Upcoming Experiments in Astroparticle Physics

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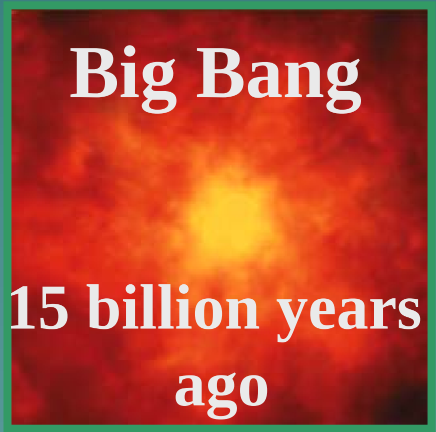
1. Astroparticle Physics
2. Cosmic Ray Experiments
3. Gamma Ray Telescopes
4. Neutrino Telescopes

Les Houches 13 May 2005

Astroparticle Physics

What happened at the beginning?

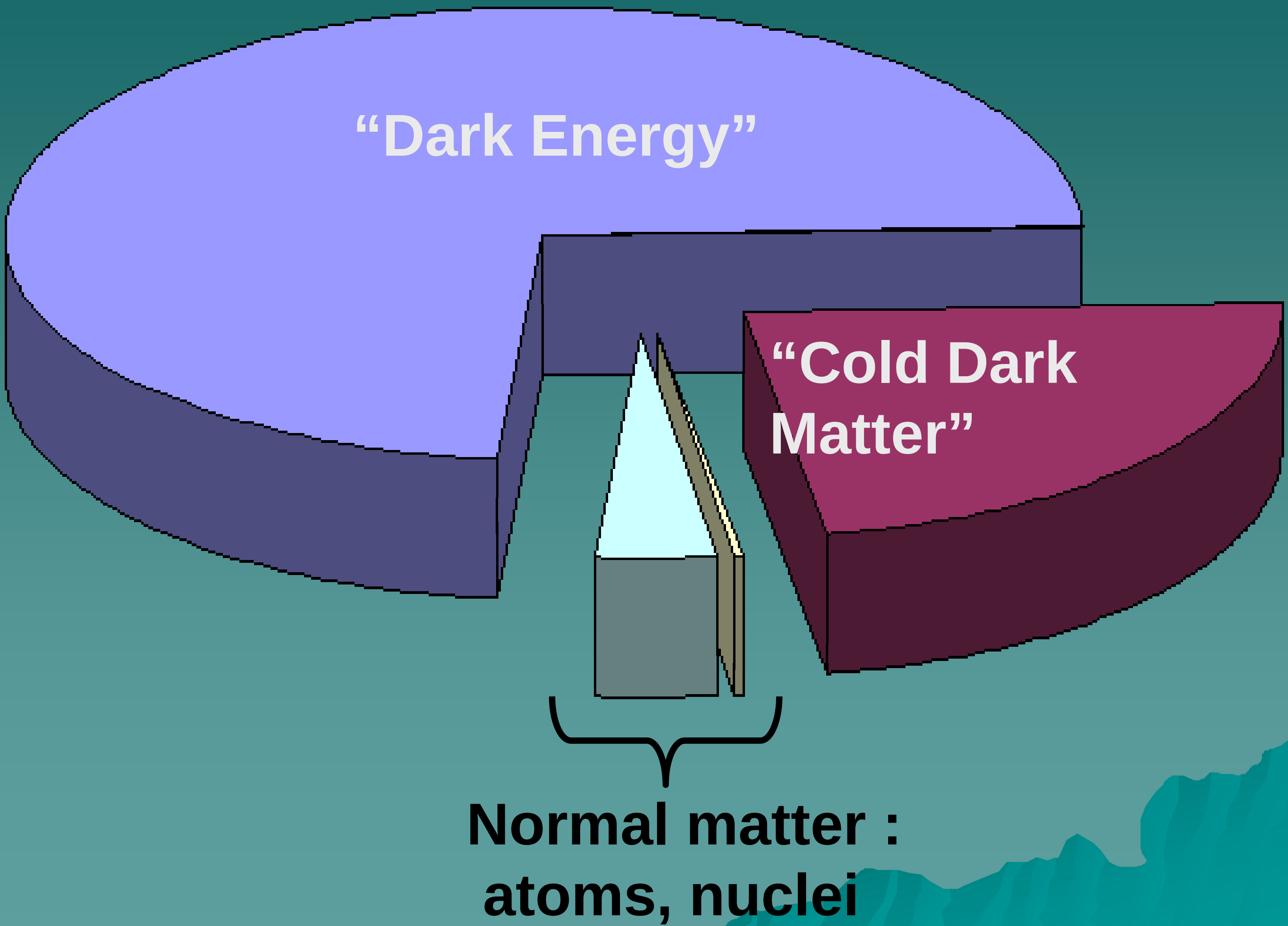


How did structure form ?

evolution

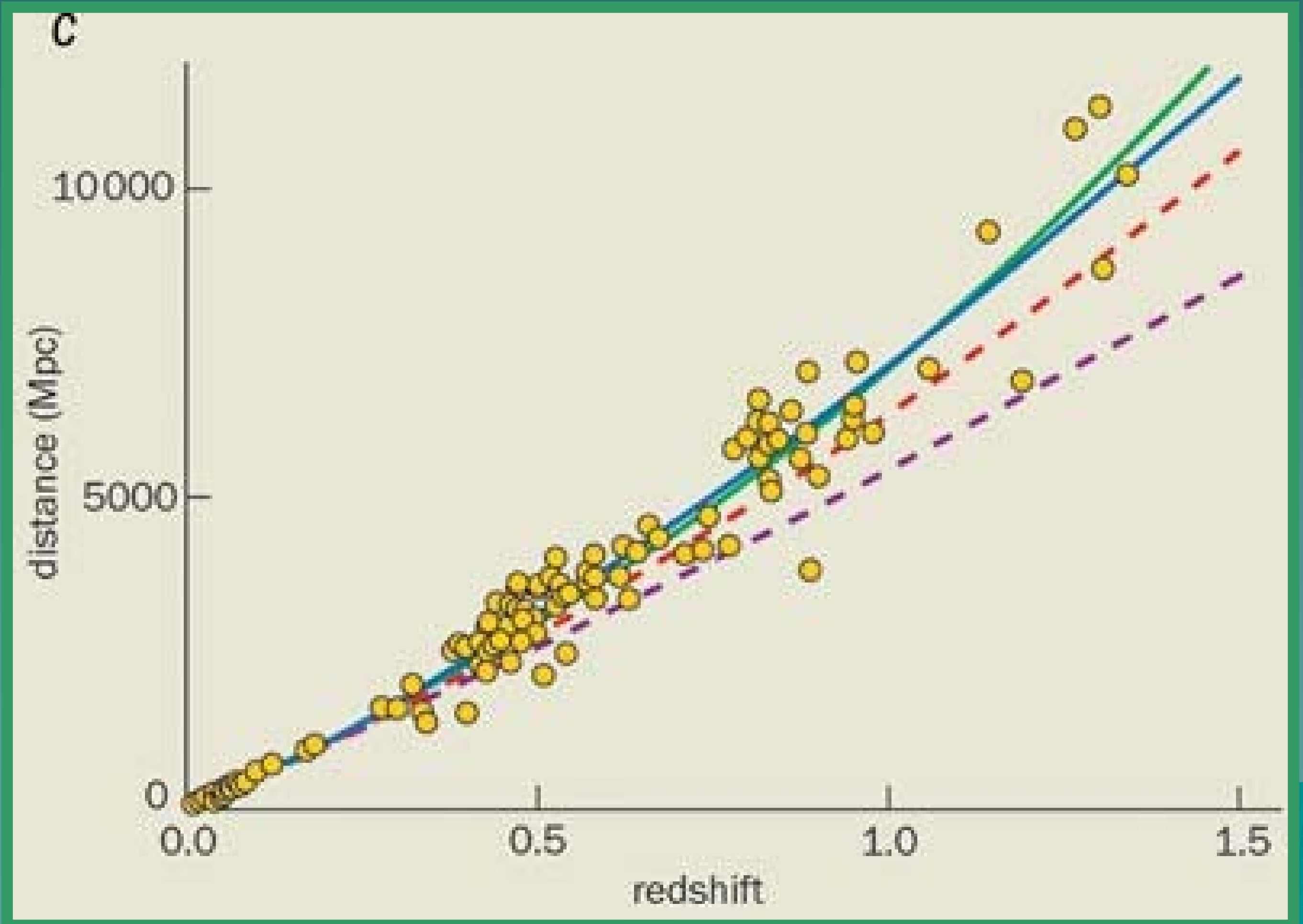
What is the present structure ?

