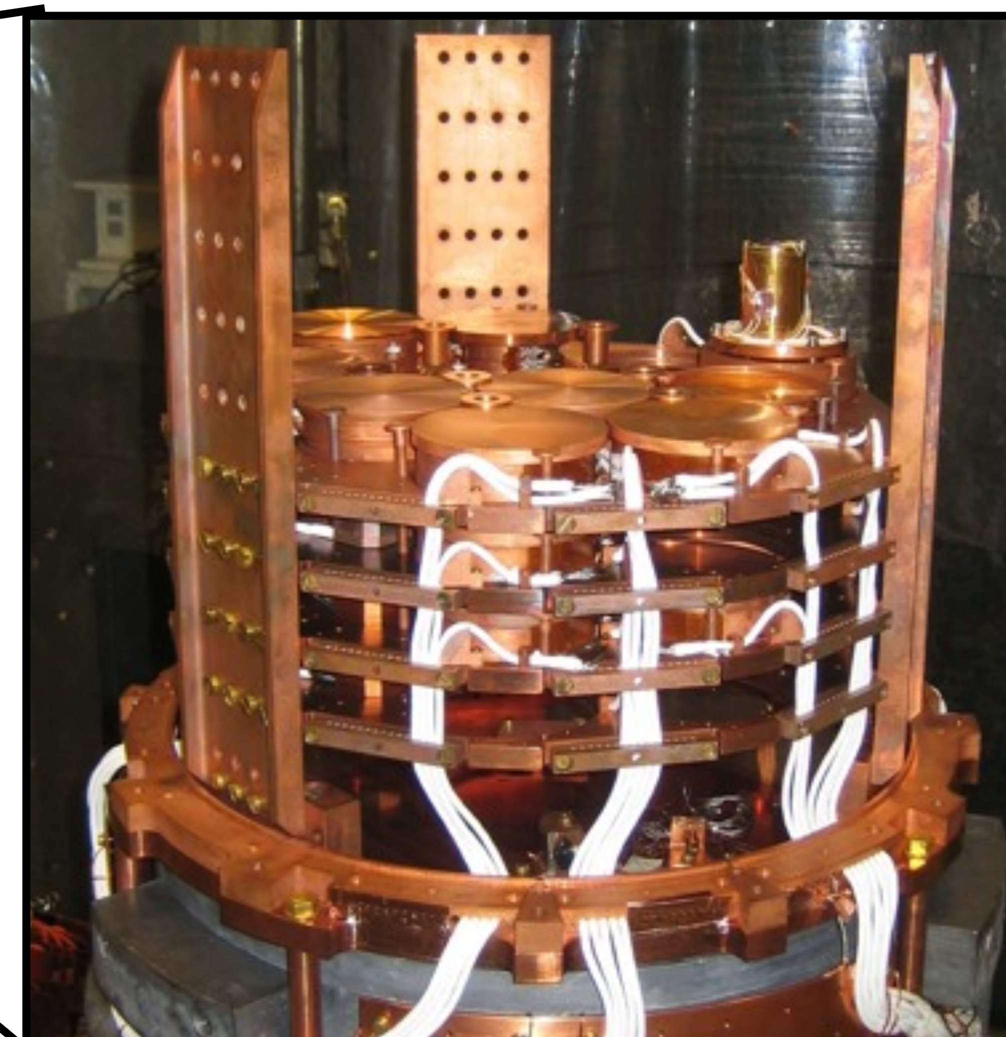




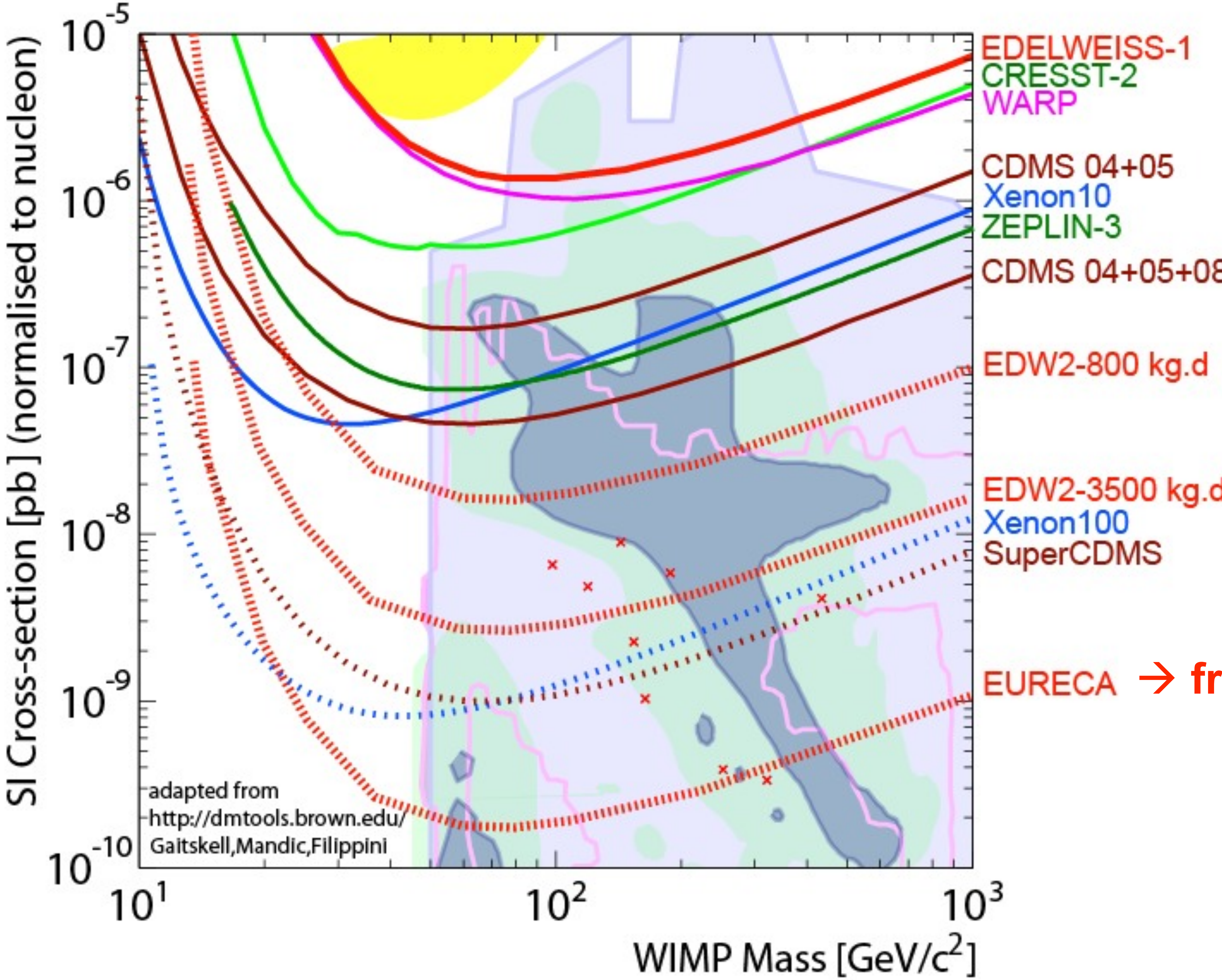
EDELWEISS


μ
n
n


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