Composition of the Universe



Dark Energy

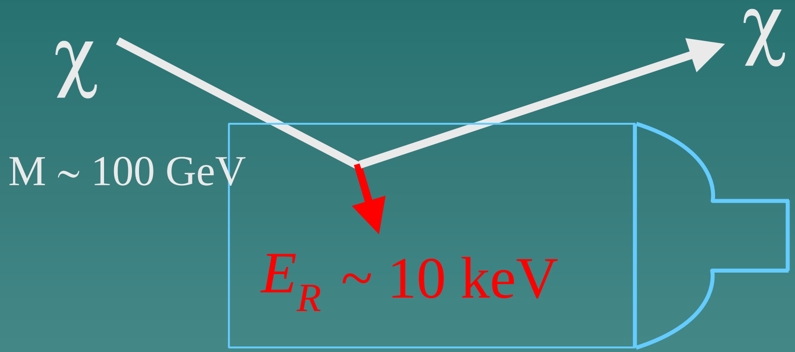
Expansion of the universe accelerating

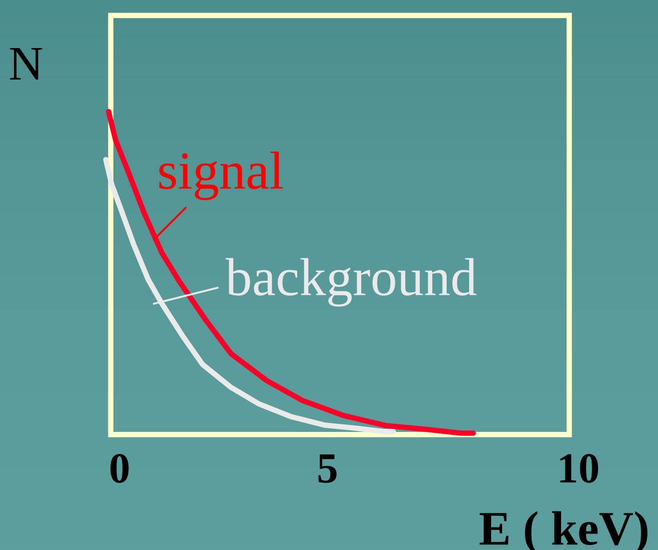


Methods to find Dark Matter

Direct

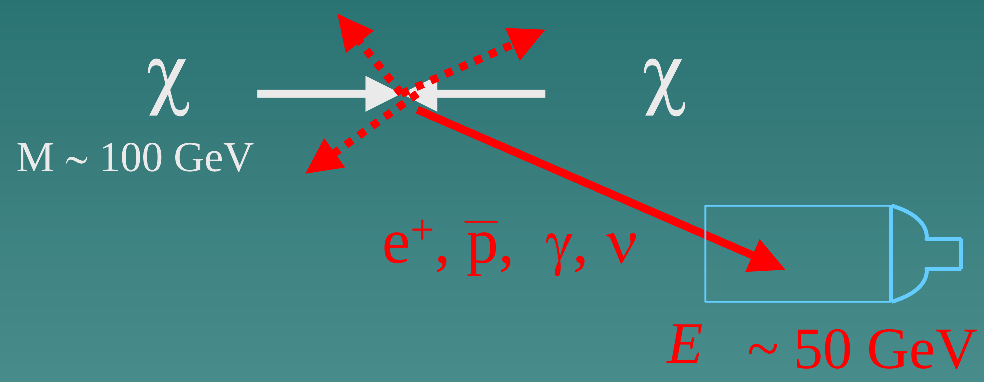
Halo: v ~ 300 km/sec

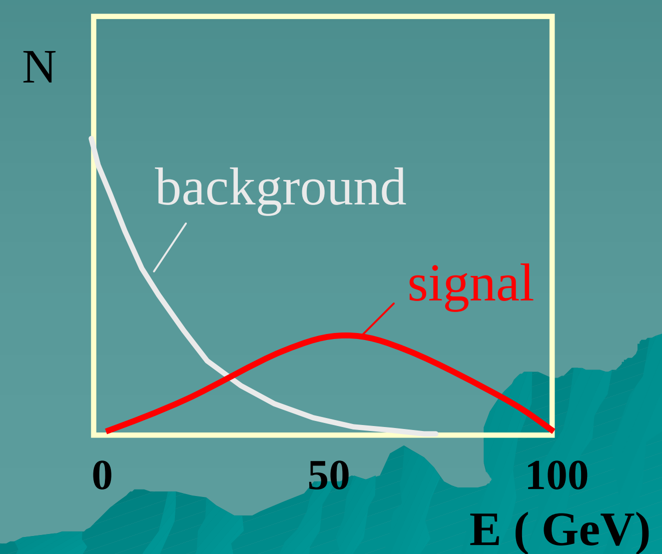




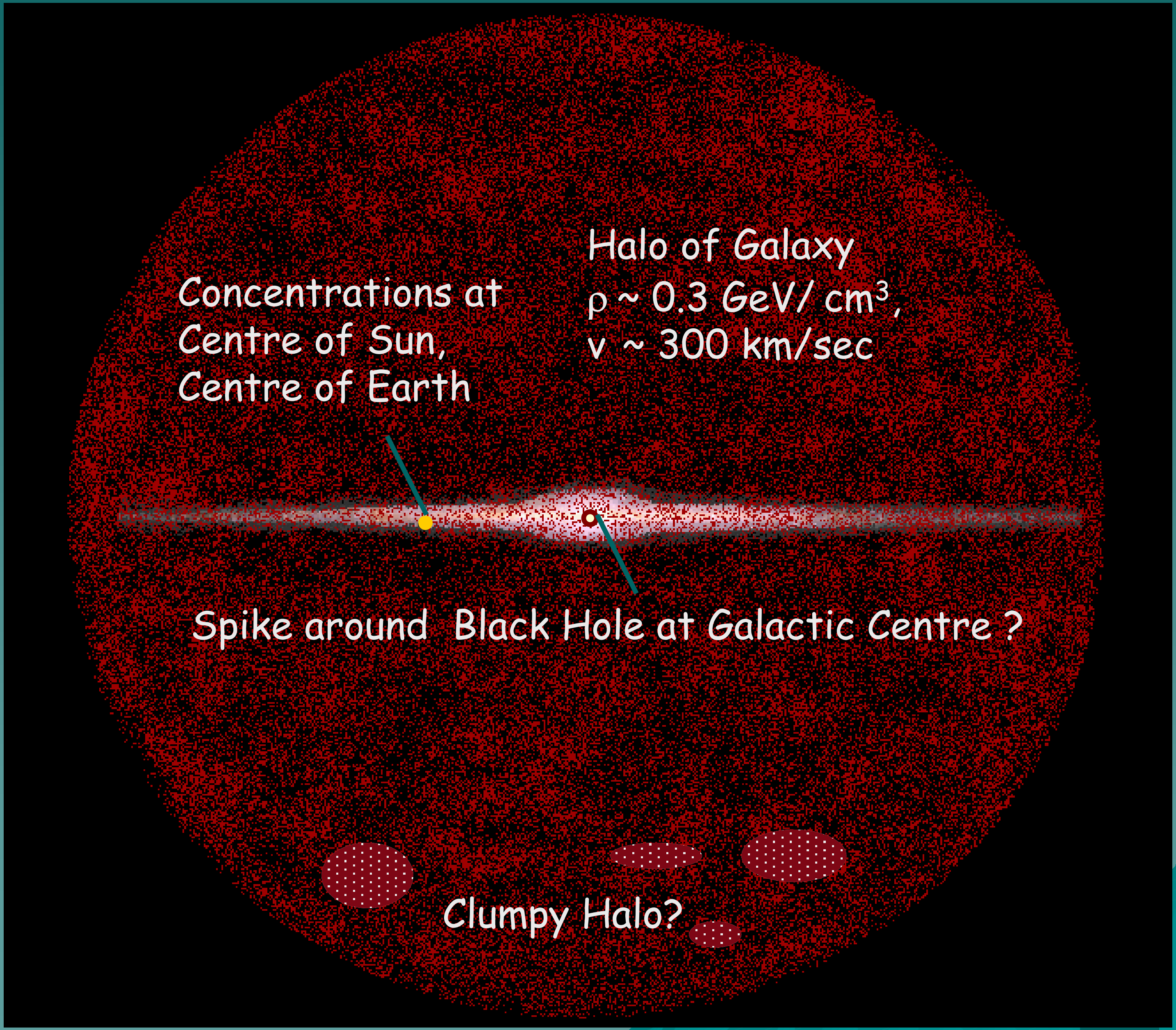
Indirect

Captured: v ~ at rest, or in Halo





WIMP Distributions in Galaxy

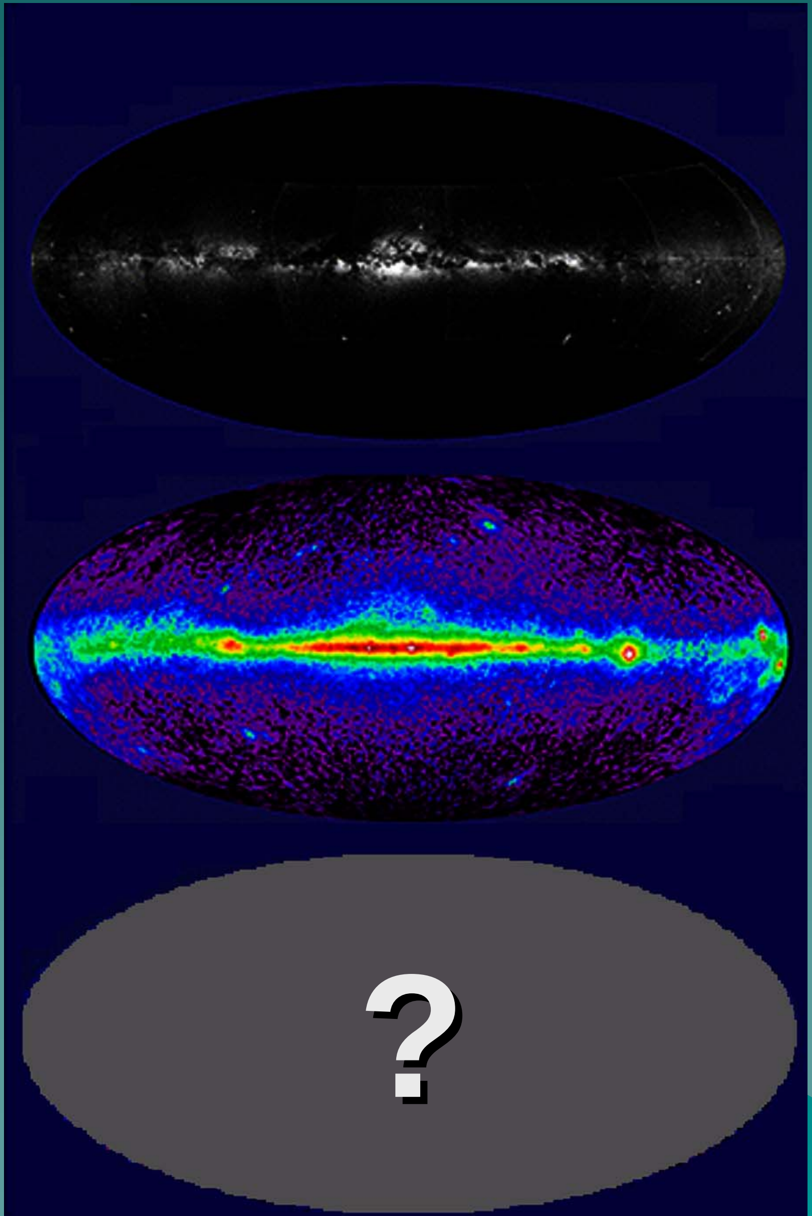


Multi-Messenger Astronomy

Visible Light

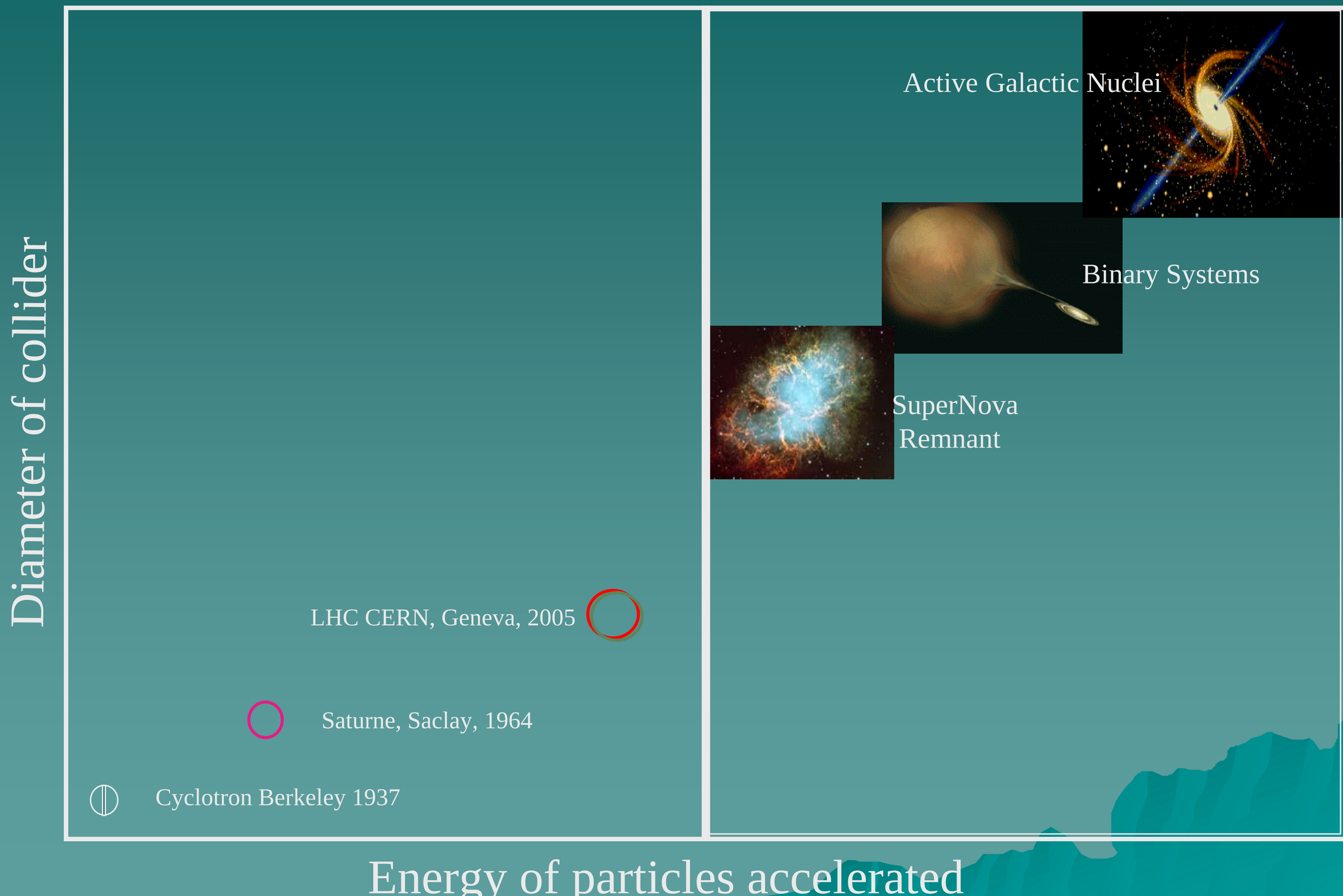
Gamma Rays

Neutrinos

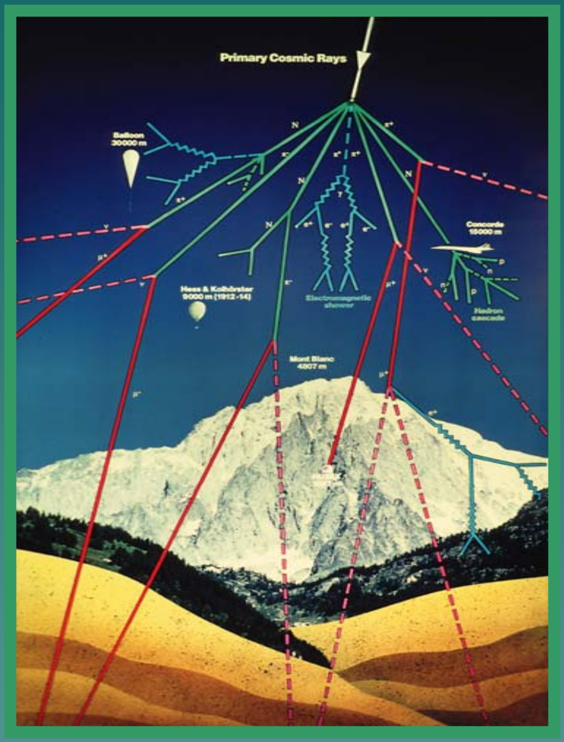


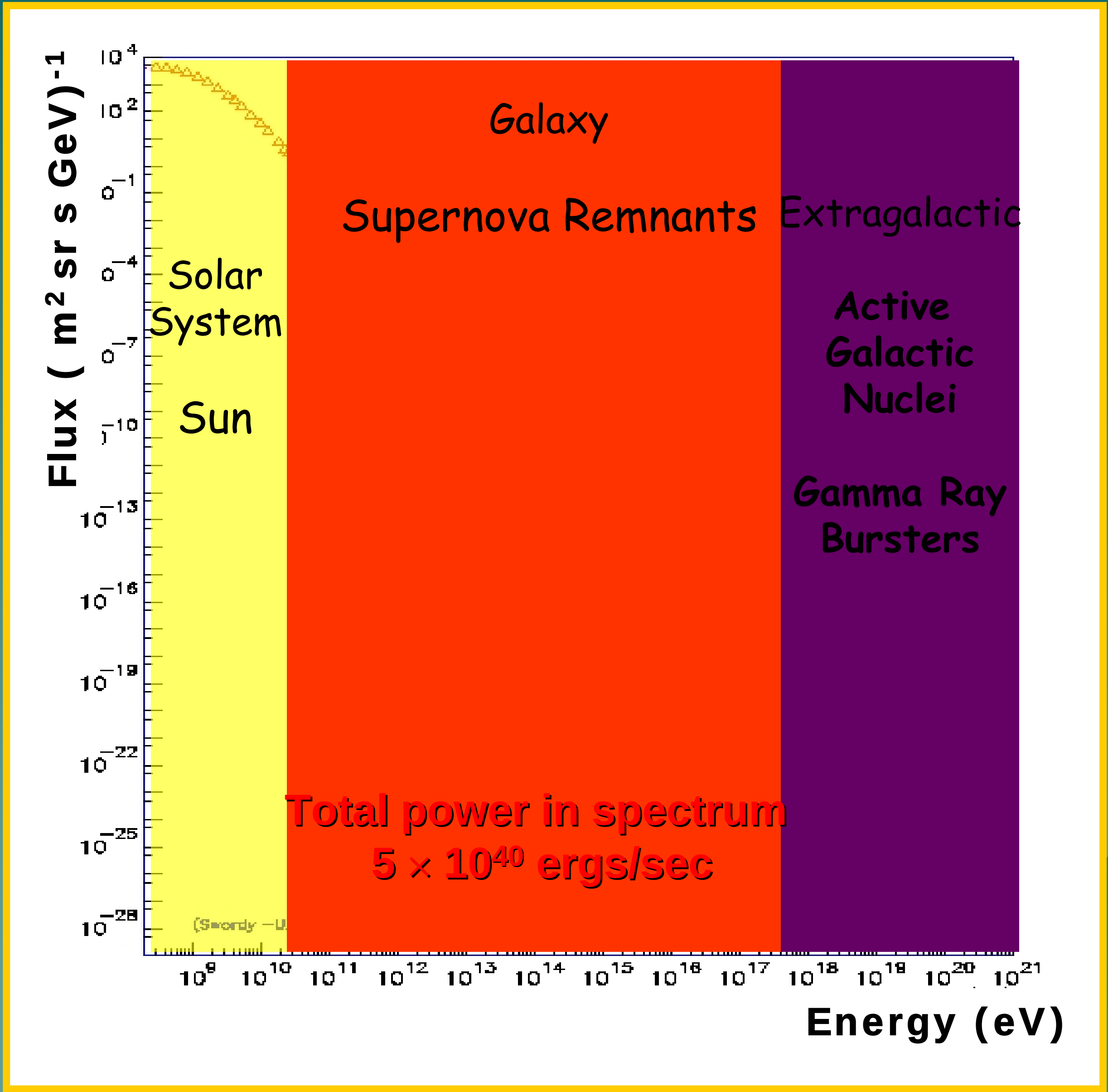
Astroparticle Physics

Terrestrial Accelerators | Cosmic Accelerators



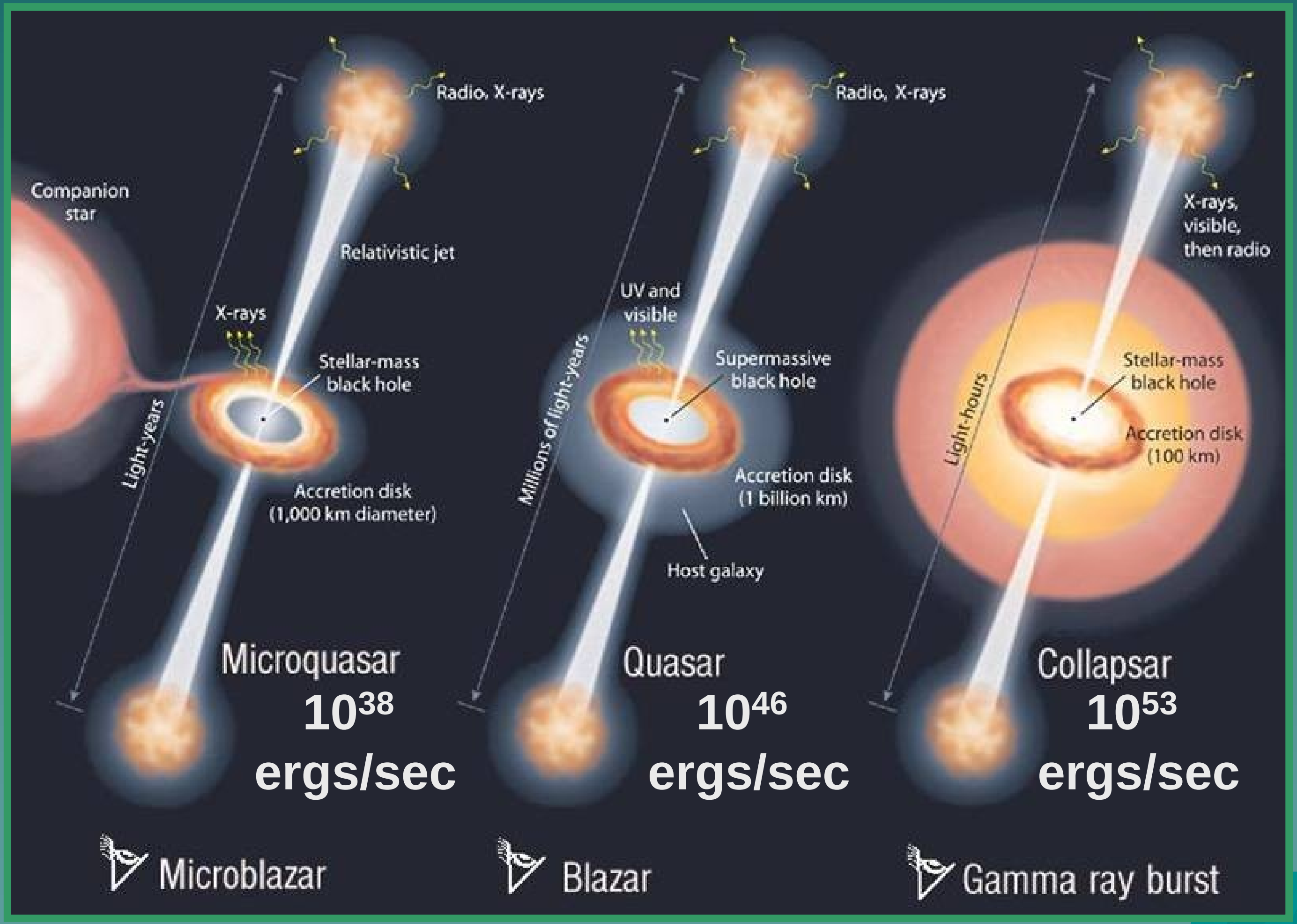
Origin of High Energy Cosmic Rays ?

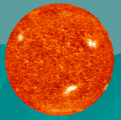




Same energy density arriving on Earth as starlight but origin is unknown.

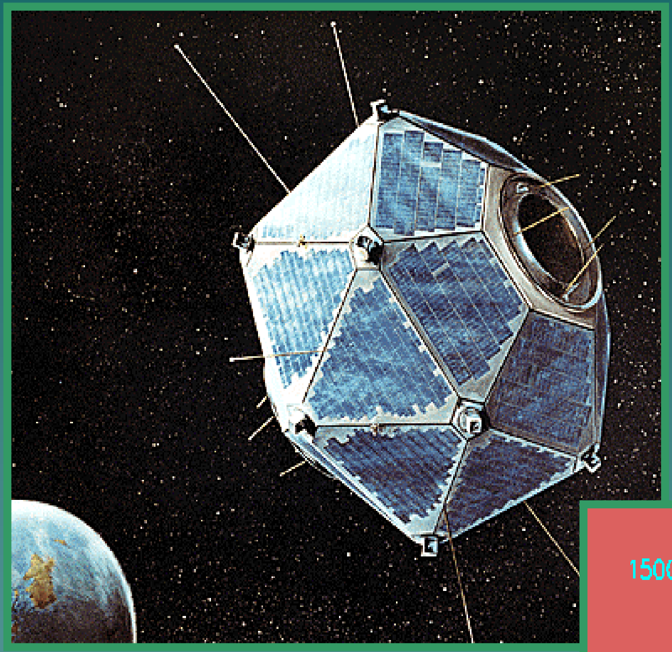
Extremely Energetic Cosmic Sources

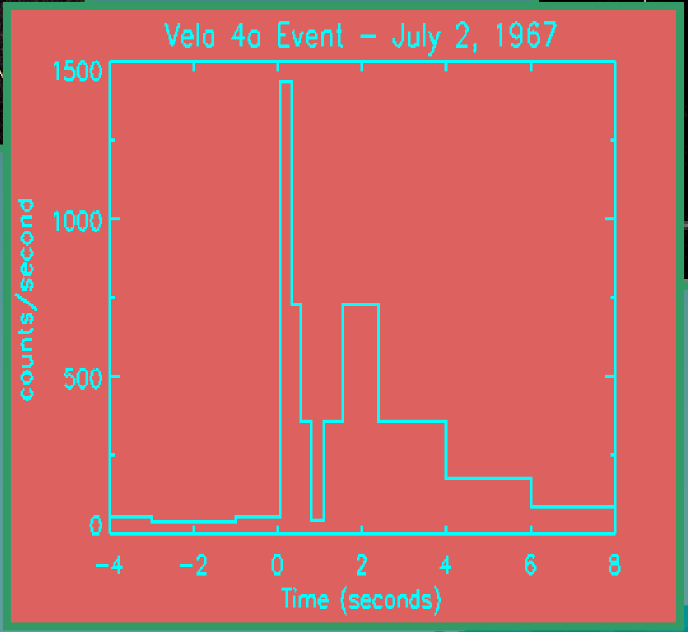


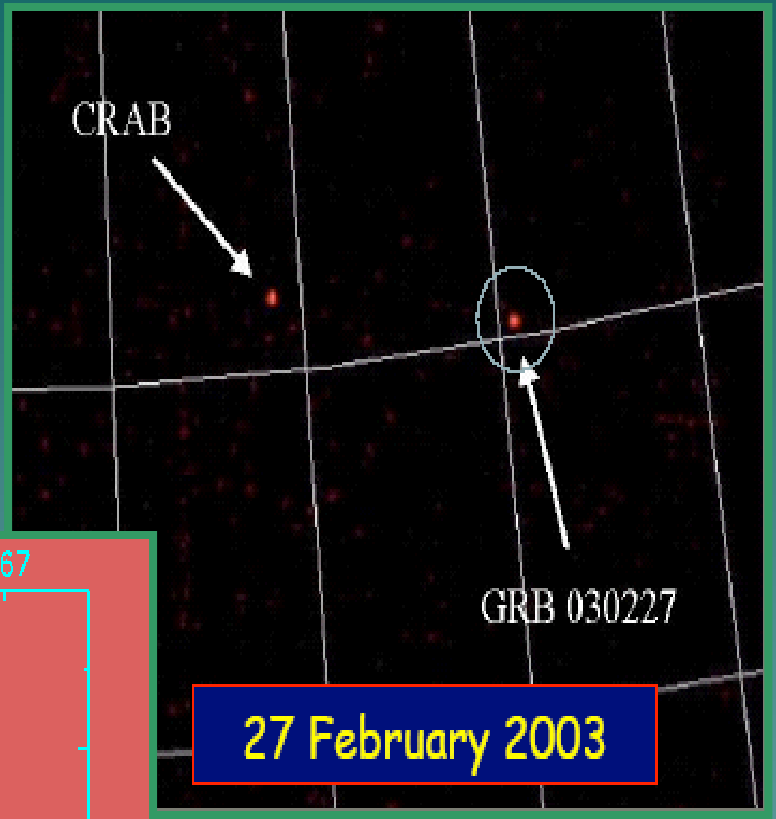


Sun :4 $\times 10^{33}$ ergs/sec

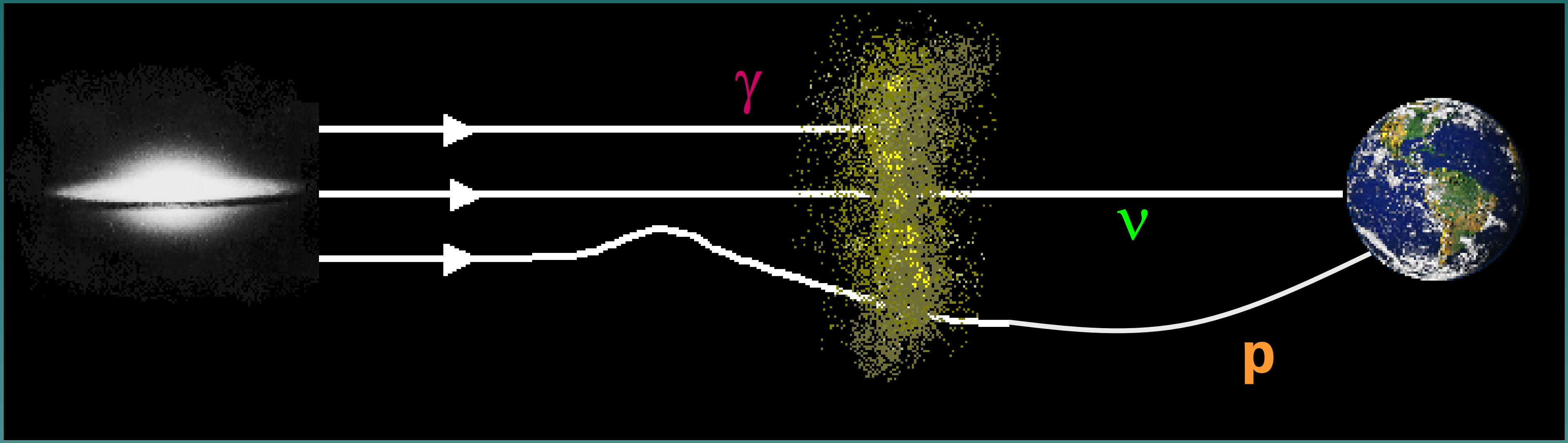
Gamma Ray Bursts





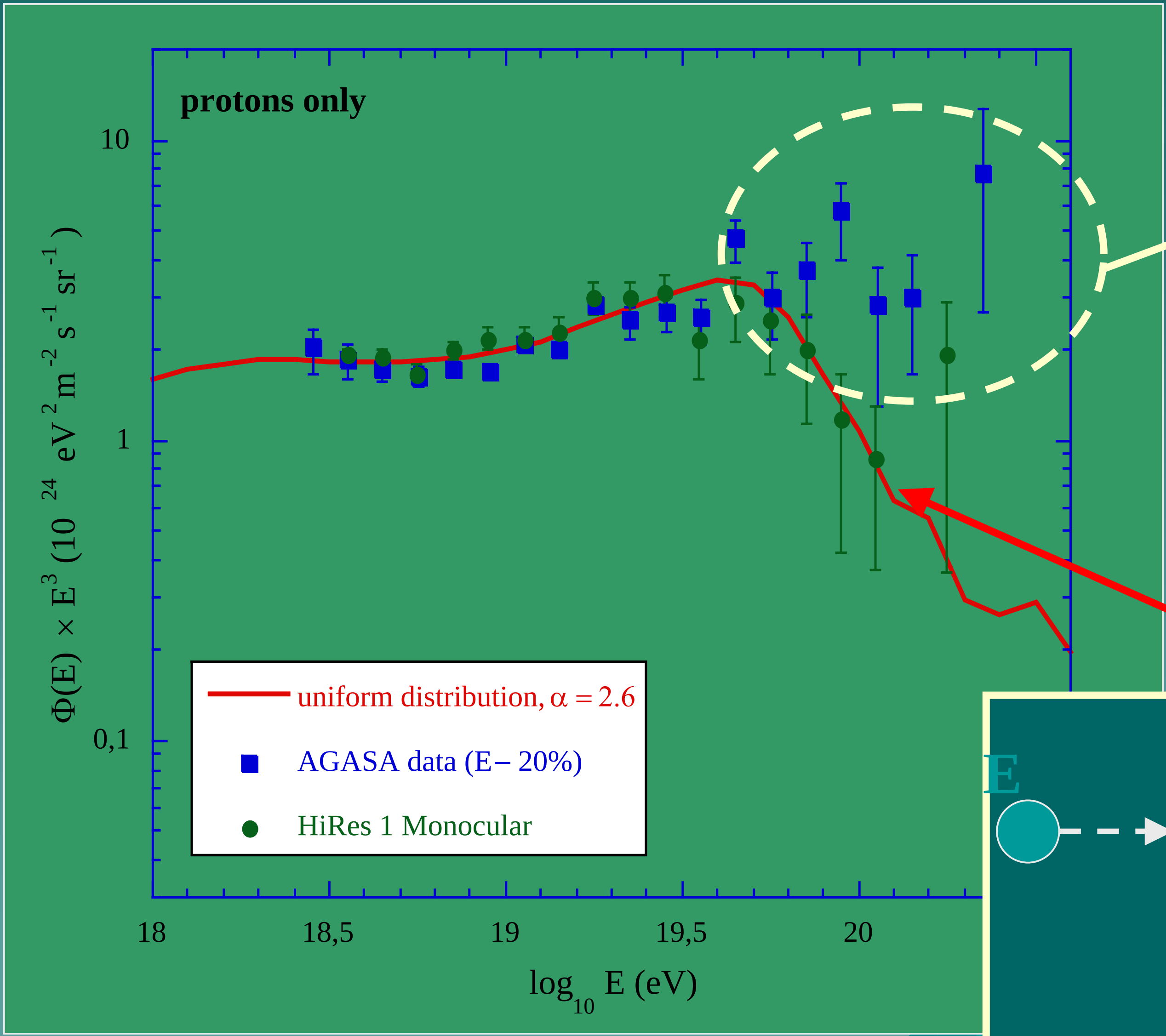


Multi-Messenger Astronomy



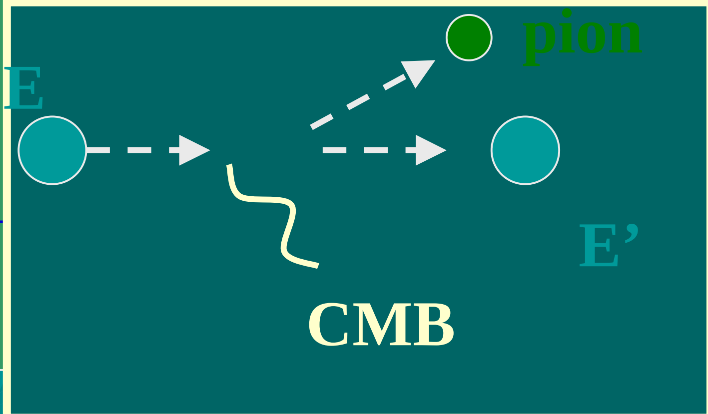
Light and gamma rays absorbed on matter and radiation
Charged cosmic rays deviated by magnetic fields
Neutrino trace back to the source, even the most distant

Ultra High Energy Cosmic Rays

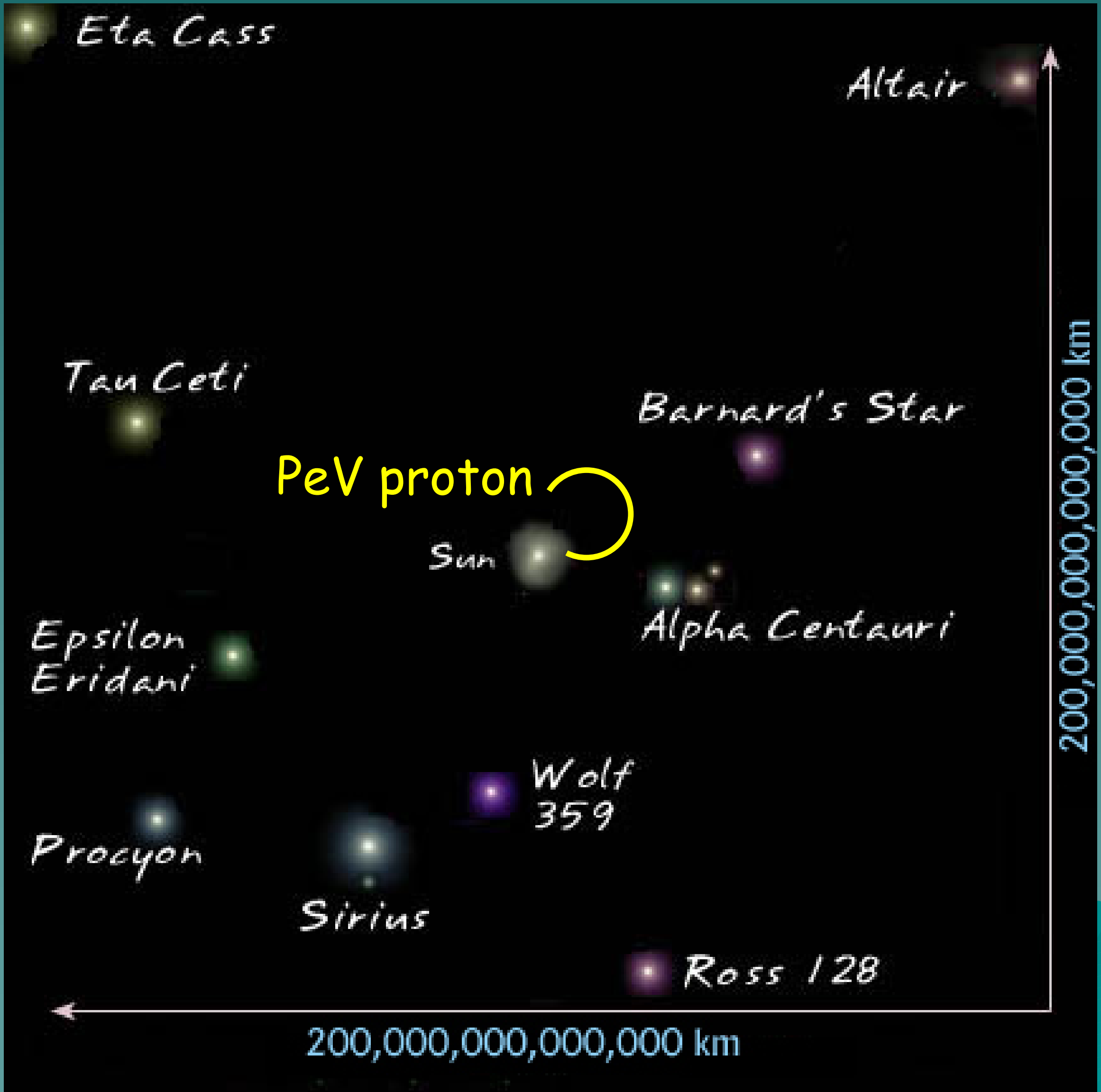


New physics ?

GZK cut-off



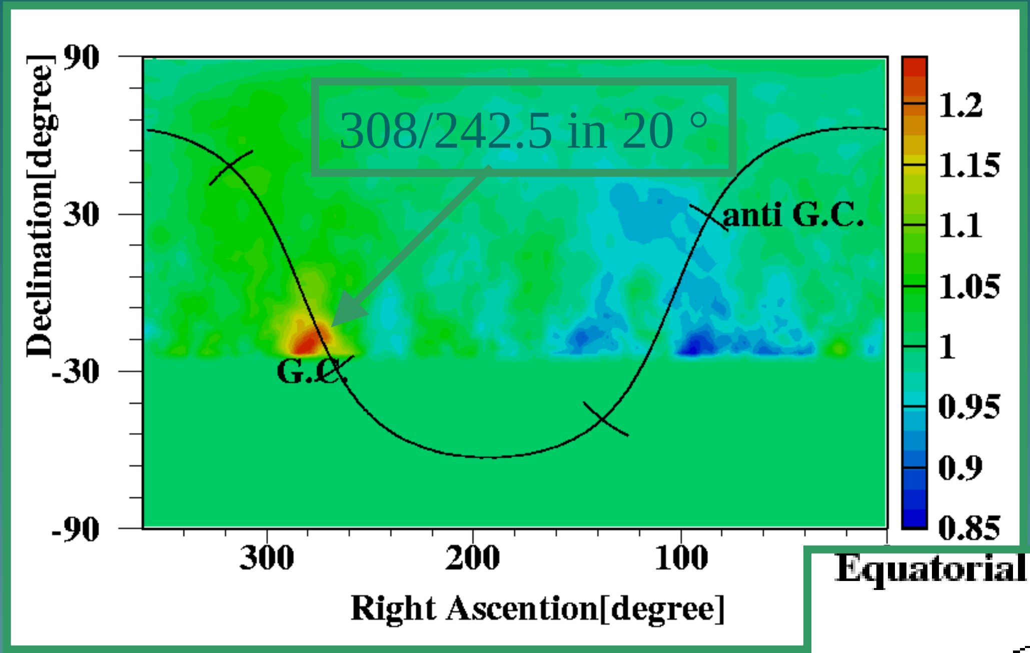
Astronomy with charged comic rays not easy ....



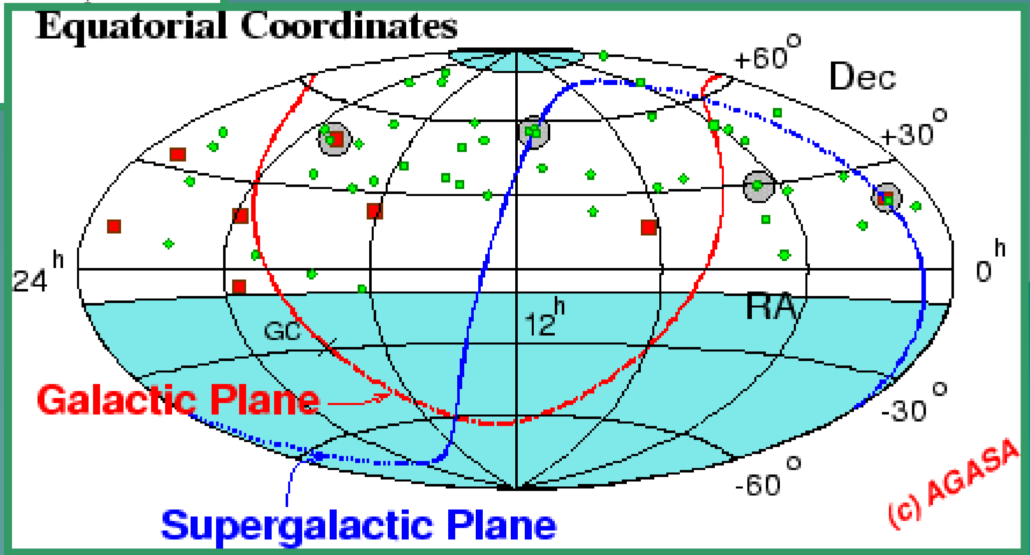
M. Masetti

Origin of Cosmic Rays

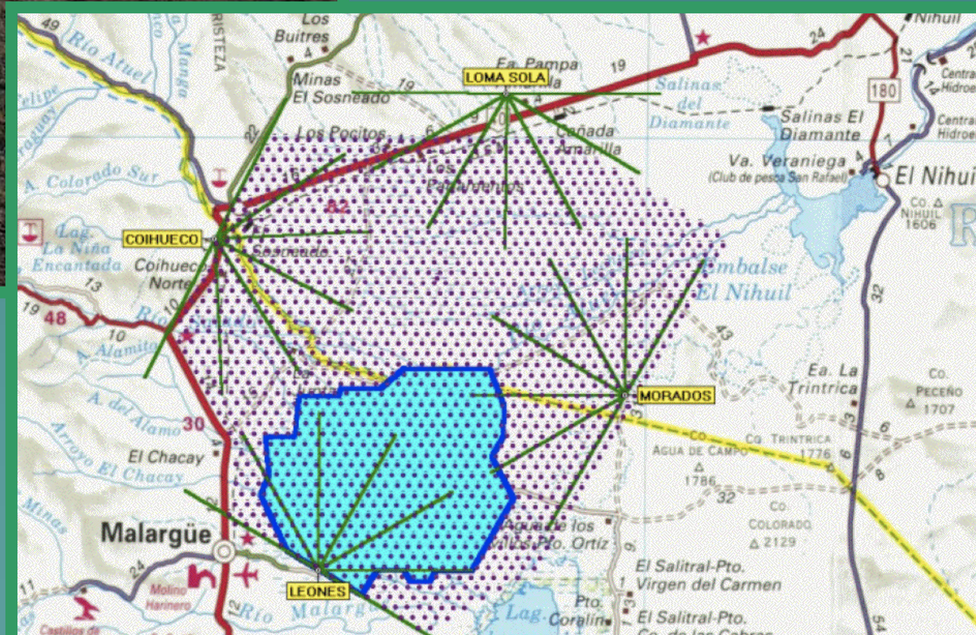
$8 \times 10^{17} < E < 8 \times 10^{18}$ eV



$E > 4 \times 10^{19}$ eV



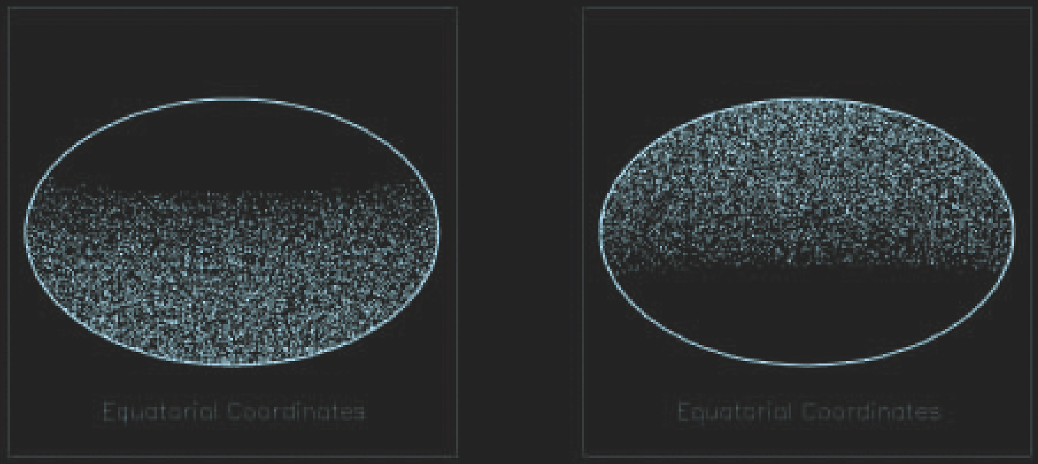
Auger Observatory in Argentina



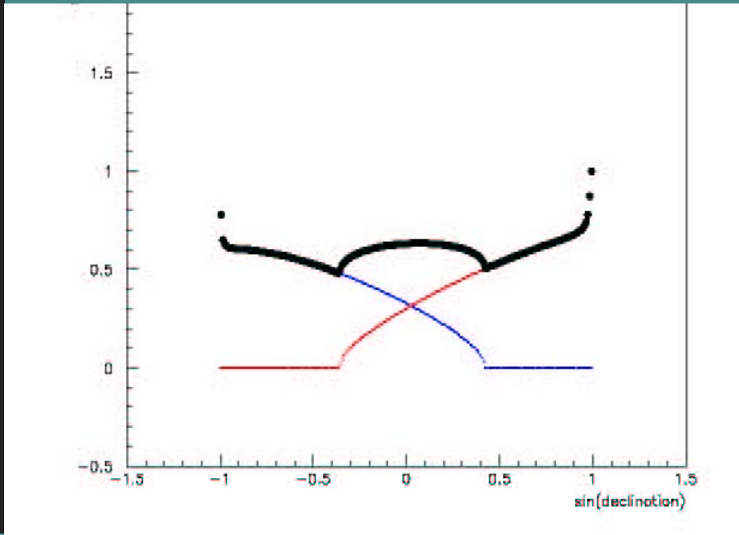
AUGER-North

Proposal for Northern site :USA Utah or Colorado

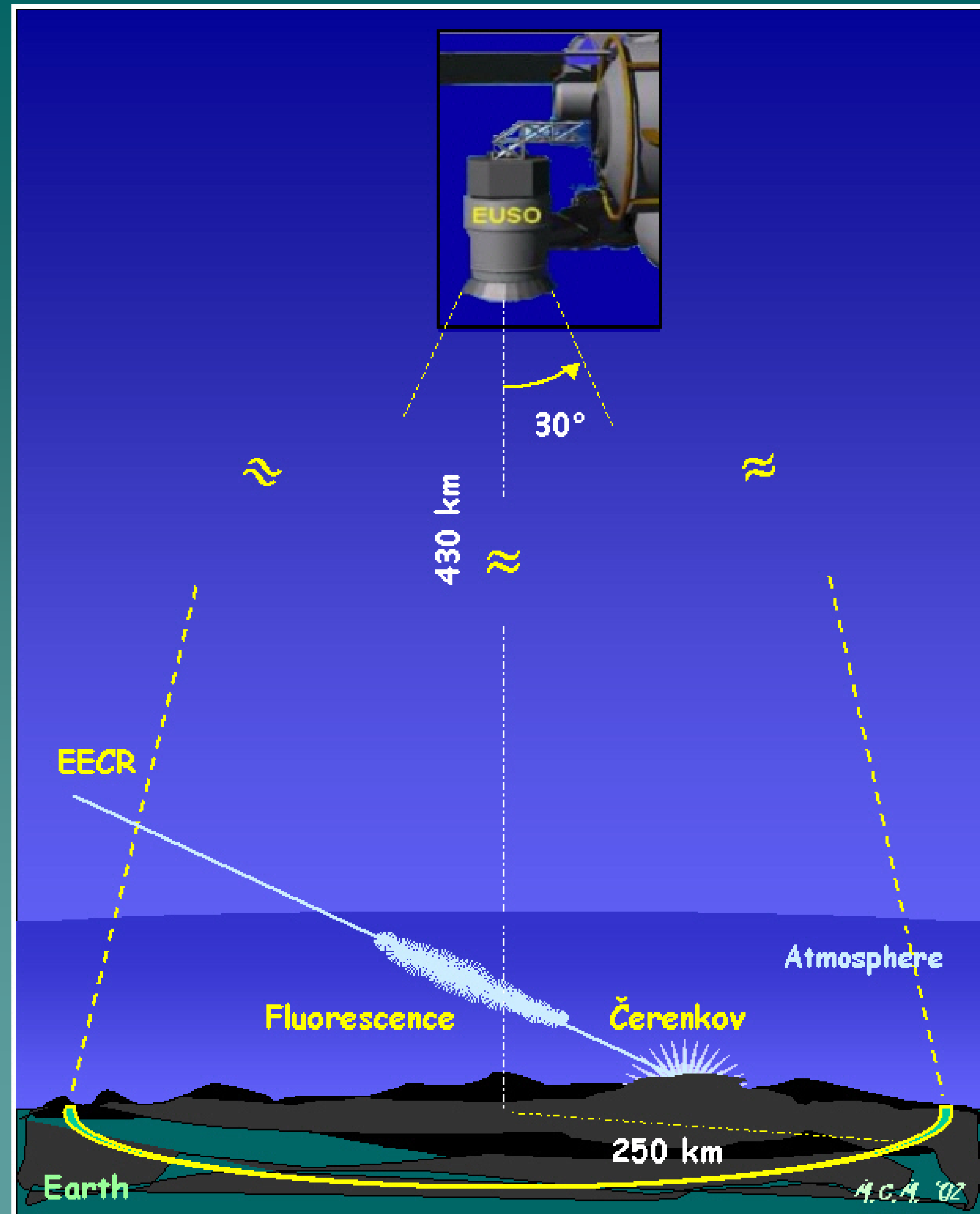
Uniform Exposure



Equatorial Coordinates



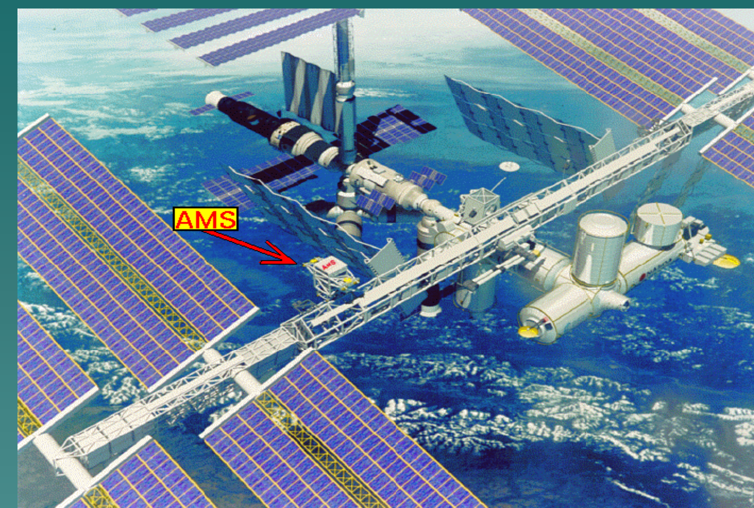
EUSO concept: Detecting air showers from space.