WIMP sensitivities



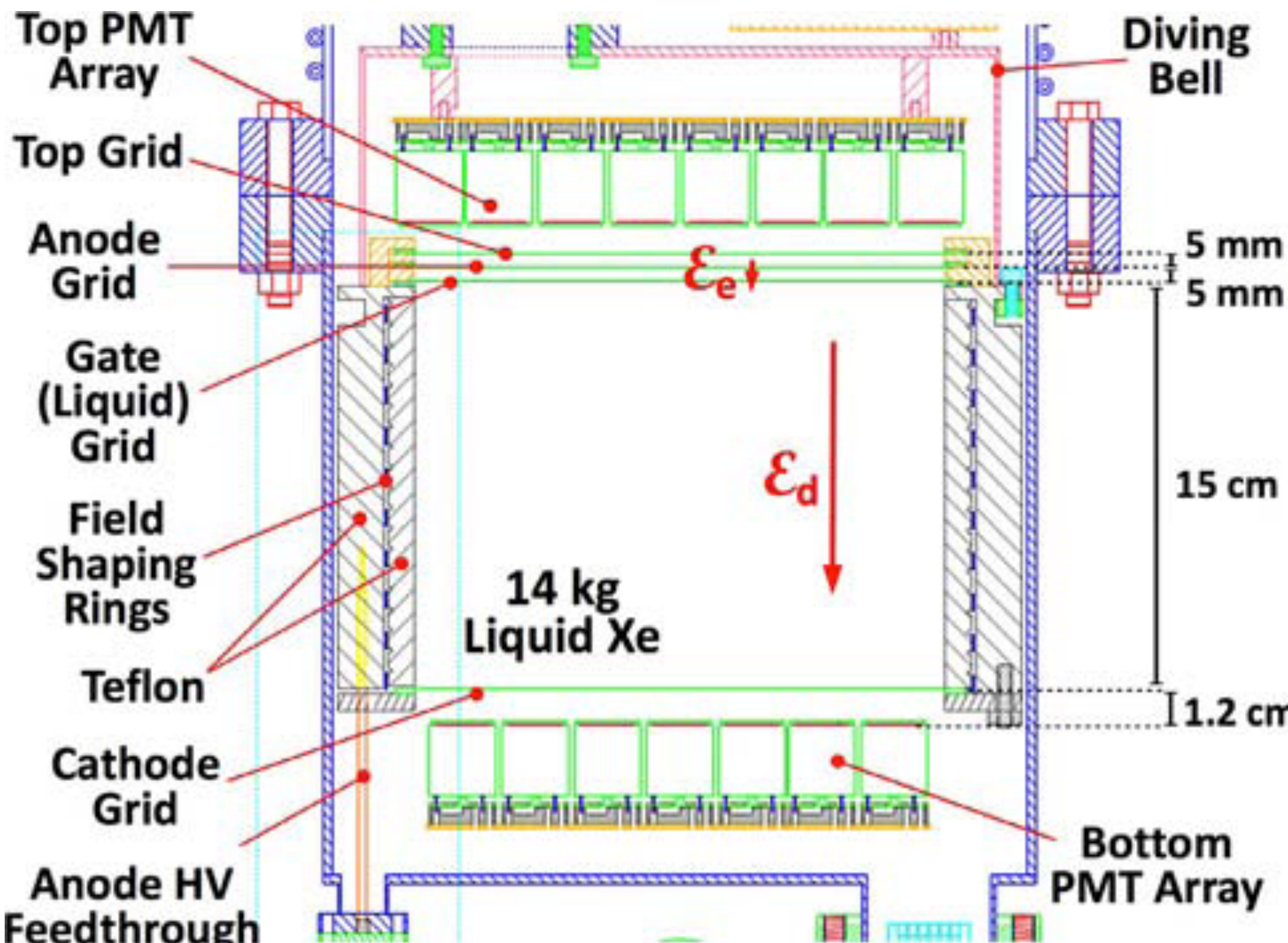
best sensitivity in 2003

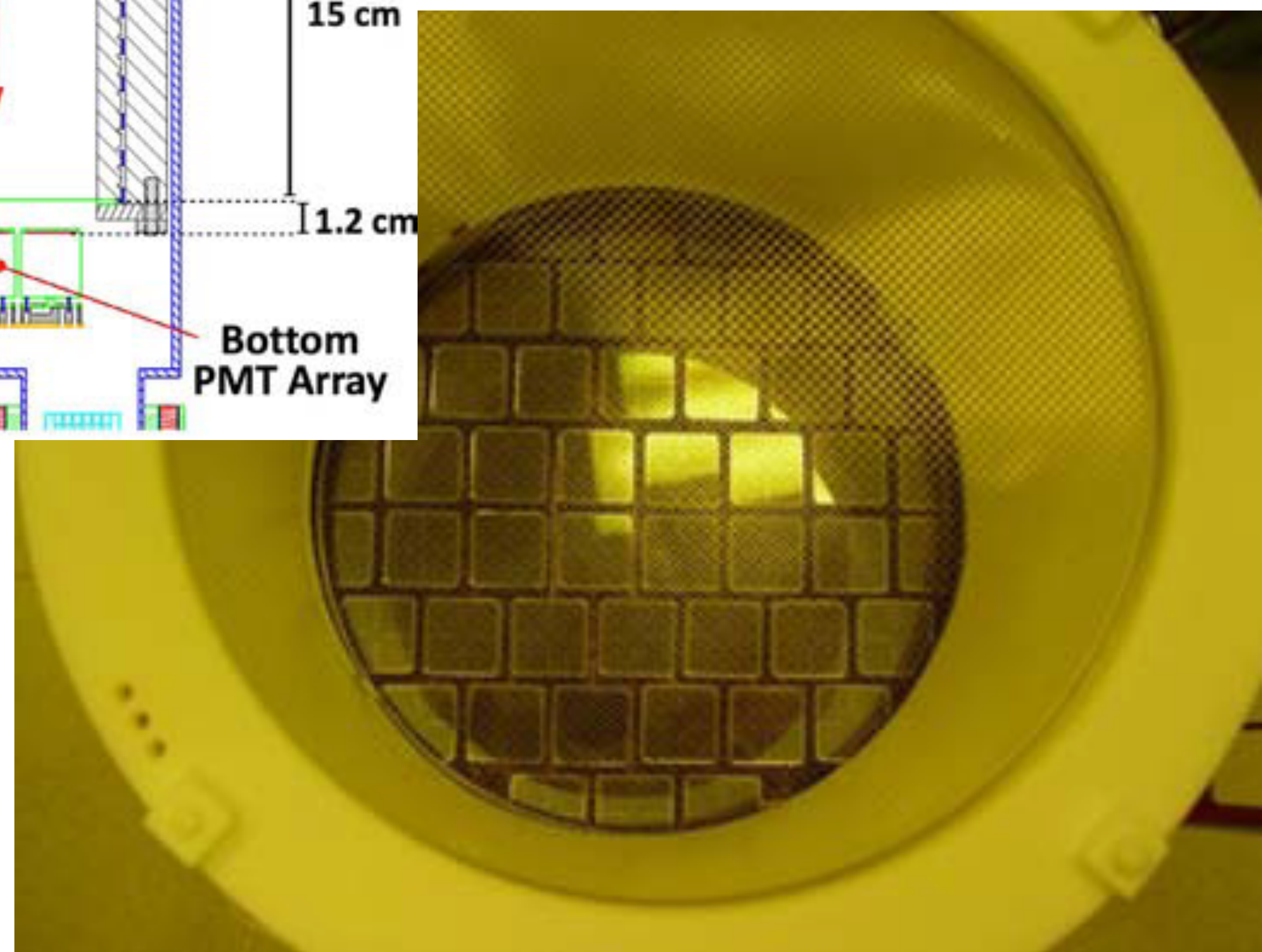