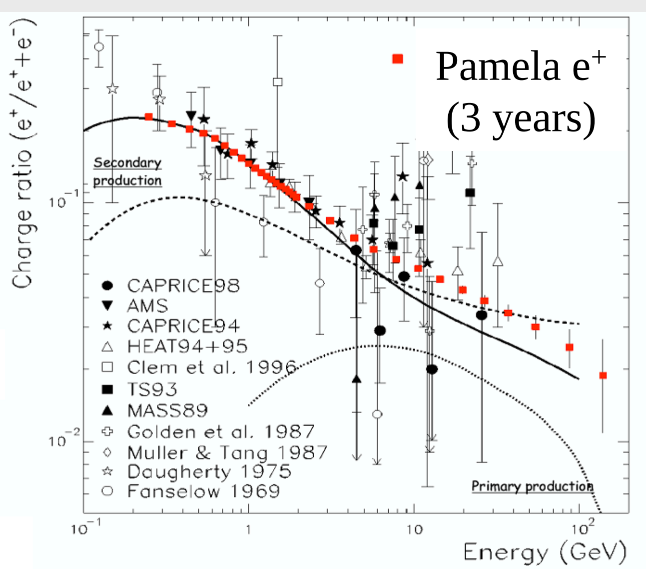


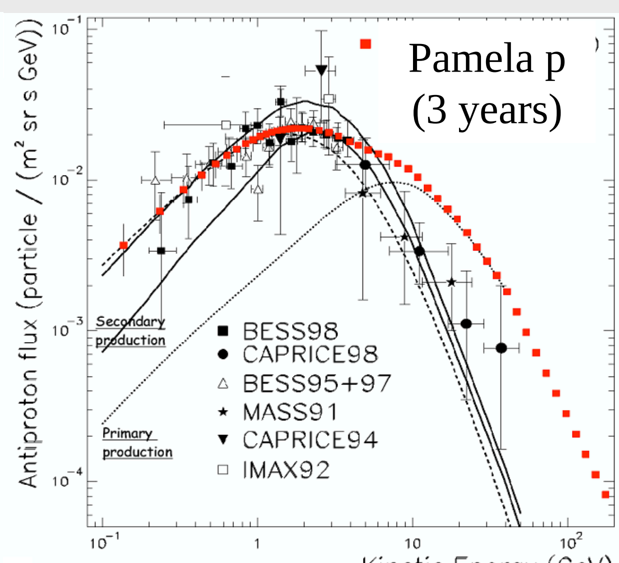
Dark matter search with charged cosmic rays and gammas

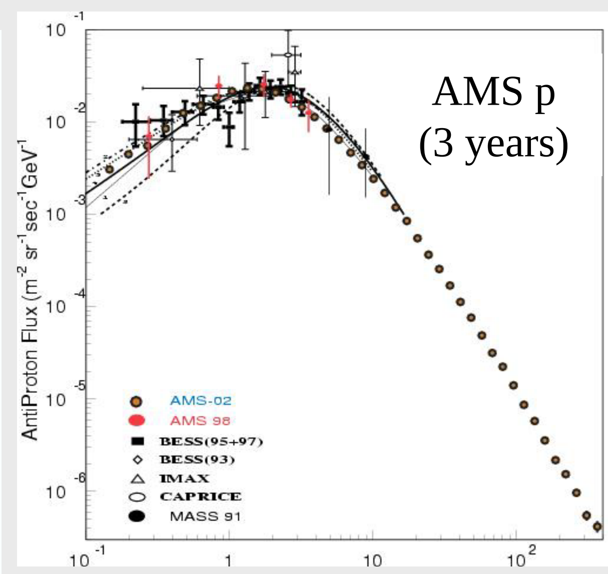
PAMELA: satellite launch 2004

AMS International Space Station: 2007





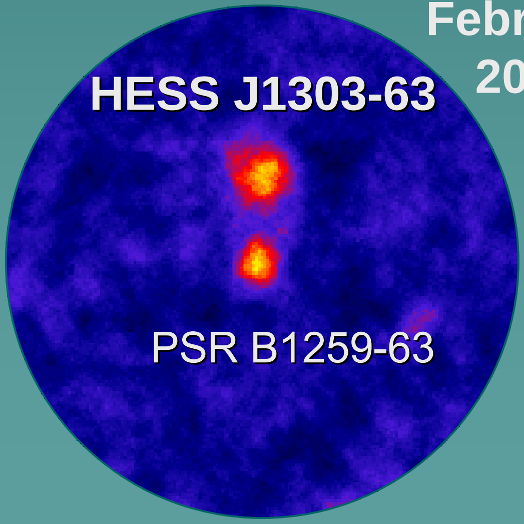


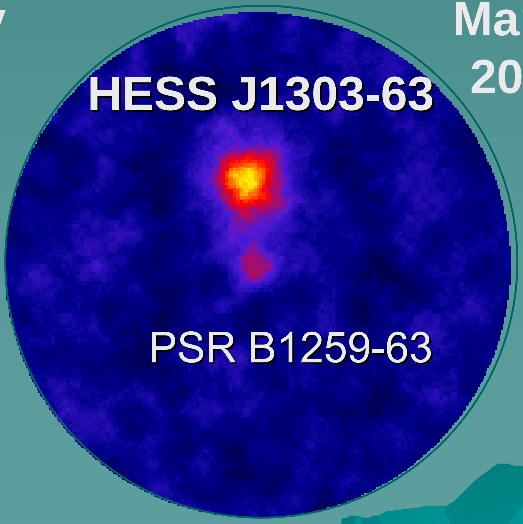


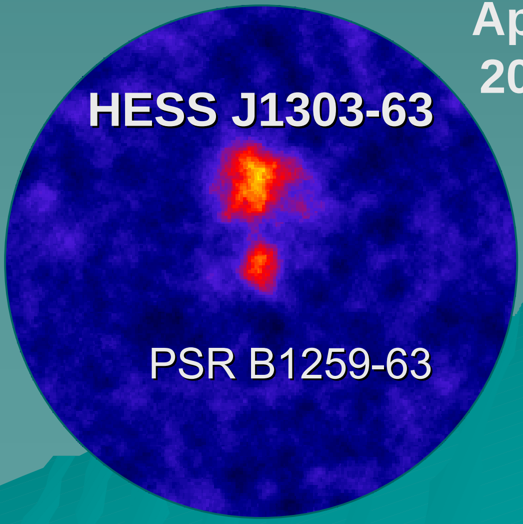
Gamma Ray Telescope Projects

HESS gamma ray telescope in Namibia

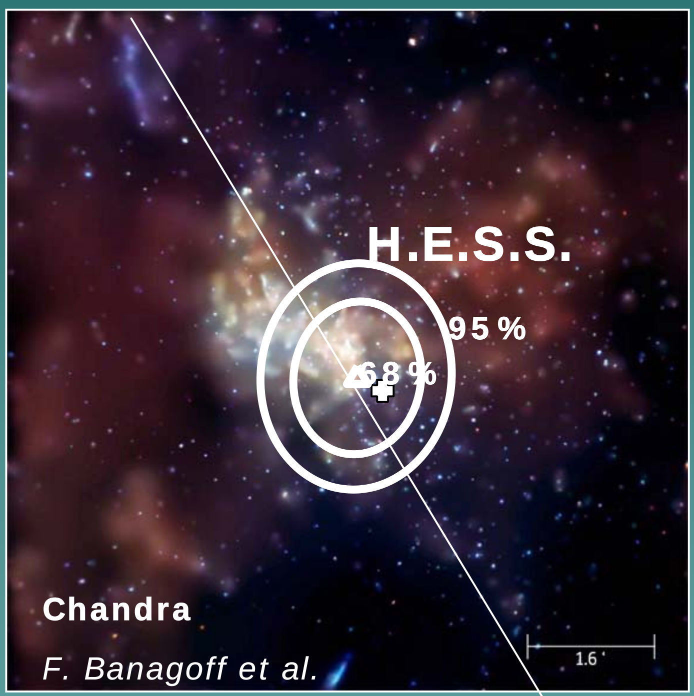
Example of recent observation previously unknown source :

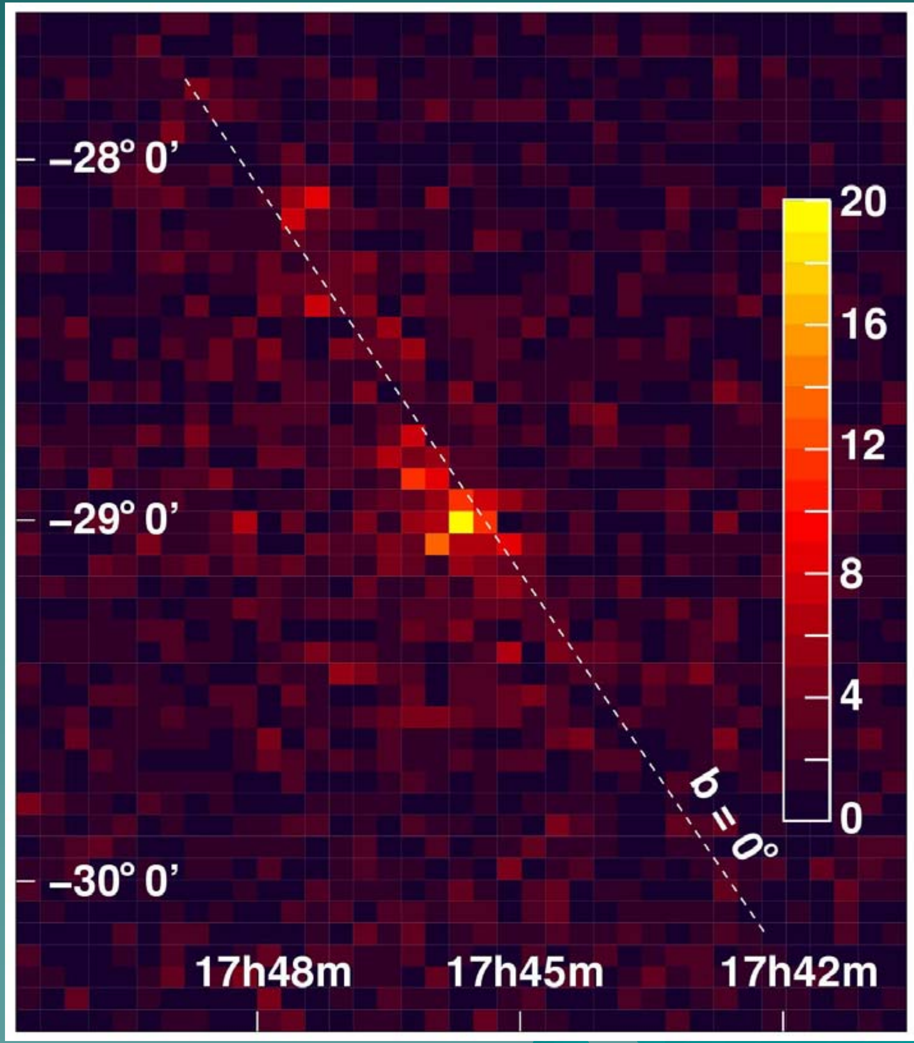




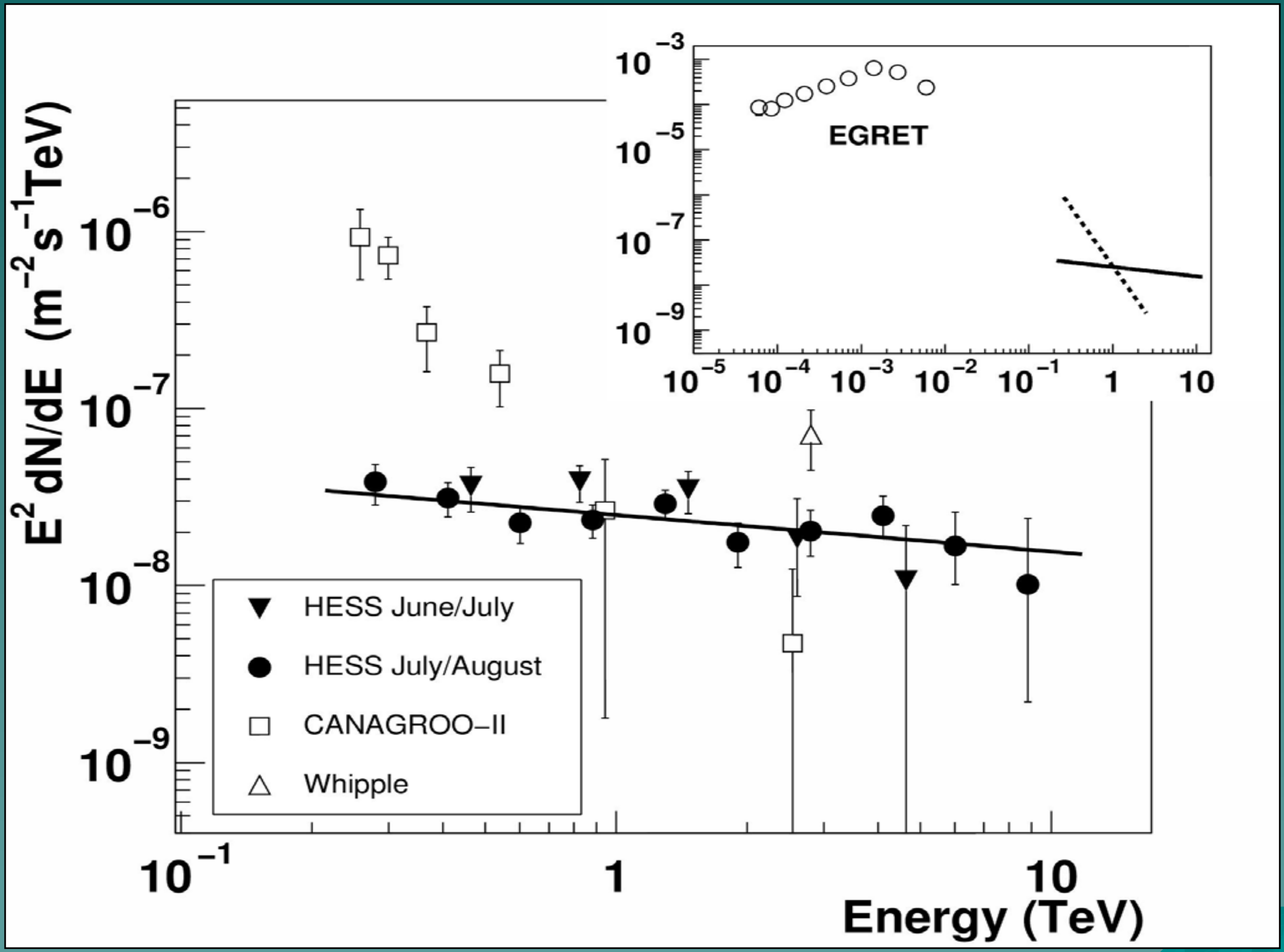


Observation of Galactic Centre : HESS





Energy Spectrum of GC



(If interpreted as Dark Matter M_χ > 12 TeV)

HESS II

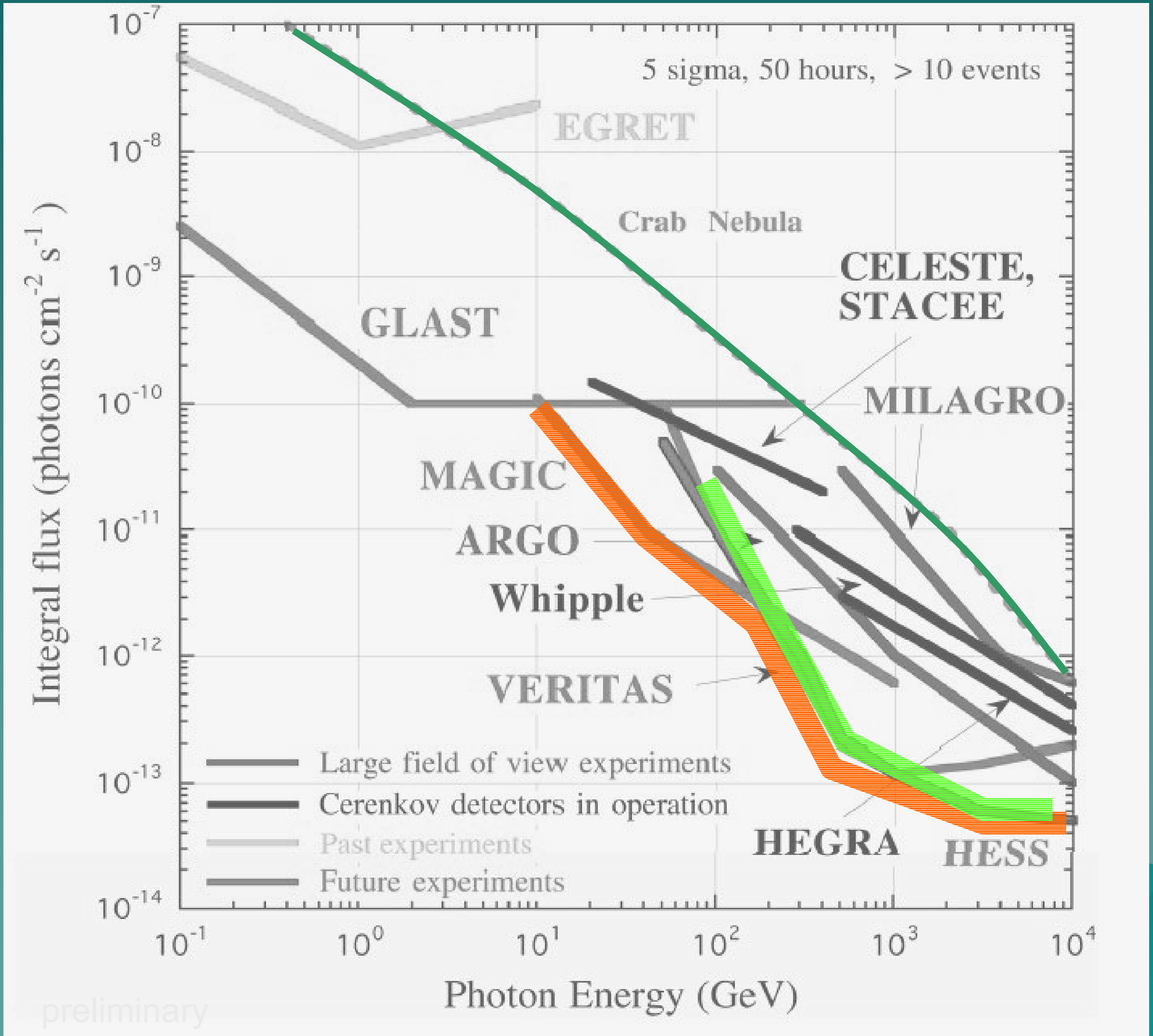
Add large 35m dish at middle of existing 4 telescopes

Future of satellite gammas: GLAST

- Launched in 2007
  Lifetime: 5 y (goal 10 y)
- Payload to be built by a wide collaboration of Astrophysics and Particle Physics institutes in USA, France, Italy, Germany, Sweden and Japan

Energy range:	10 MeV to > 300 GeV
Field of view:	> 3 sr
Source location accuracy:	30" - 1'
Energy resolution (1 σ):	2% (> 10 GeV)
Sensitivity (2-y survey):	$2\ 10^{-9}\ cm^{-2}\ s^{-1}$ (> 100 MeV)

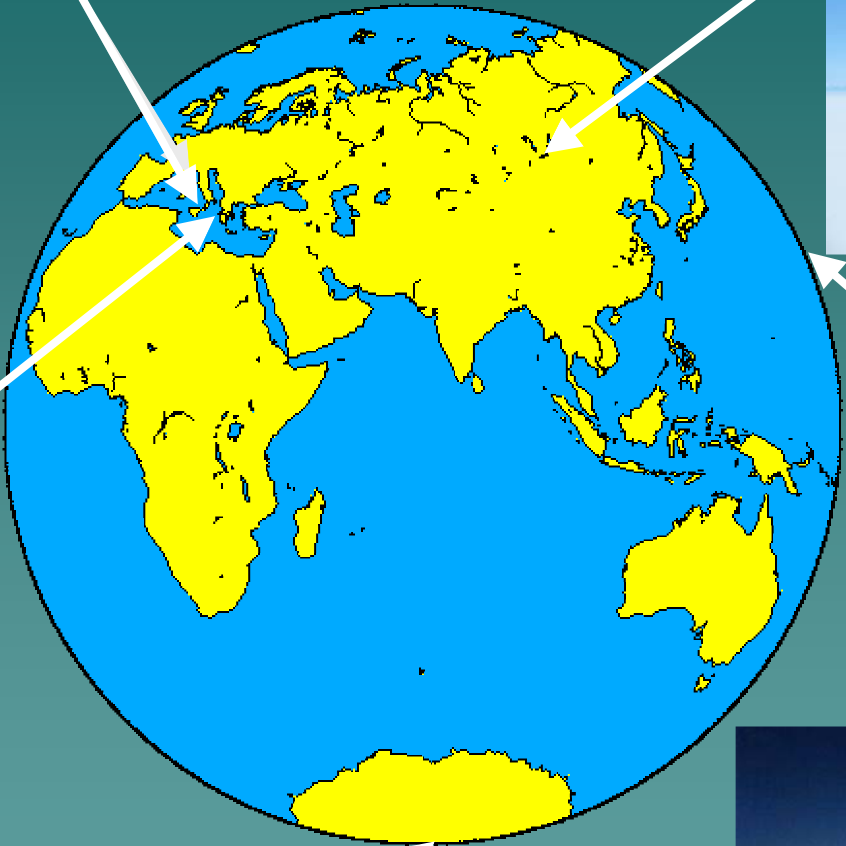
Gamma Ray Astronomy in 2008



Neutrino Telescope Projects

ANTARES La-Seyne-sur-Mer, France
(NEMO Catania, Italy)

BAIKAL: Lake Baikal, Siberia



NESTOR : Pylos, Greece

DUMAND,
Hawaii
(cancelled 1995)

AMANDA, South Pole, Antarctica

Neutrino weak interactions with matter

Unique properties of neutrinos :

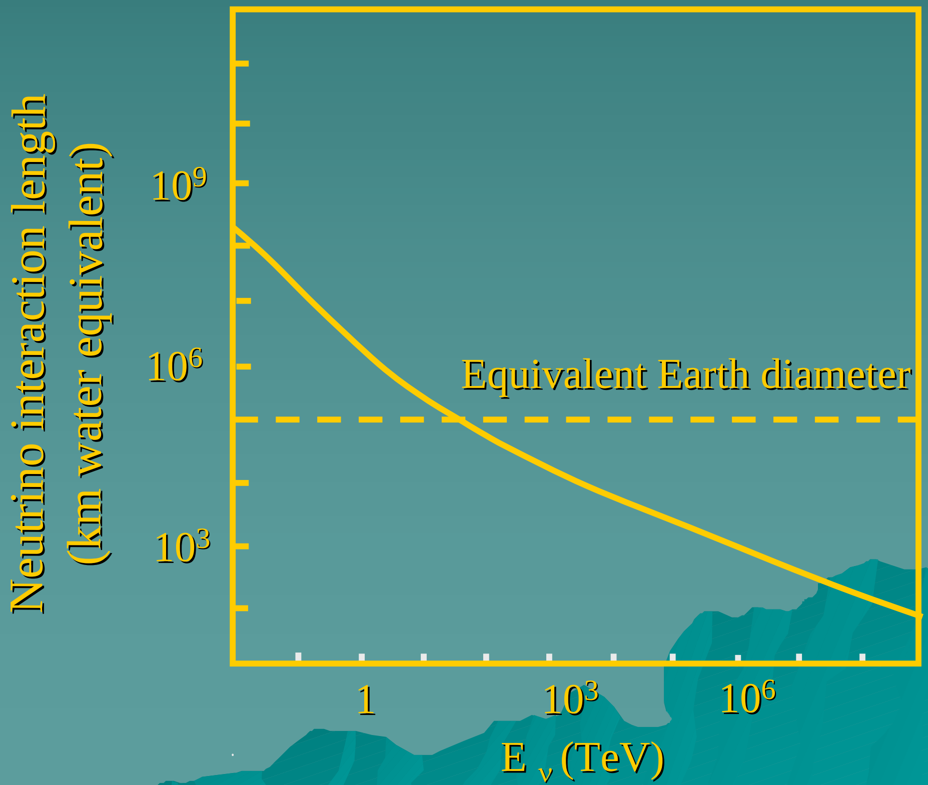
Astronomic sources and universe transparent to neutrinos

but …

Need massive detectors to observe them

Interaction length of neutrinos vs energy

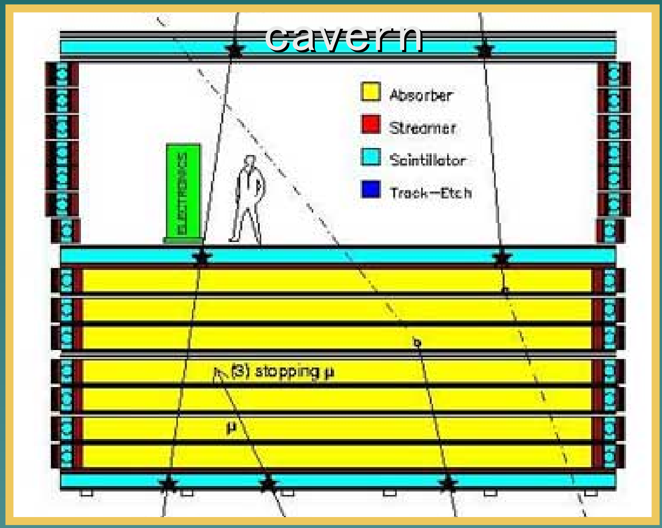
Earth transparent up to 100 TeV



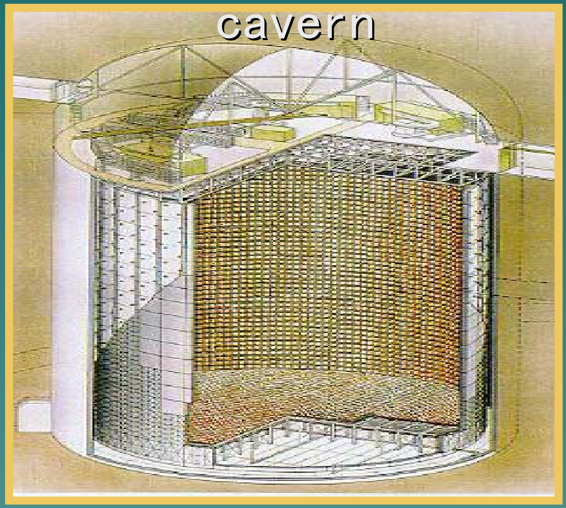
Probability of interaction
~ 10^{-5} / km water at 100 TeV

Evolution of Neutrino Telescopes

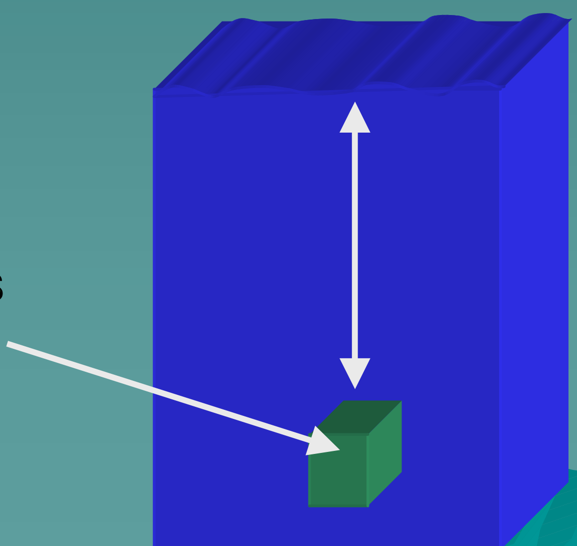
MACRO
4 K tonnes iron in cavern



SuperKamiokande
30 K tonnes water in cavern

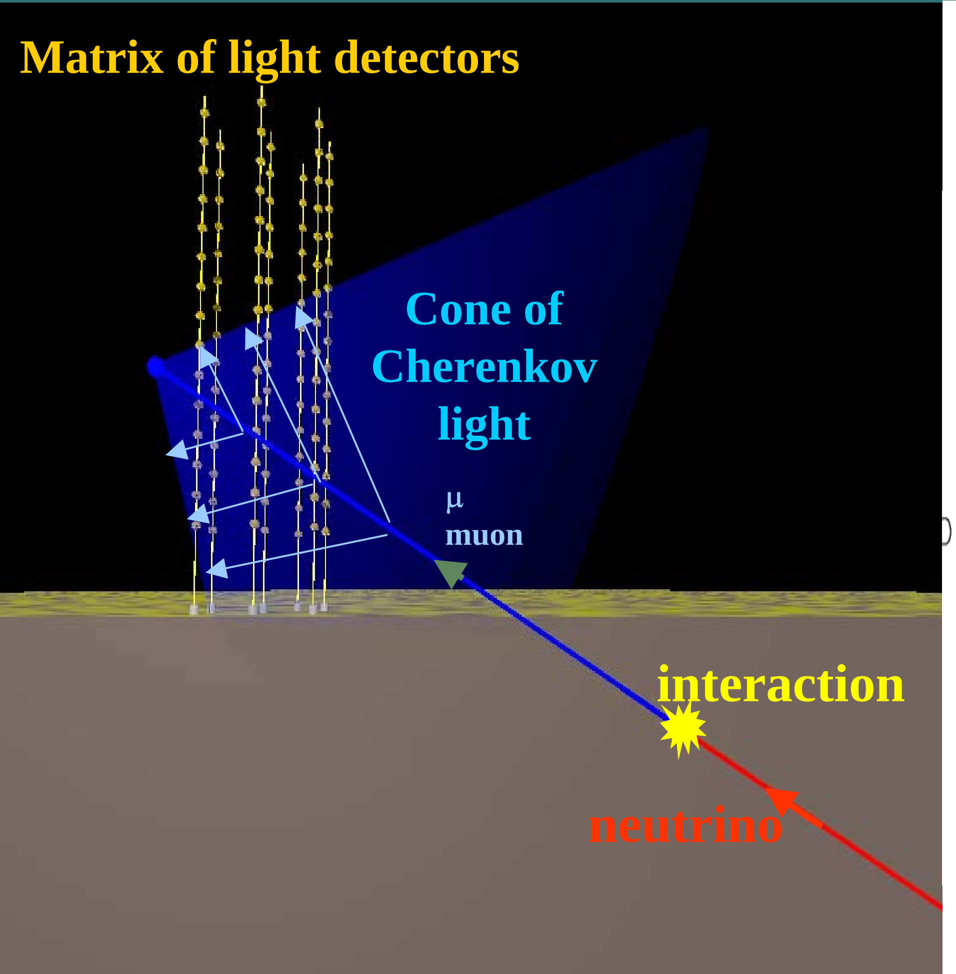


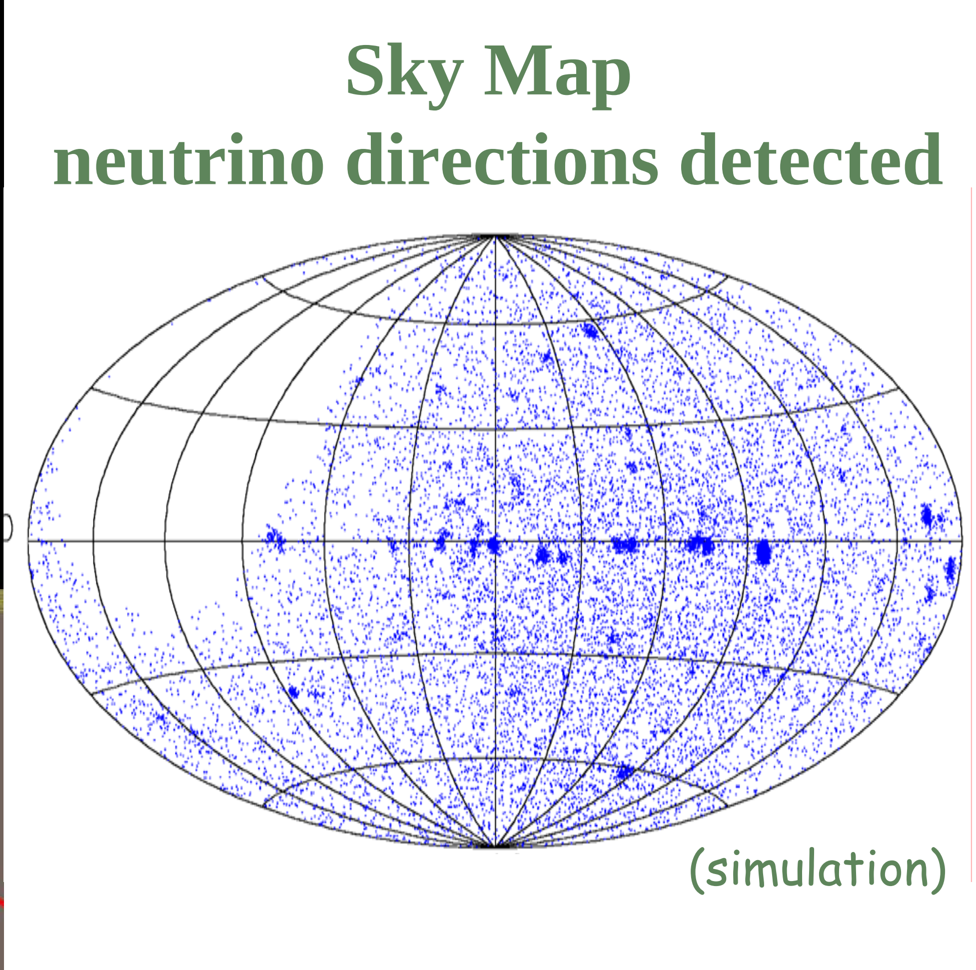
ANTARES
10 000 K tonnes water
In deep sea



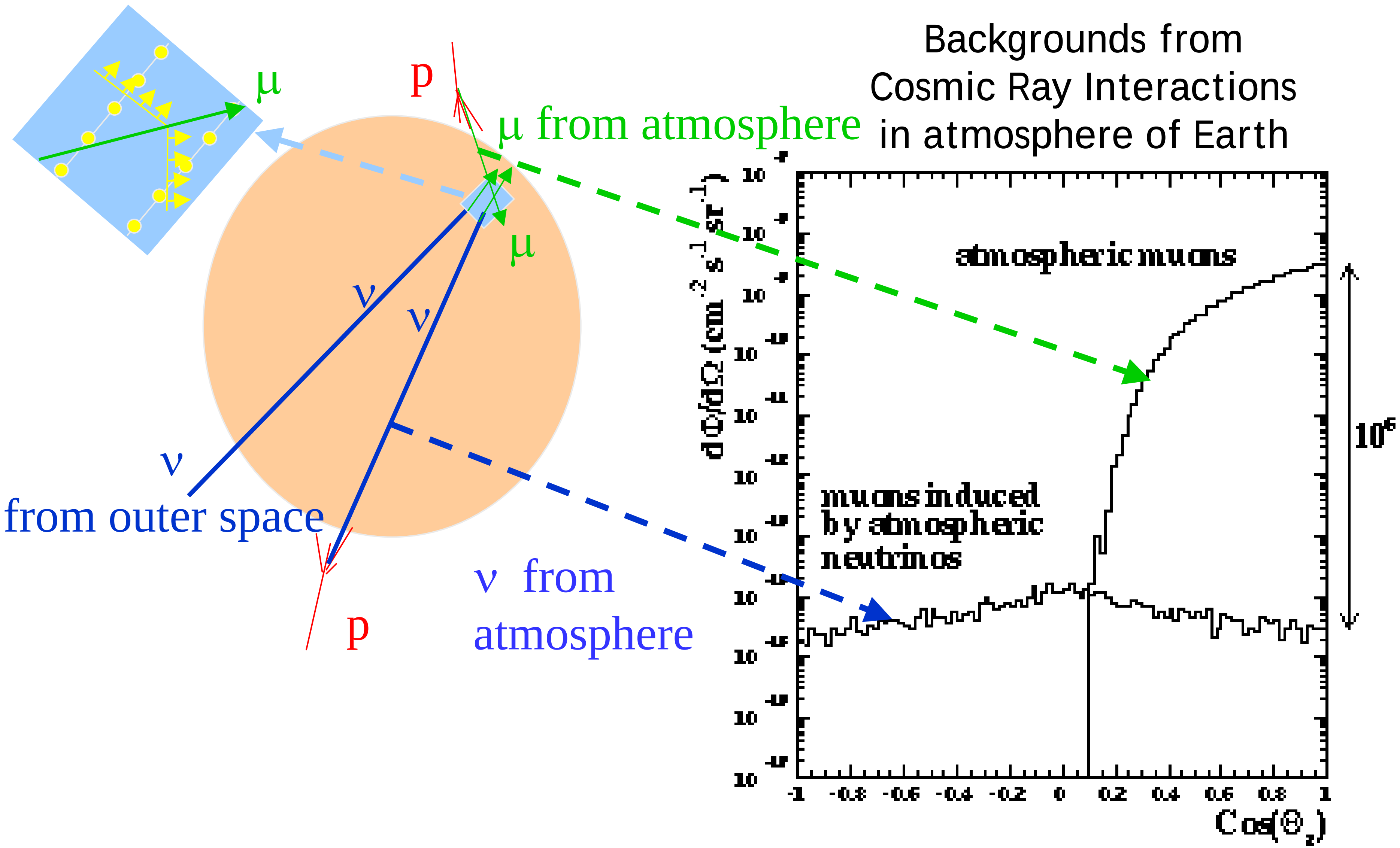
Need > 1000 m depth
to absorb light
and cosmic rays