200kg.d$_{fid.}$ → 09/2009

← early 2011

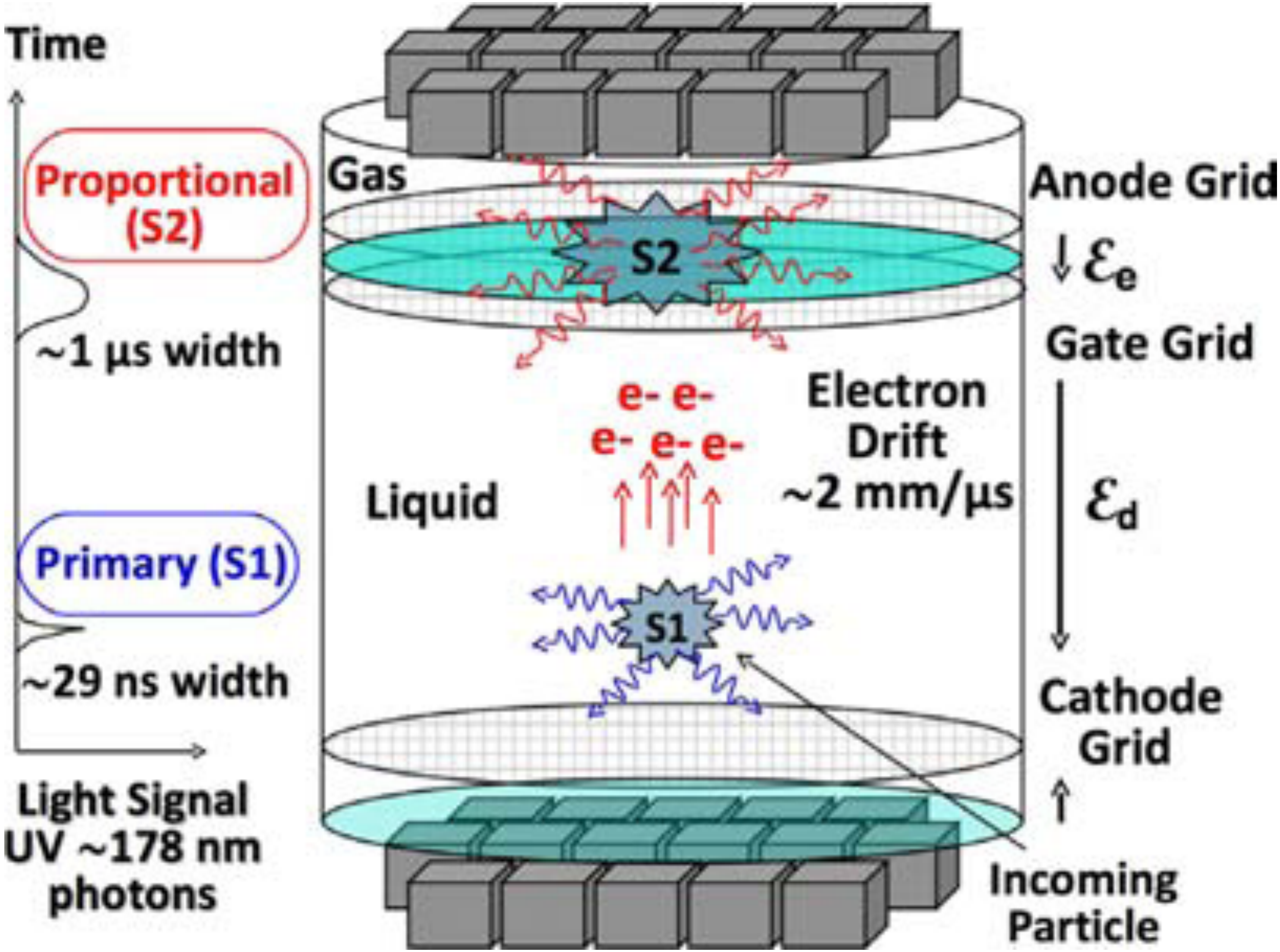
← 2012

→ from 2015 on





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