Principle of Neutrino Astronomy

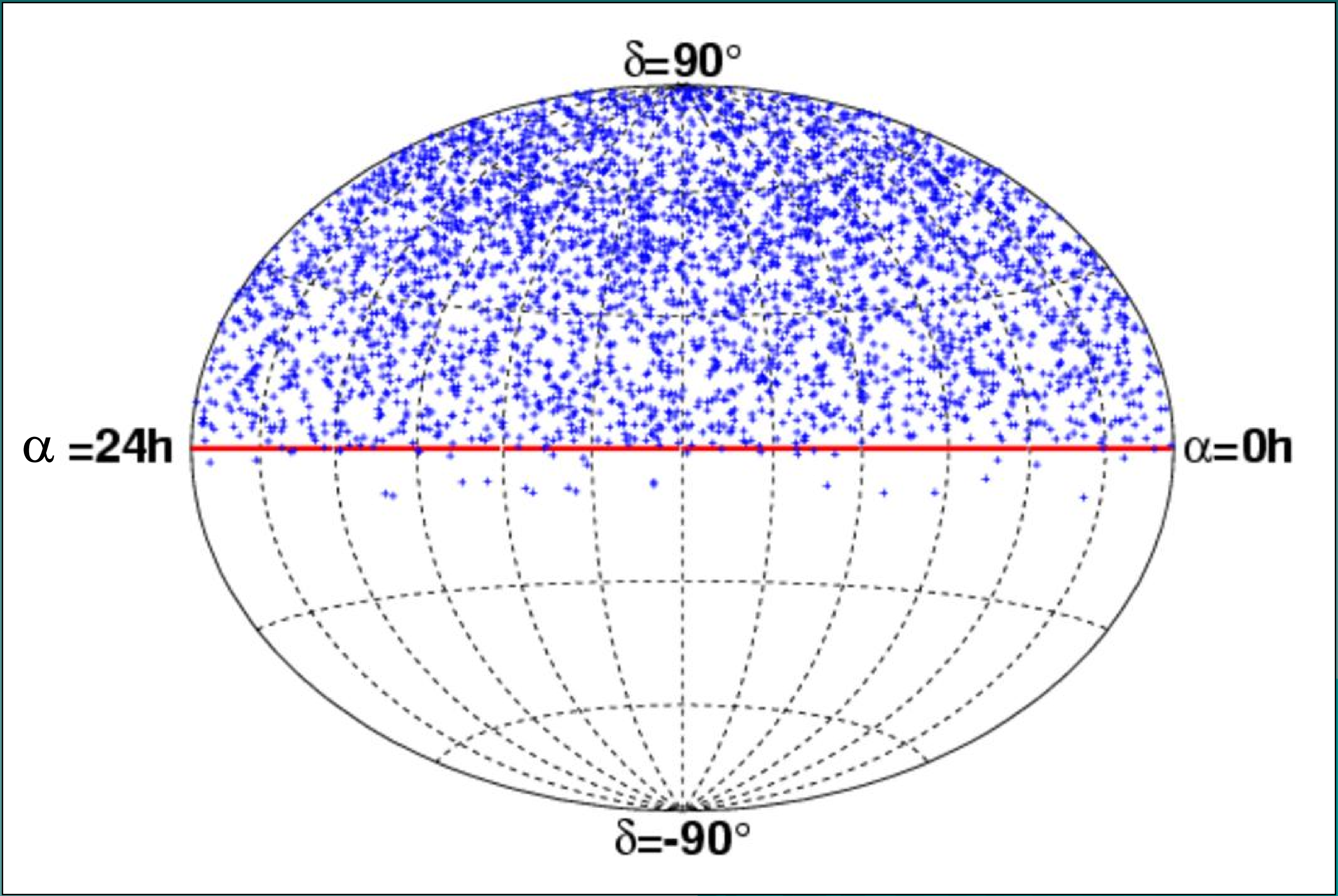




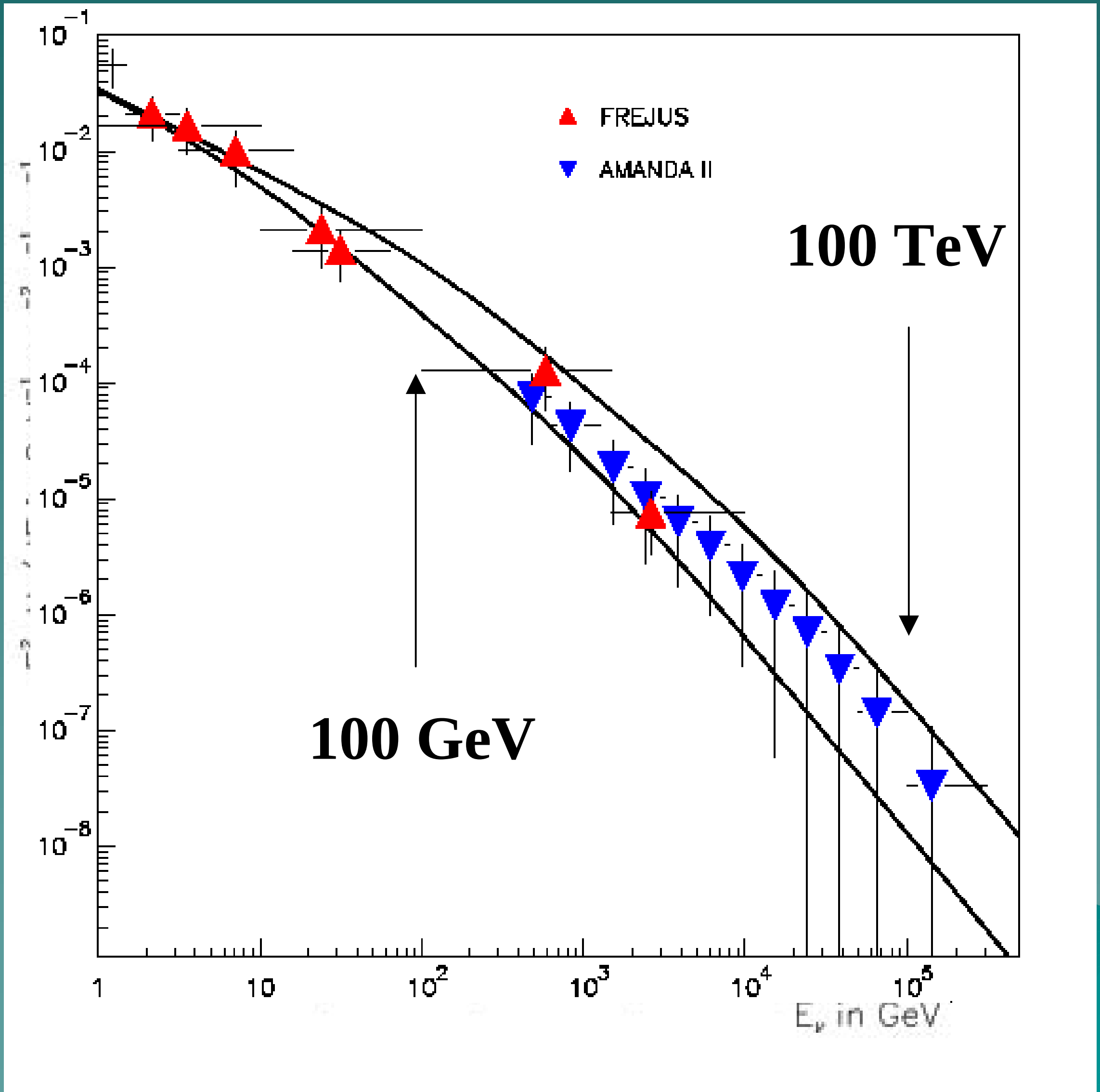
Undersea Neutrino Telescope



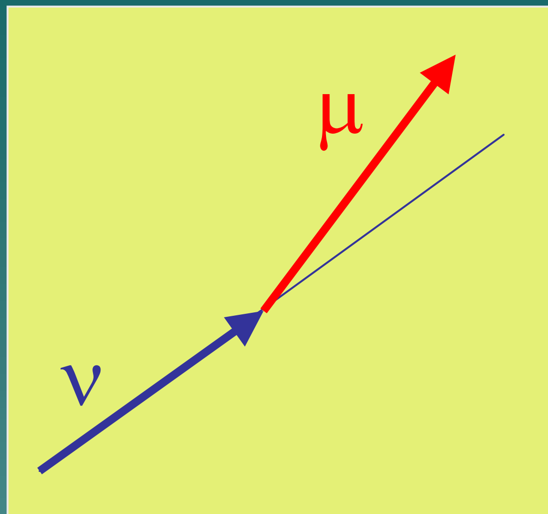
AMANDA data

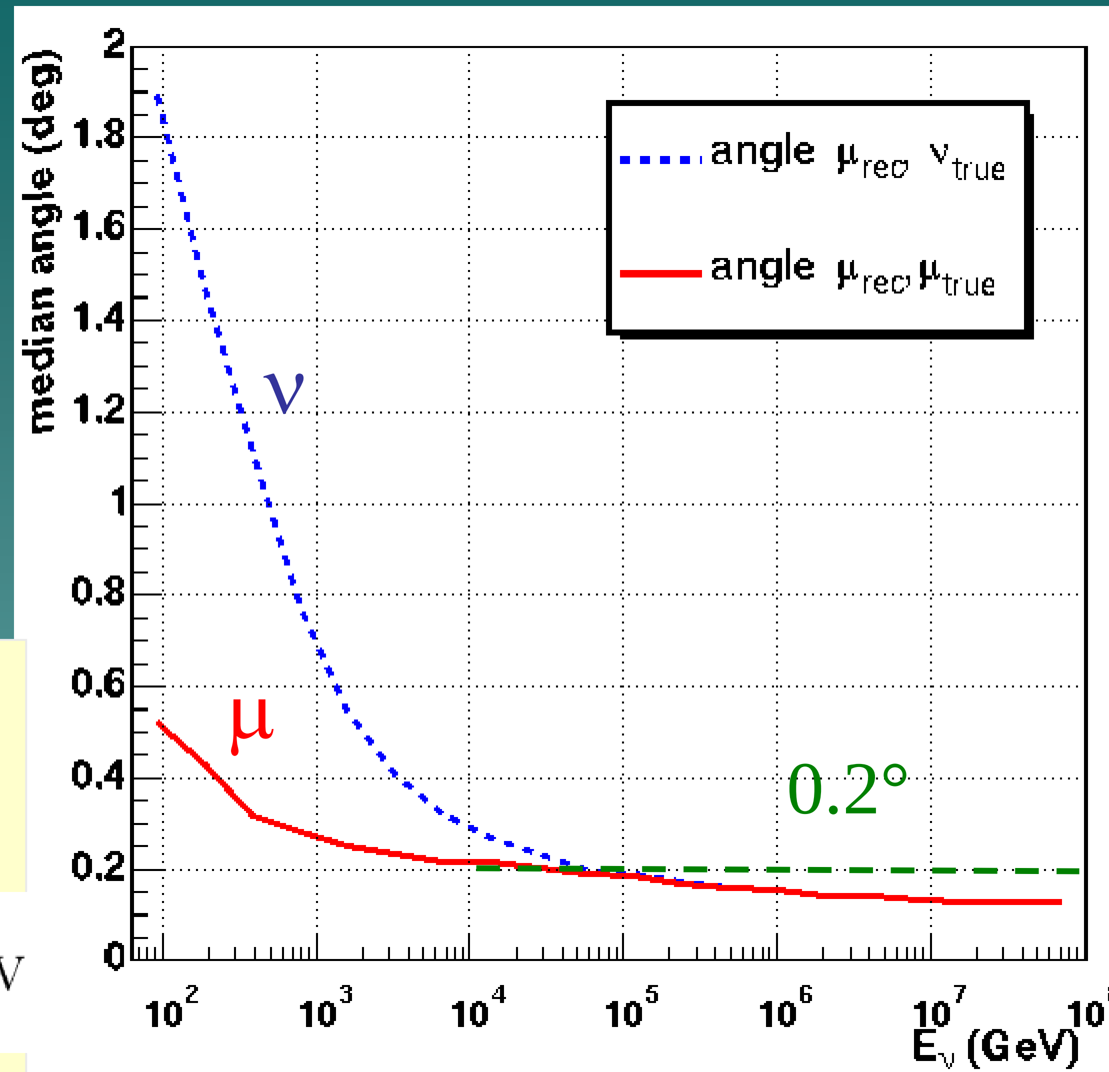


AMANDA data
Flux of atmospheric neutrinos



Angular Resolution





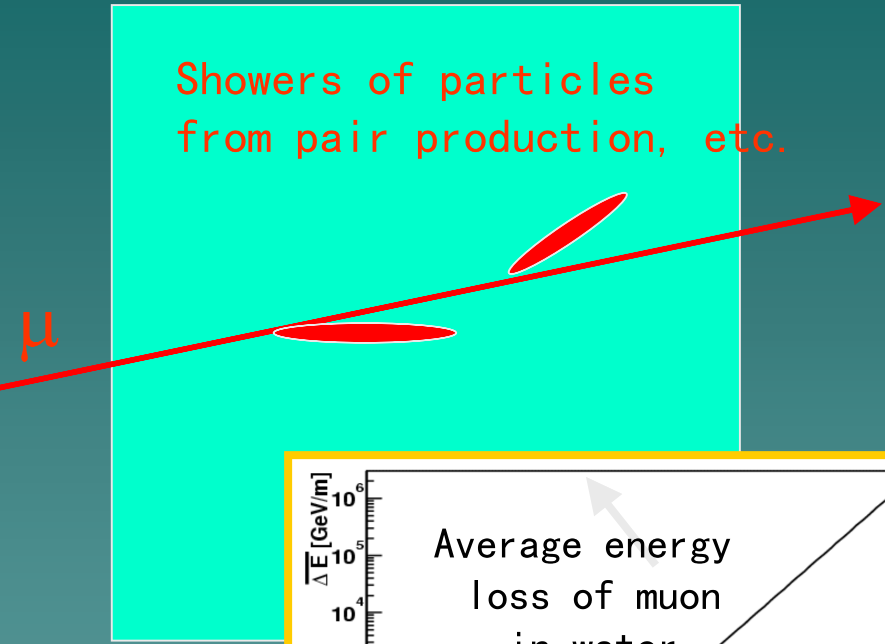
Deep inelastic scattering :

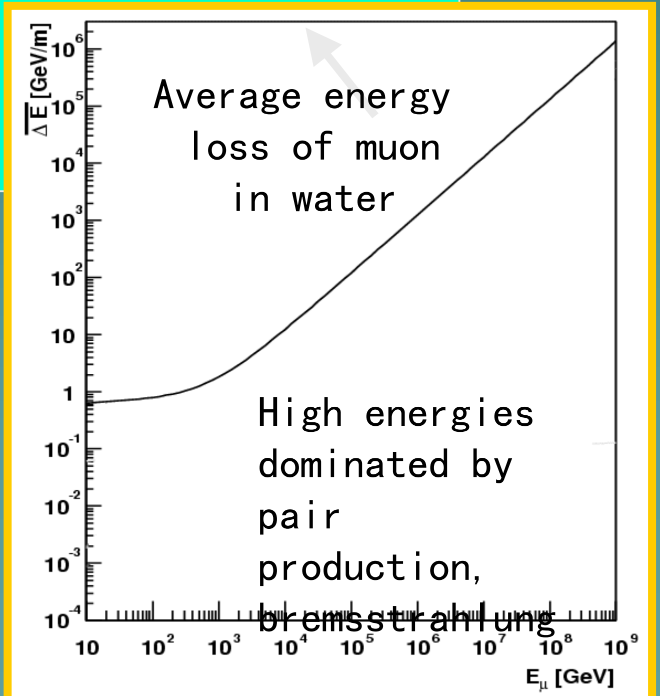
$$\sqrt{\langle \theta^2_{\mu\nu} \rangle} \approx \sqrt{\frac{m_N}{E_\nu}}$$

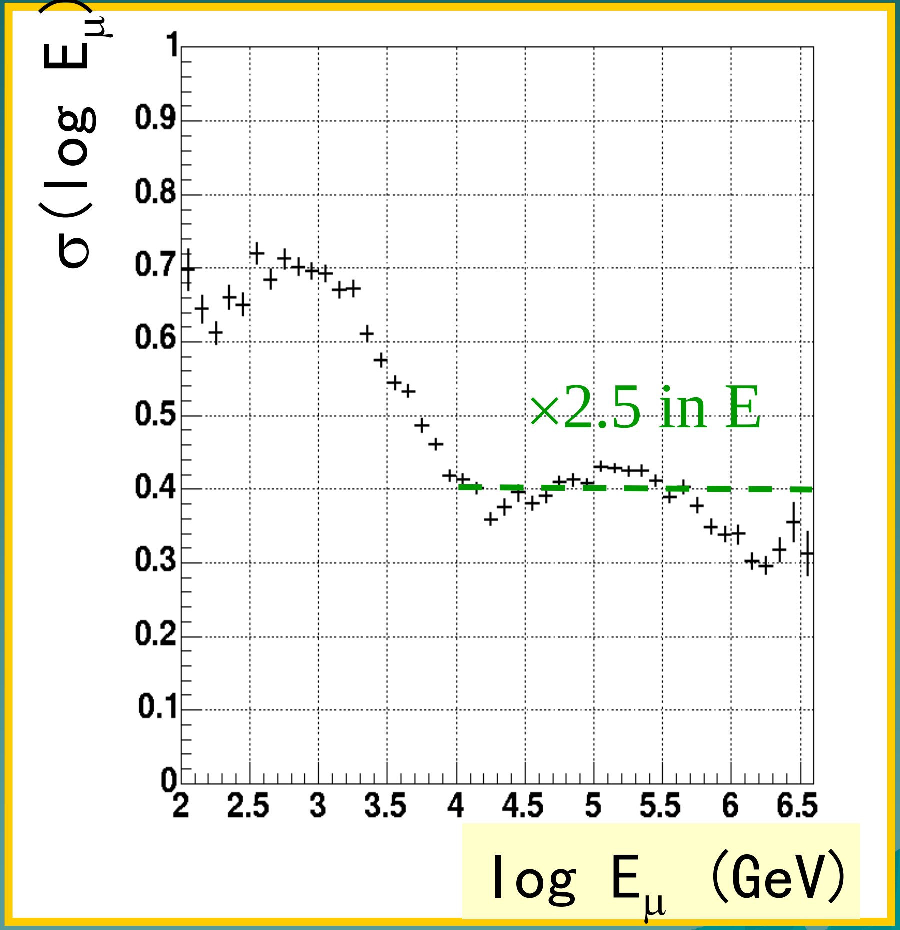
$$\langle \theta_{\mu\nu} \rangle = \frac{0,64^\circ}{(E_\nu/TeV)^{0,56}} \qquad E_\nu > 10\ \mathrm{TeV}$$

~ 0.2° at 100 TeV :dominated by detector resolution

Energy measurement







Water versus Ice

Deployment

Ice gives solid platform to install detector

Sea experiments need boats/ platforms

Ice detectors worked first (Baikal deploys from ice)

Angular Resolution

Light scattering much less in water

AMANDA : ~ 3° (real detector)

ANTARES : ~ 0.2 ° (simulations)

Uniformity of Detector response

Water homogeneous

Ice has dust layers, bubbles

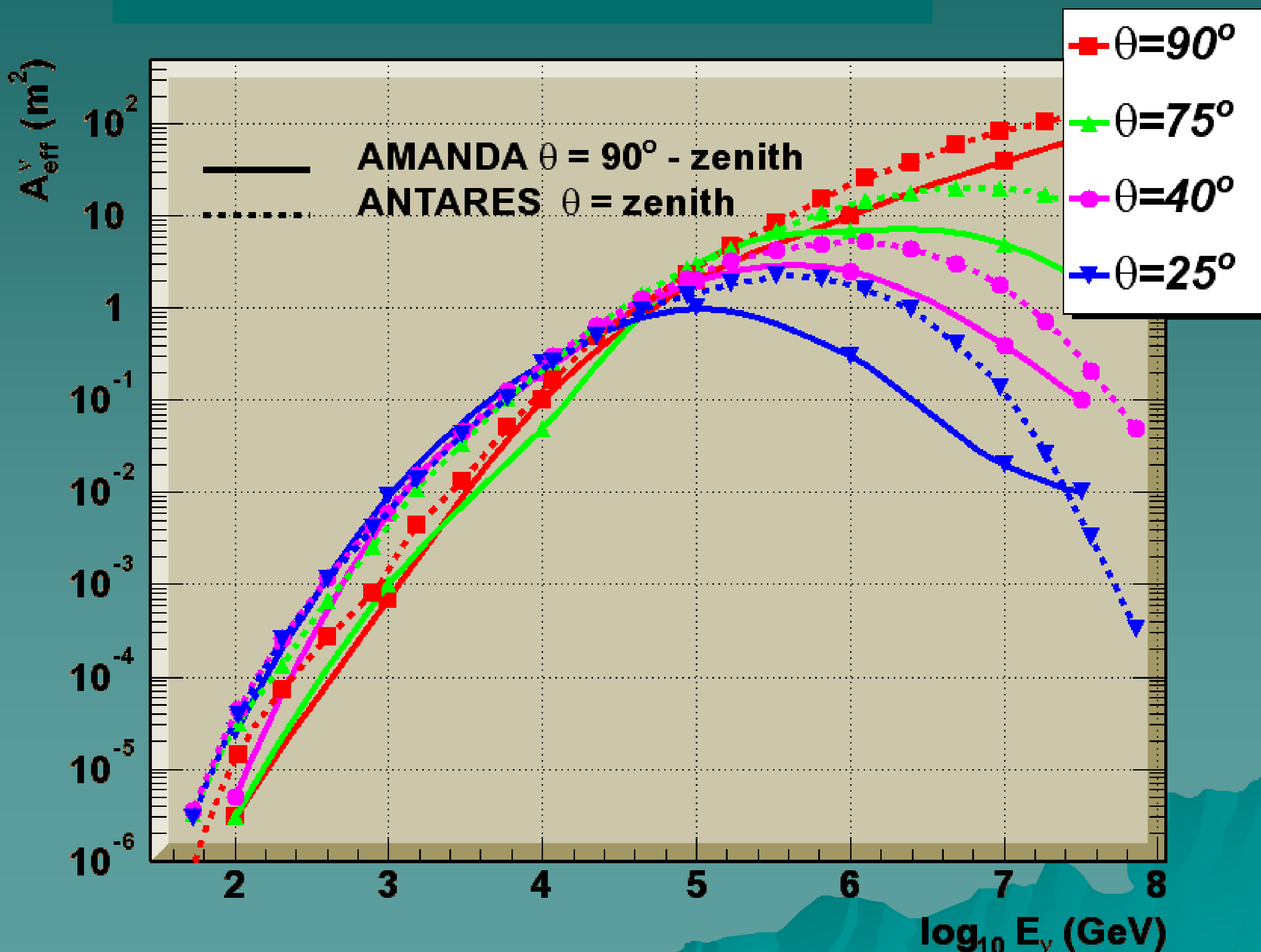
Knowledge of efficiency simpler in water

Noise Backgrounds

Water: ^{40}K /bioluminescence ~ 60kHz / PMT

Ice: only dark tube noise ~ 500Hz / PMT

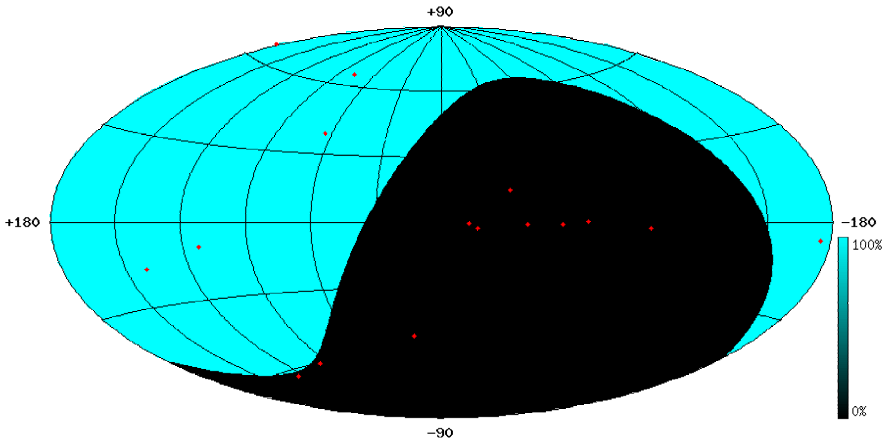
Effective Neutrino Area AMANDA / ANTARES

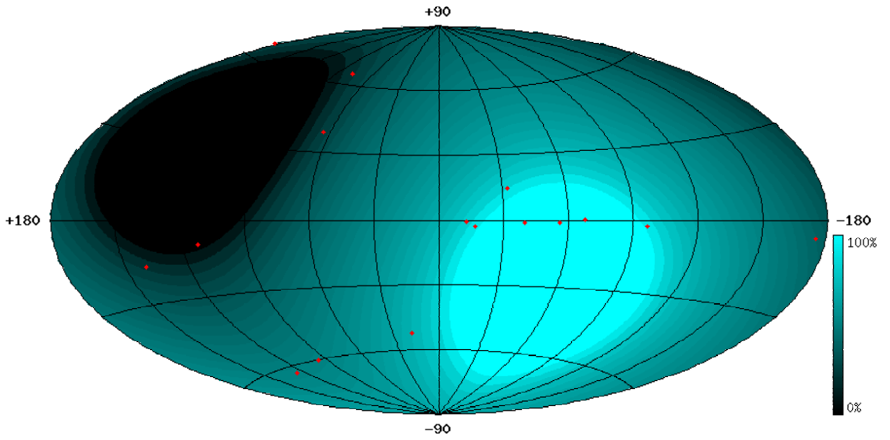


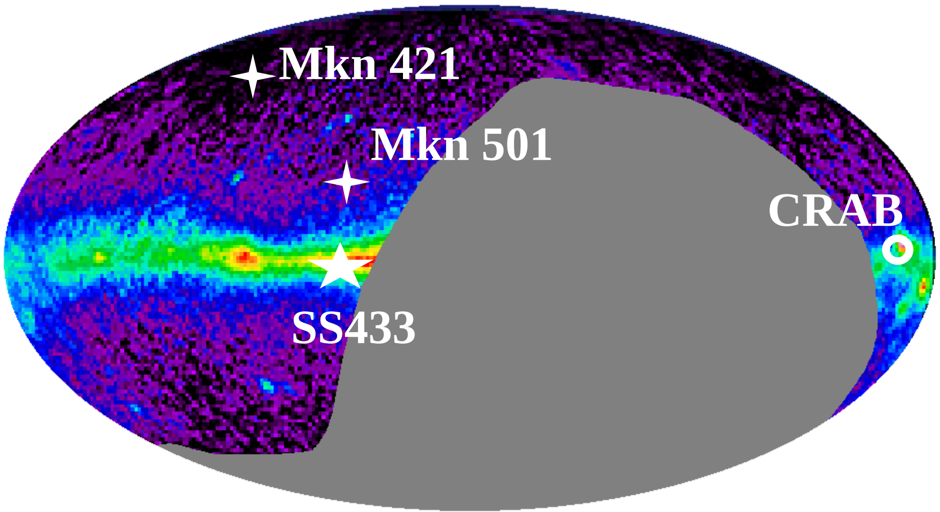
Region of sky observable by Neutrino Telescopes

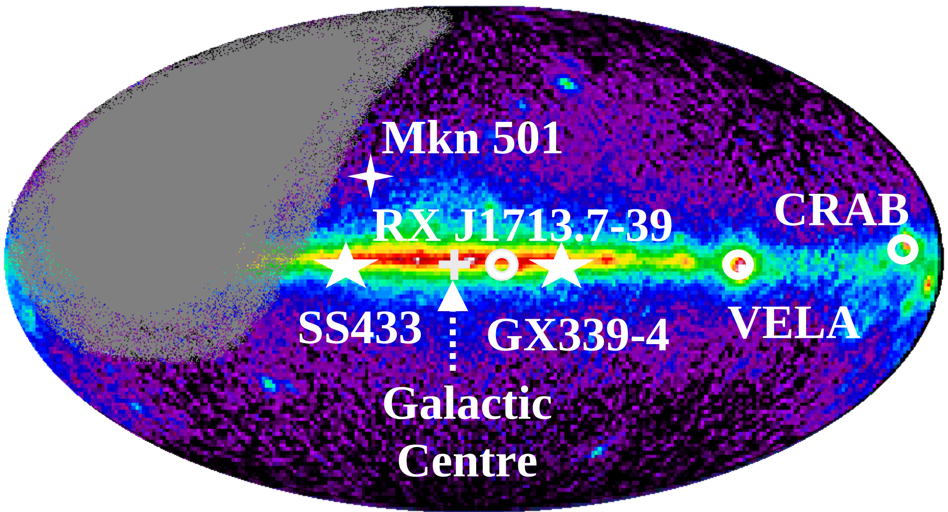
AMANDA (South Pole)

ANTARES (43° North)

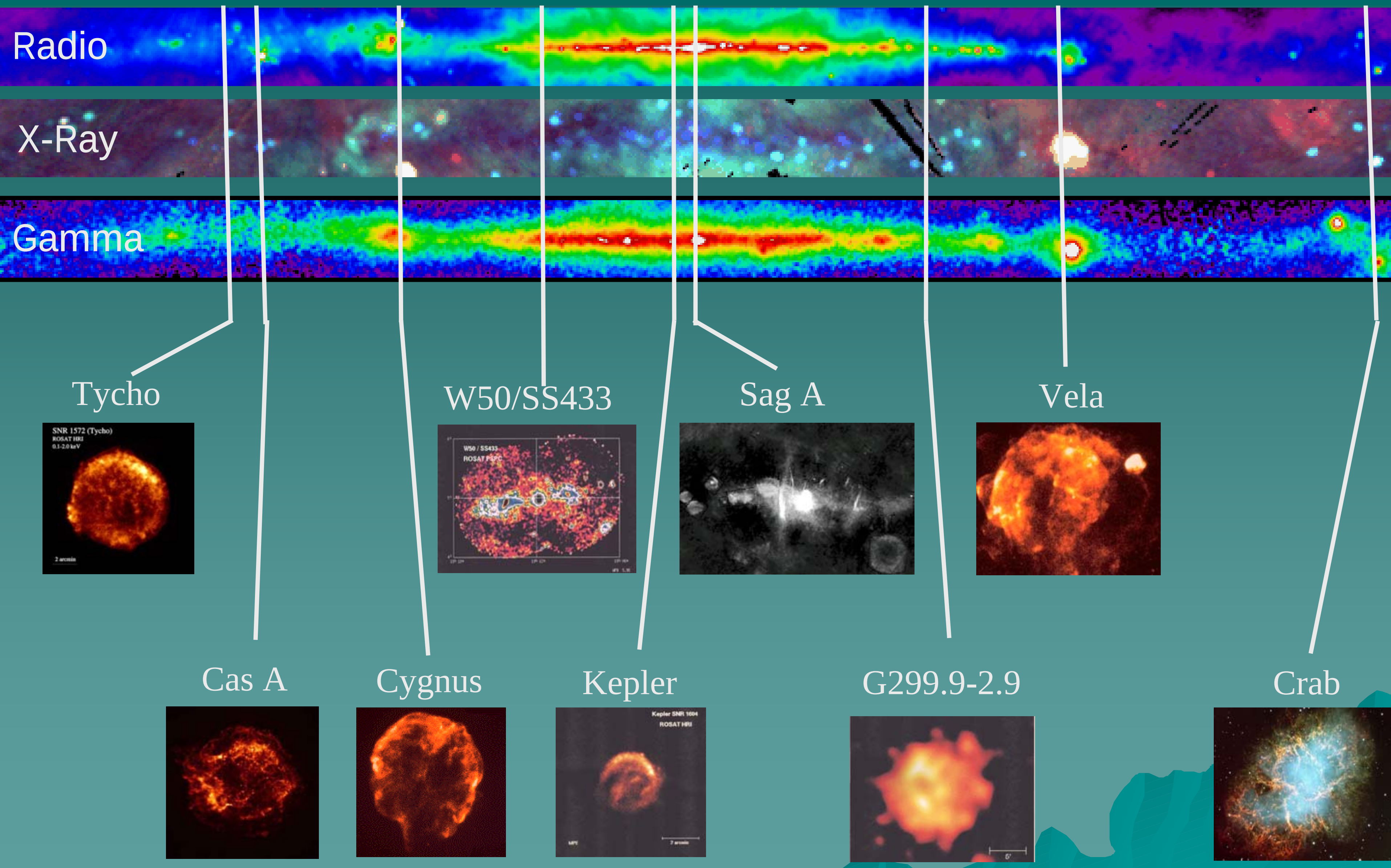








SuperNova Remnants



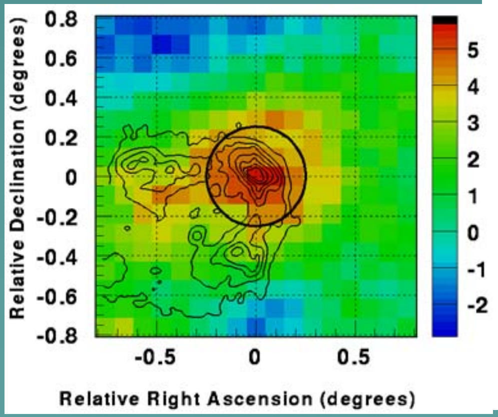
Energy Argument for Supernova Origin of Cosmic Rays

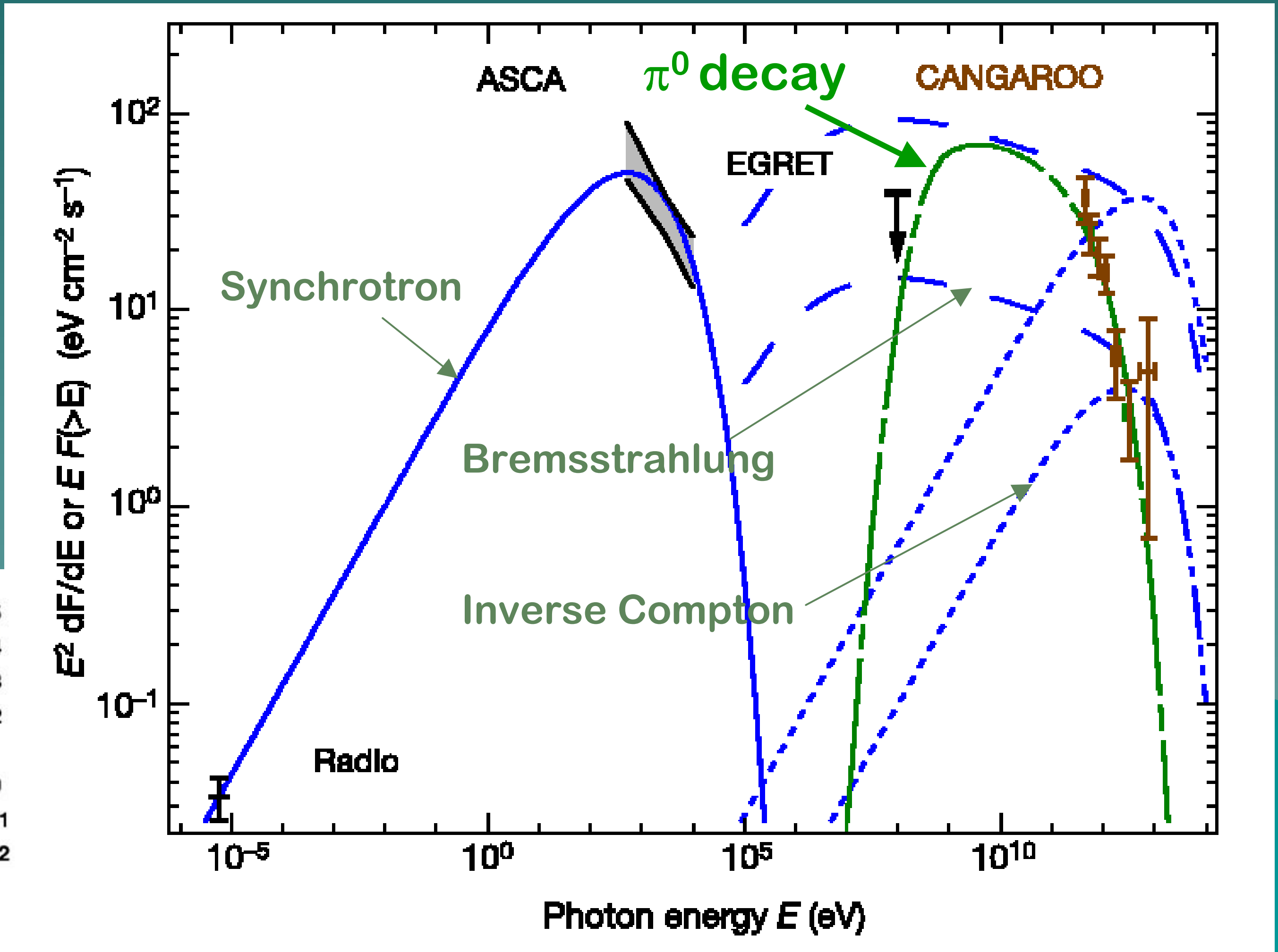
One supernova $\sim 10^{51}$ ergs
In galaxy 1 SN / 30 years (1/ 10^9 sec)
Power in supernova $\sim 10^{42}$ ergs / sec
If efficiency to convert SN power to CR 5%
$\Rightarrow 5 \times 10^{40}$ ergs/sec

Total power in cosmic rays: 5×10^{40} ergs/sec

Evidence for Acceleration of cosmic-ray protons in supernova remnant RX J1713.7-3946 ?

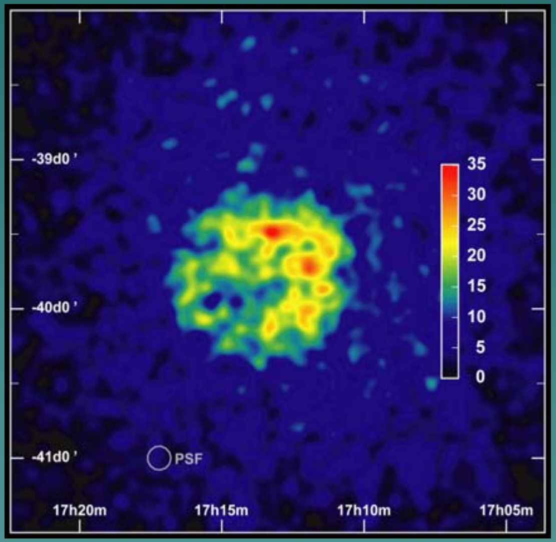
CANGAROO Gamma Ray Telescope



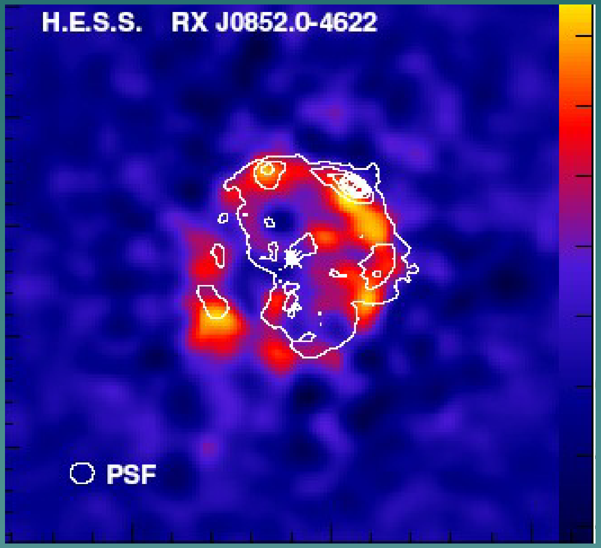


Recent results from HESS gamma ray telescope

RX J1713.7-3946



Vela Junior

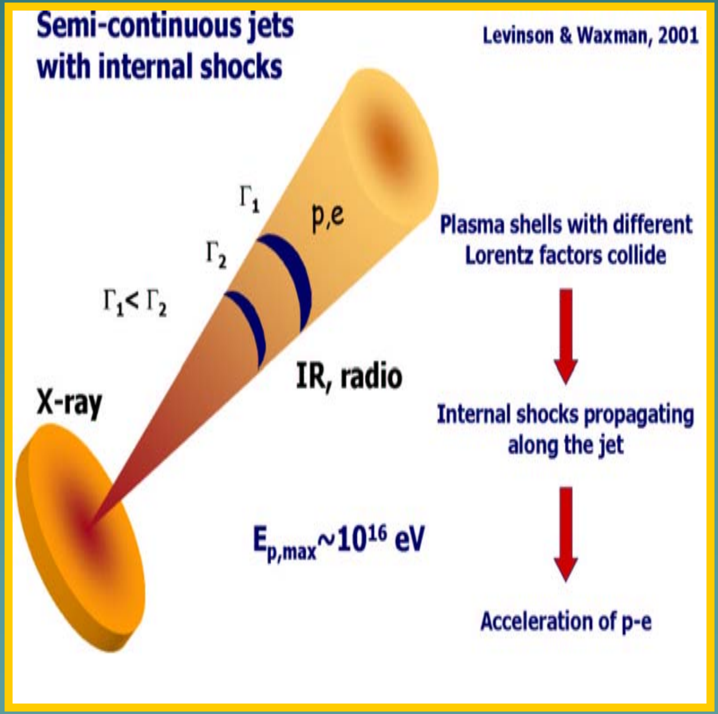


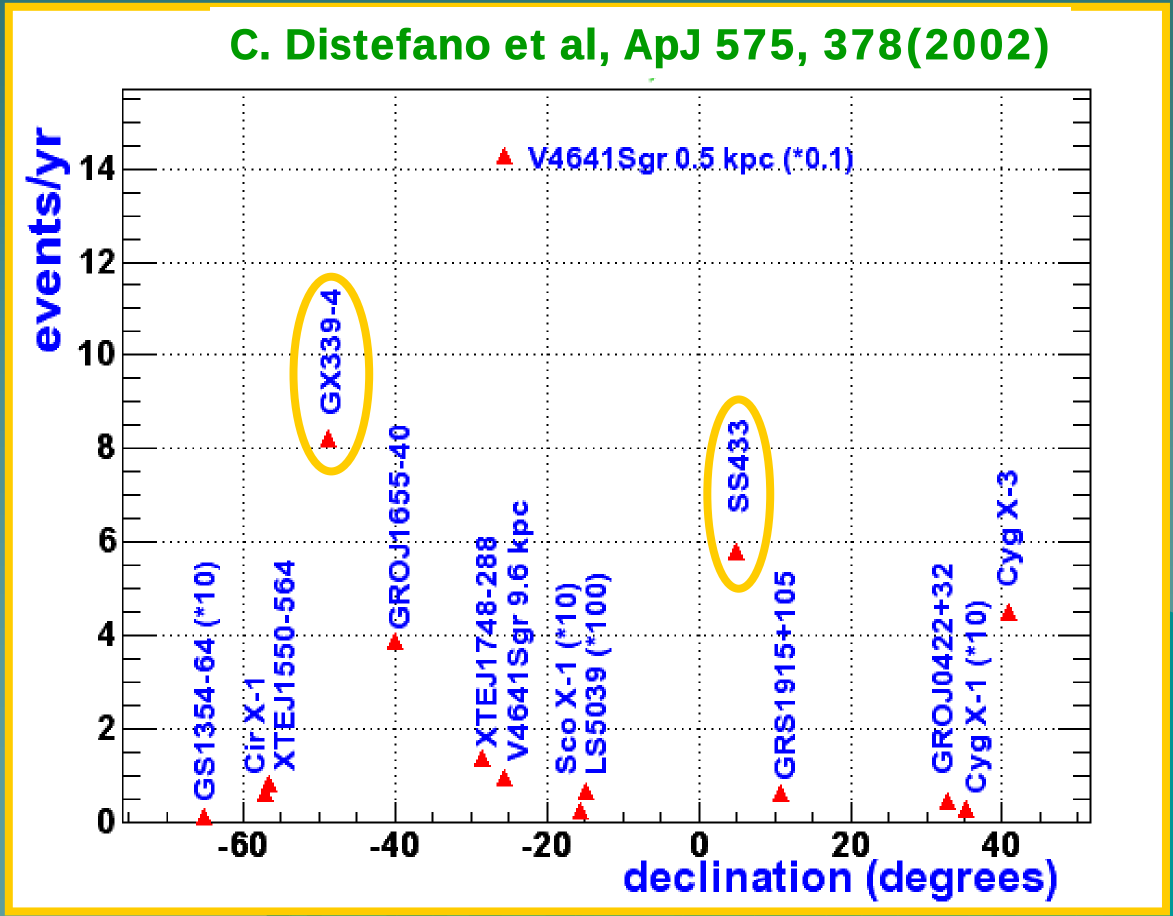
Signal for Northern Hemisphere Neutrino Telescopes
(few events / year in ANTARES)