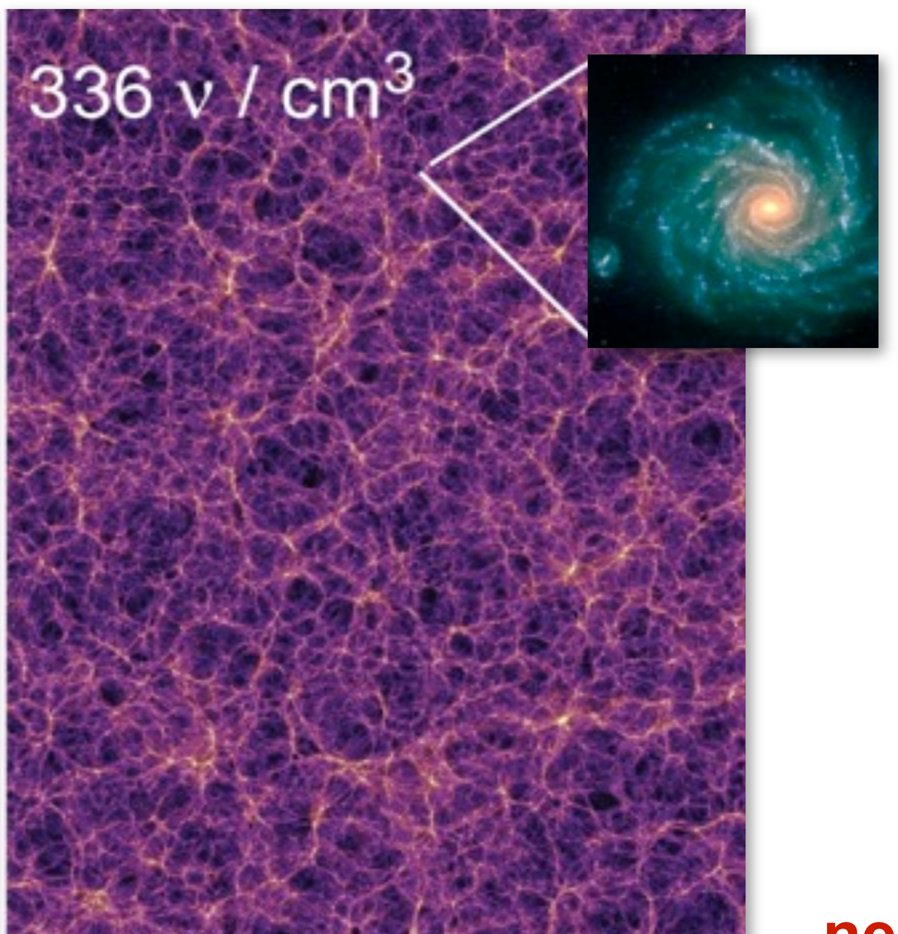

Time
Proportional (S2)
~1 μs width
Primary (S1)
~29 ns width
Light Signal
UV ~178 nm
photons
Gas
Liquid
S2
S1
e- e-
e- e- e-
Electron
Drift
~2 mm/μs
Anode Grid
$\mathcal{E}_e$
Gate Grid
$\mathcal{E}_d$
Cathode
Grid
Incoming
Particle

Neutrino mass

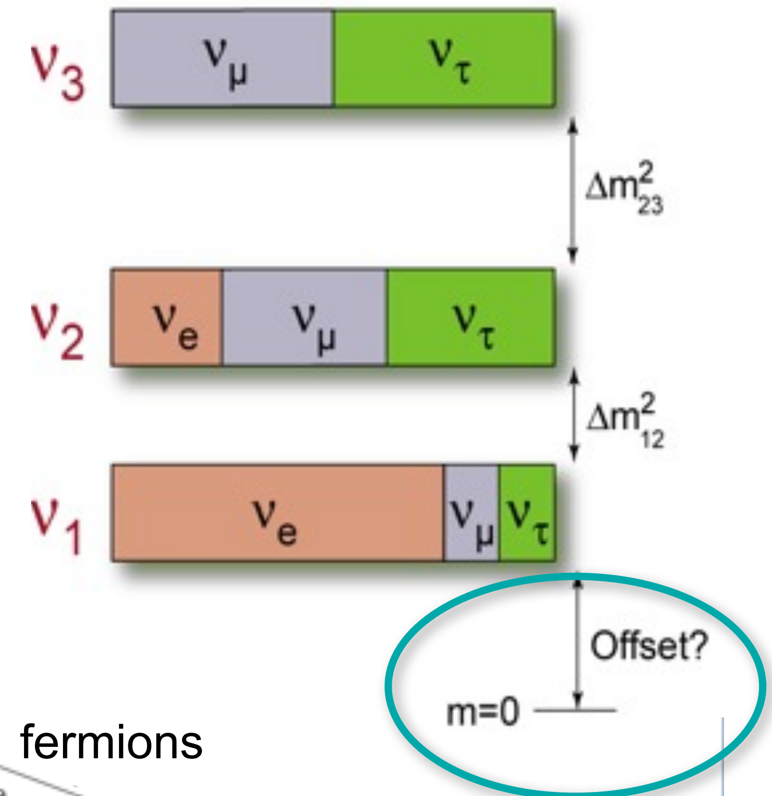
motivation: ν´s in astroparticle physics

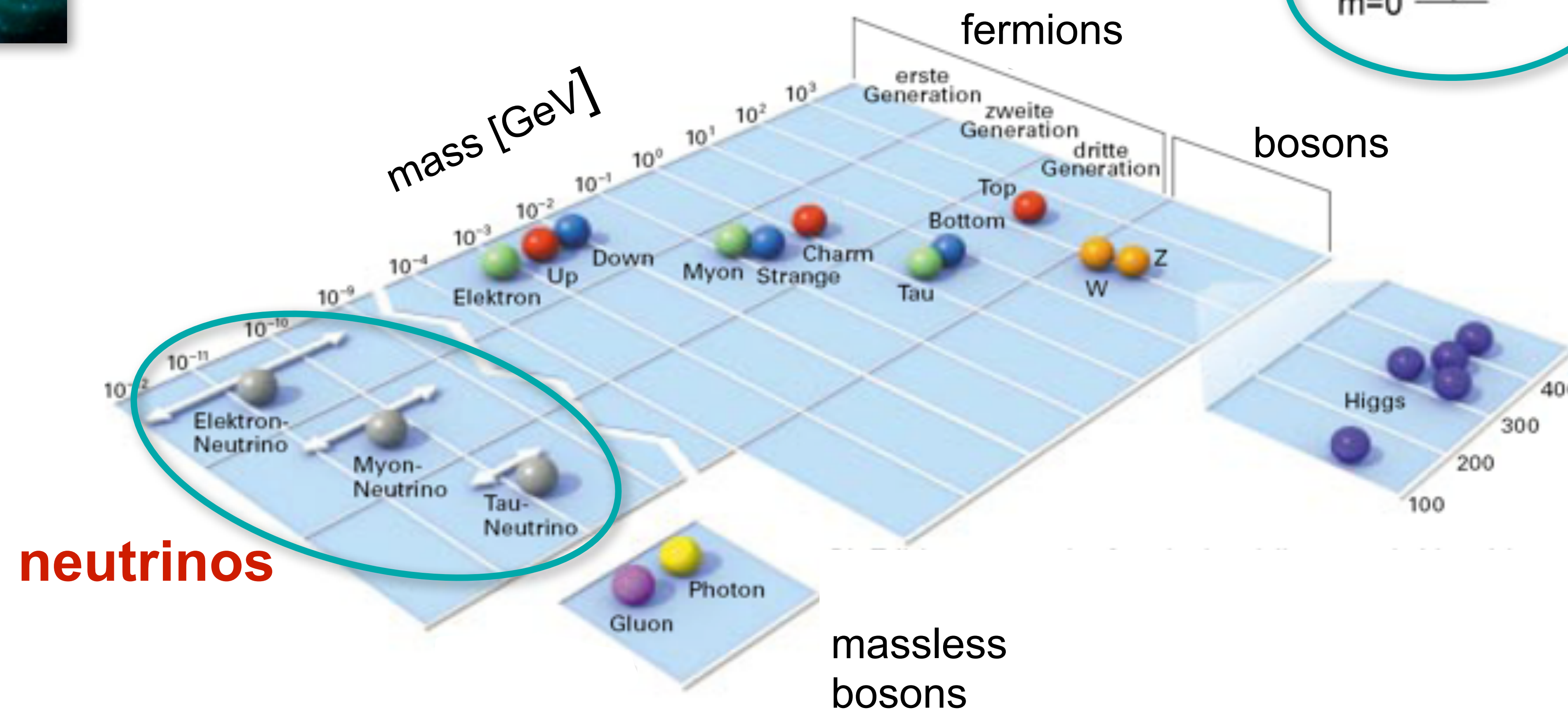
cosmic architects: role of ν´s as hot dark matter?
microscopic keys: origin of the ν-mass?

cosmology ⟺ **particle physics**

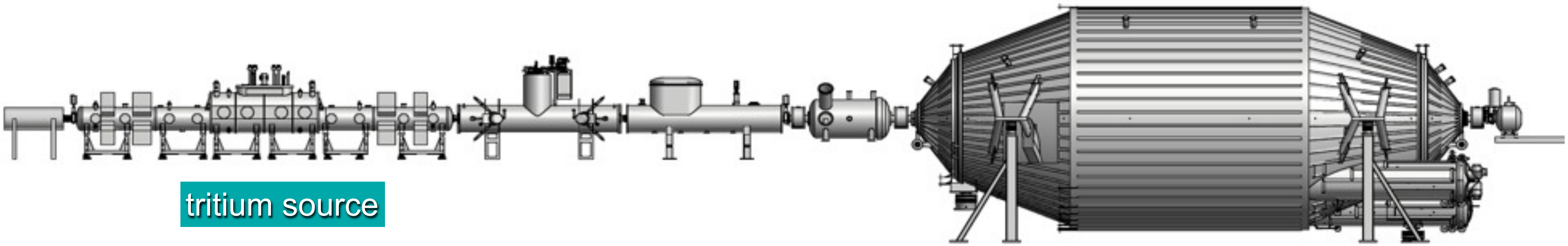


structure of the universe
(Millenium Simulation)





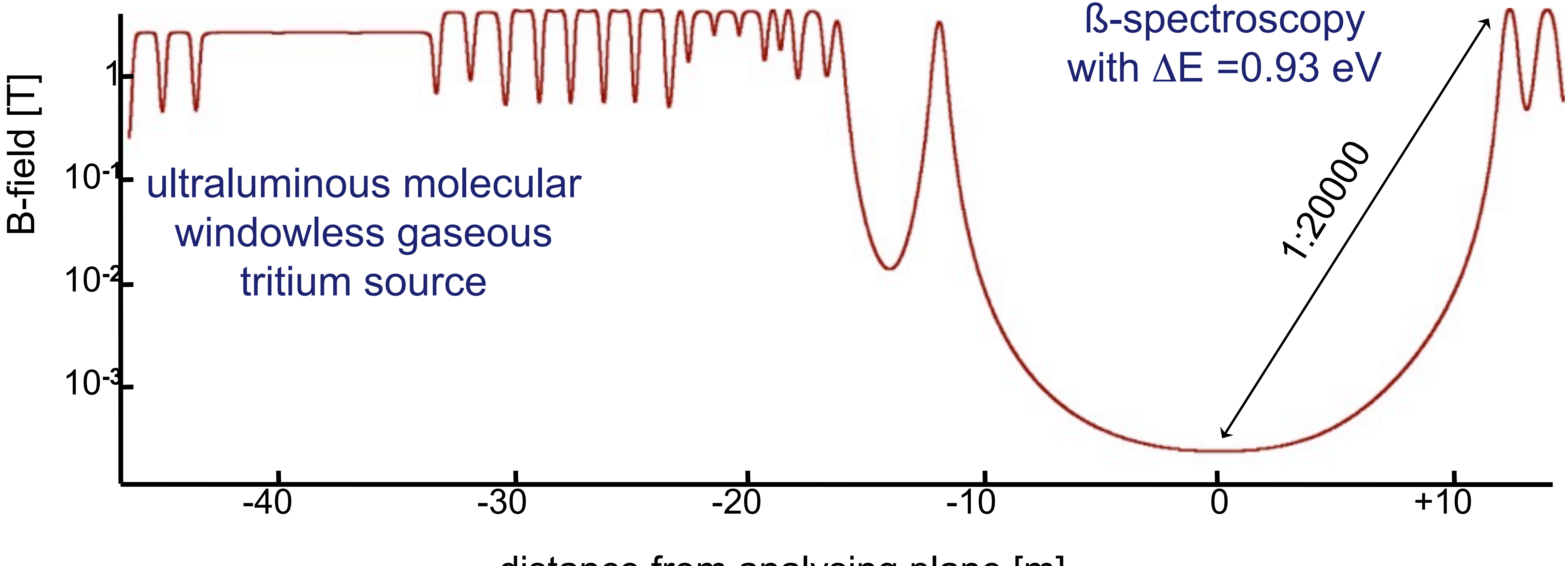
KATRIN – a MAC-E filter system



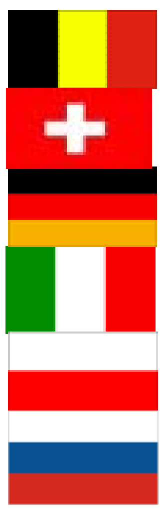
adiabatic particle transport over 70 m

spectrometer

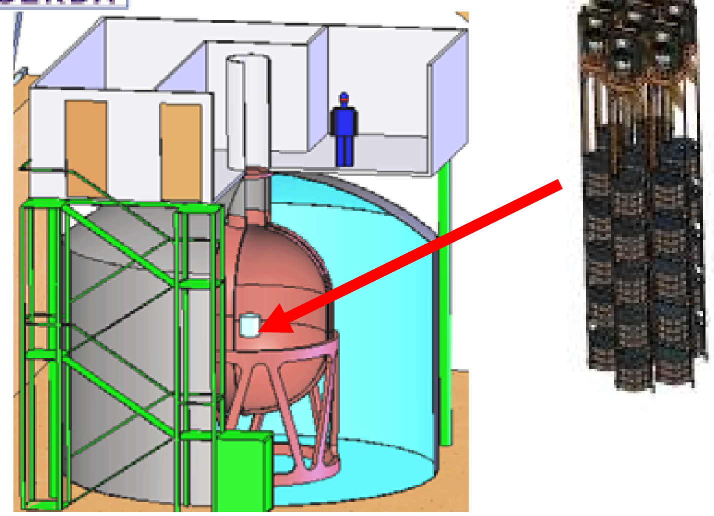
detector



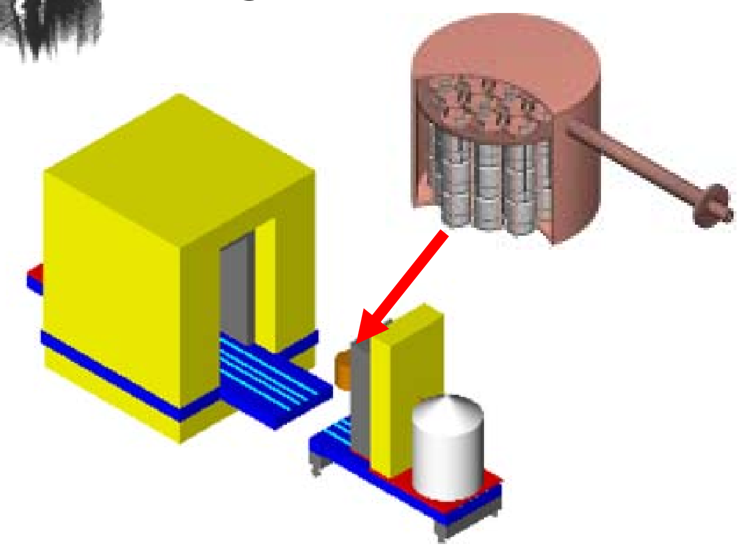
Two new ^{76}Ge Projects:

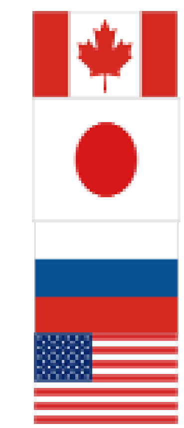


GERDA



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

Multi-messenger astroparticle physics

particles from the cosmos

messenger	instrument	message
photons	telescopes	many sources known many sources unknown not all understood
cosmic rays	particle detectors	sources unknown propagation unknown composition unknown
neutrinos	neutrino telescopes	4 known sources: Earth, 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 four extremes: extremely harsh operating conditions - extremely large systems - extremely high precision – extremely low backgrounds
- You/we have exciting times ahead!