Observation of neutrinos would give clear proof
for hadronic acceleration and so source of cosmic rays

Event rates from Microquasars in ANTARES

Model of Levisson and Waxman:
Proton interactions on synchrotron gamma from electrons
- assuming 10% of jet energy in protons



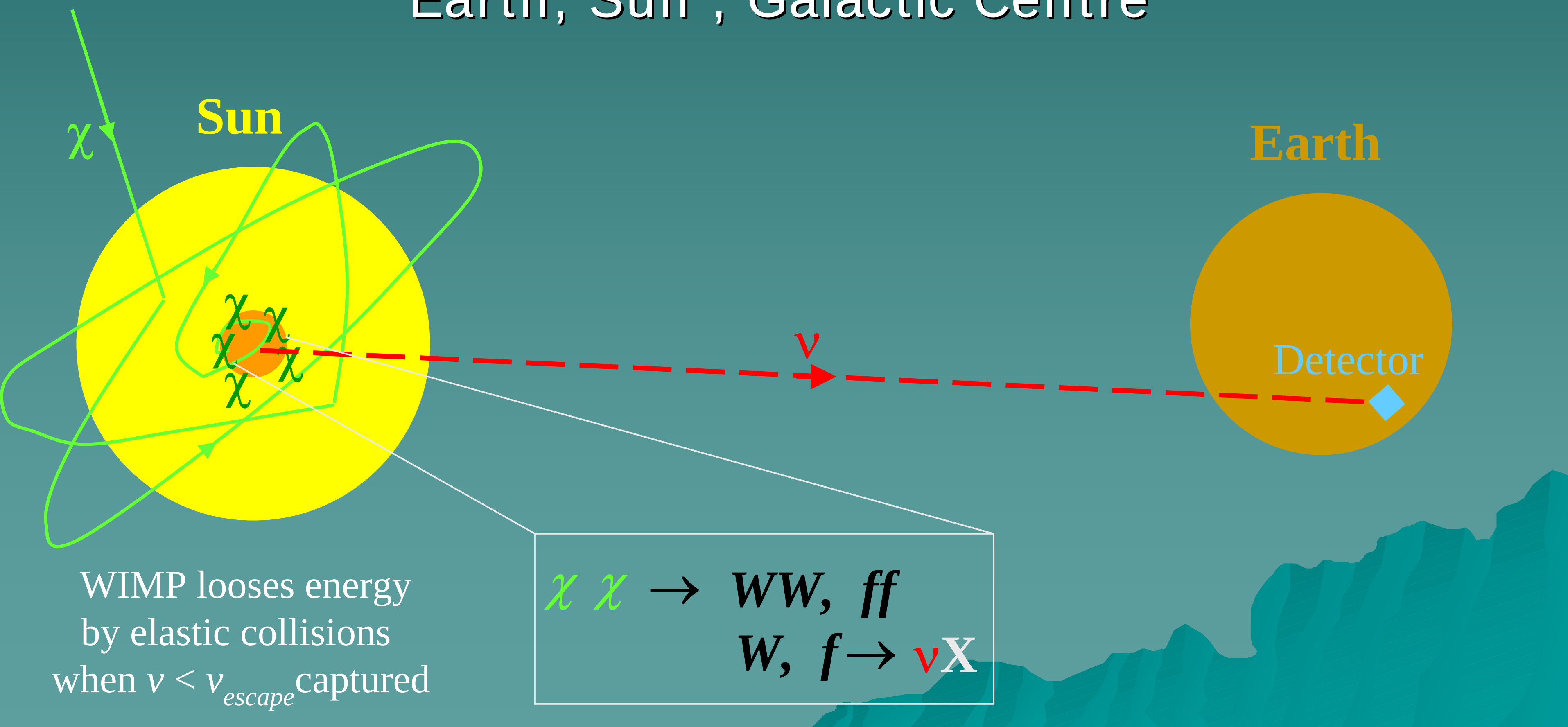


Search for concentrations of Dark Matter

Indirect detection of WIMPS

Searches for annihilation in

Earth, Sun , Galactic Centre



DM : ANTARES versus Direct Detection

Using example of

mSUGRA model

A_0=0, μ>0,

tanβ=10,

$M_{1/2}$=0-800 GeV,

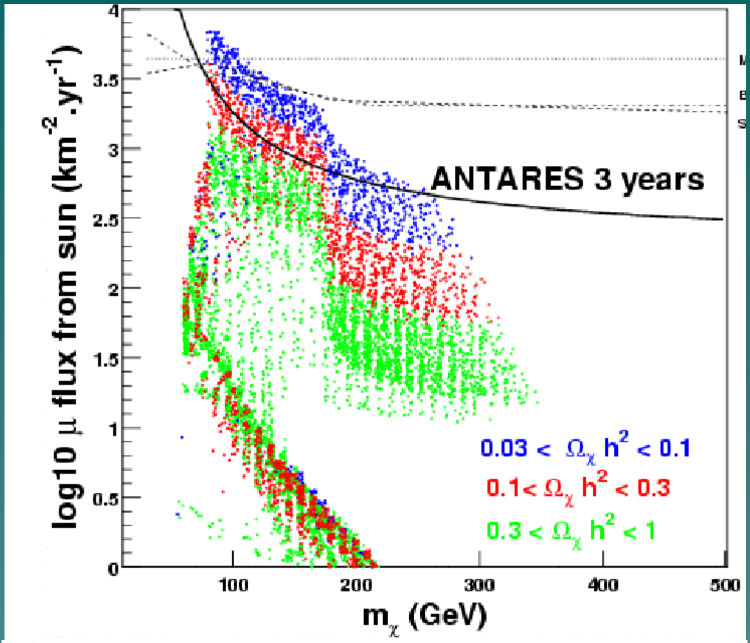
M_0=0-1000 GeV

+ $\Omega_{wimp}h^2 < 1$

+ LEP constraints

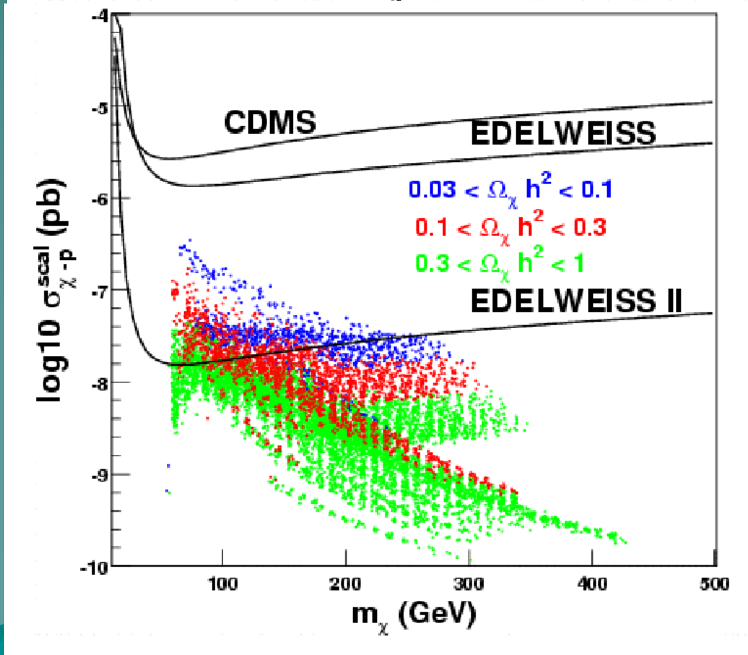
Neutrino telescope

ν flux from sun

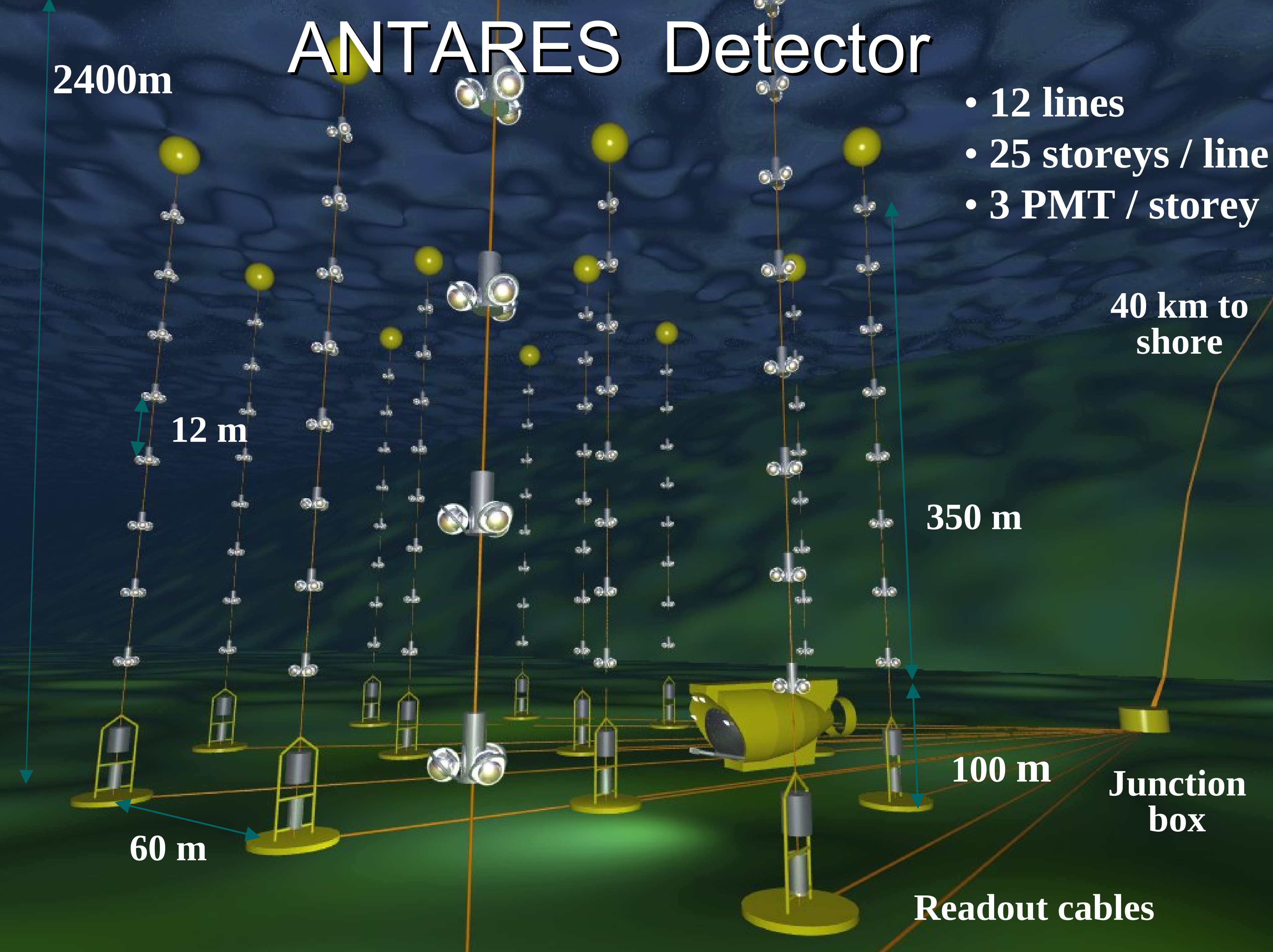


Direct Detection

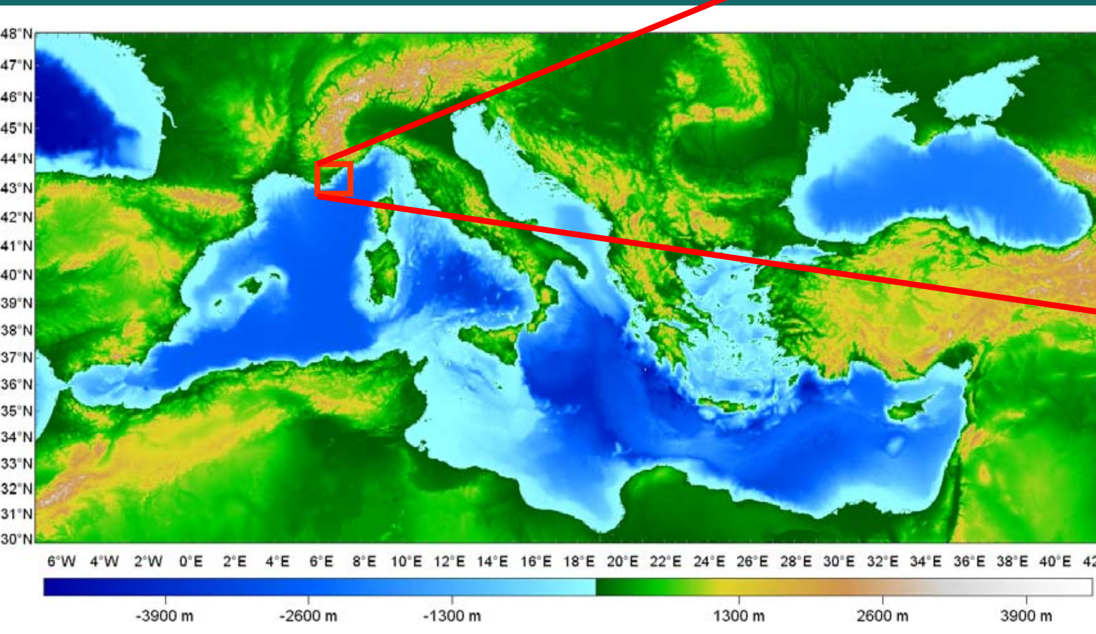
spin-independent cross-section

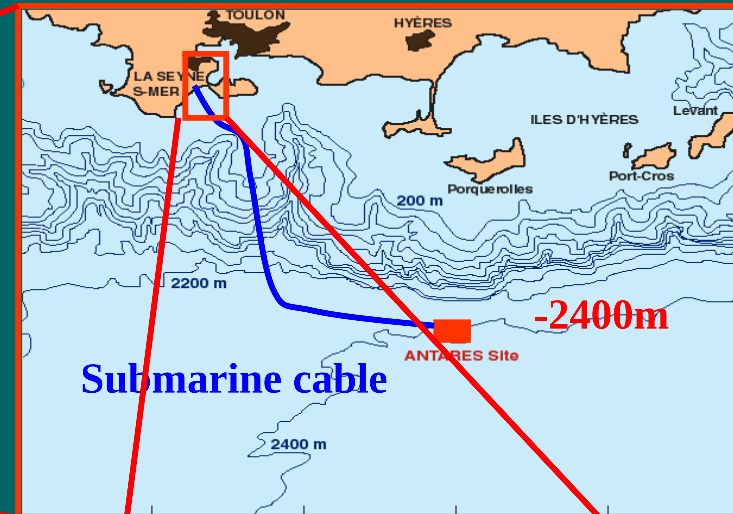


⇒ Neutrino Telescopes very competitive for some regions of MSSM phase space


ANTARES Detector
2400m
• 12 lines
• 25 storeys / line
• 3 PMT / storey
40 km to shore
12 m
350 m
100 m
Junction box
60 m
Readout cables

Site location

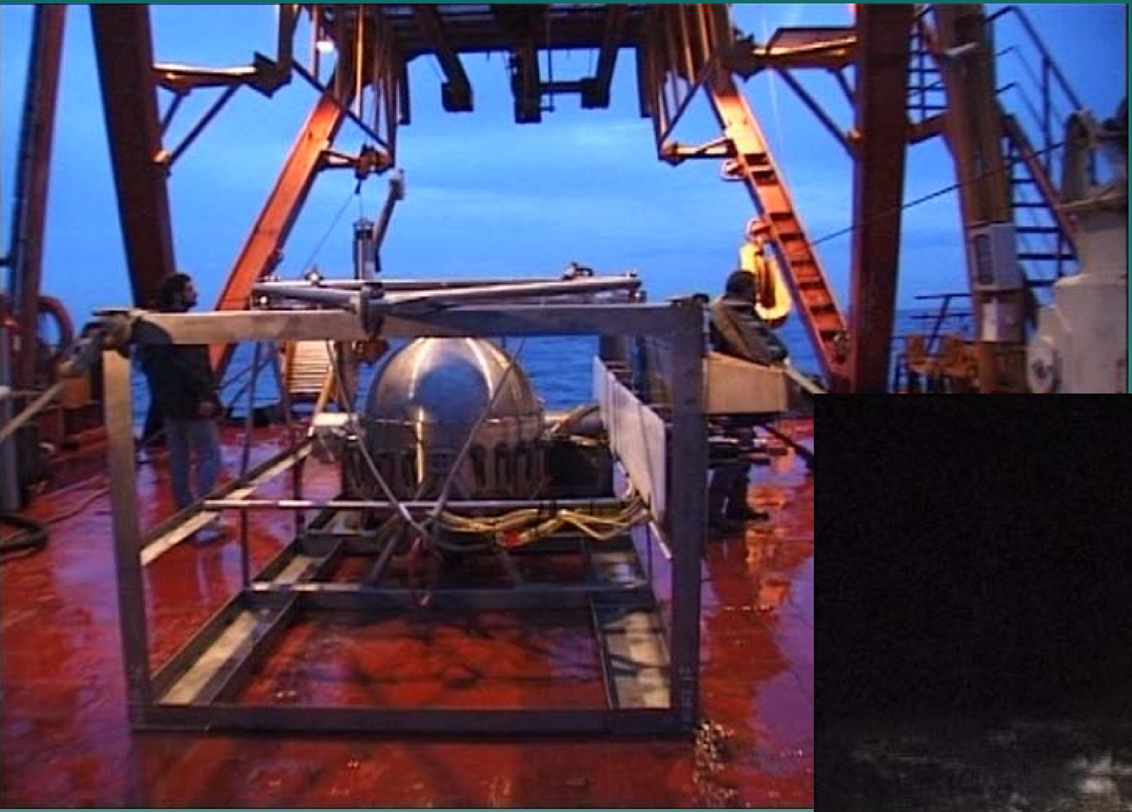




Shore Station

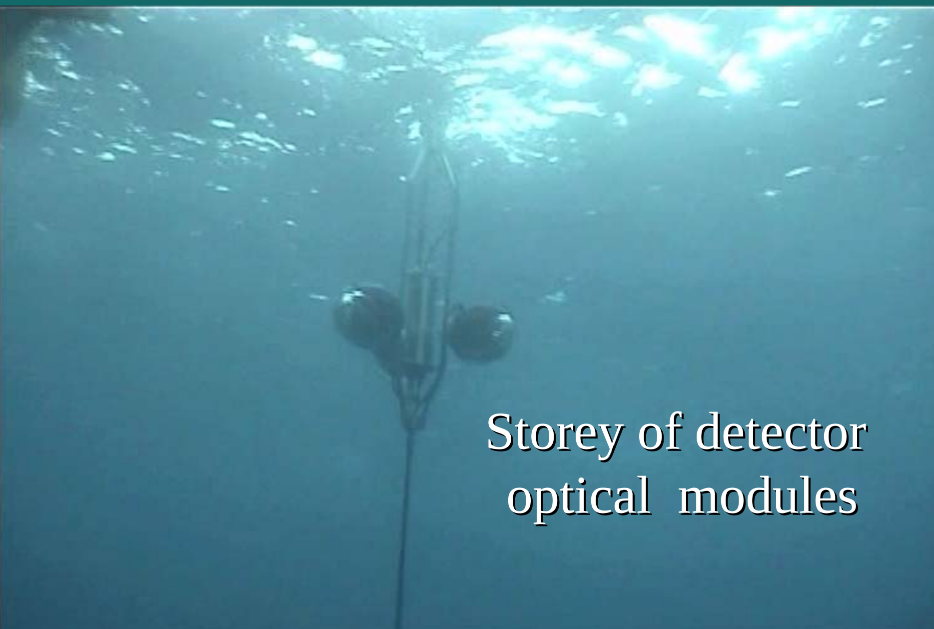
Deployment of Sea Cable, Nov 2001

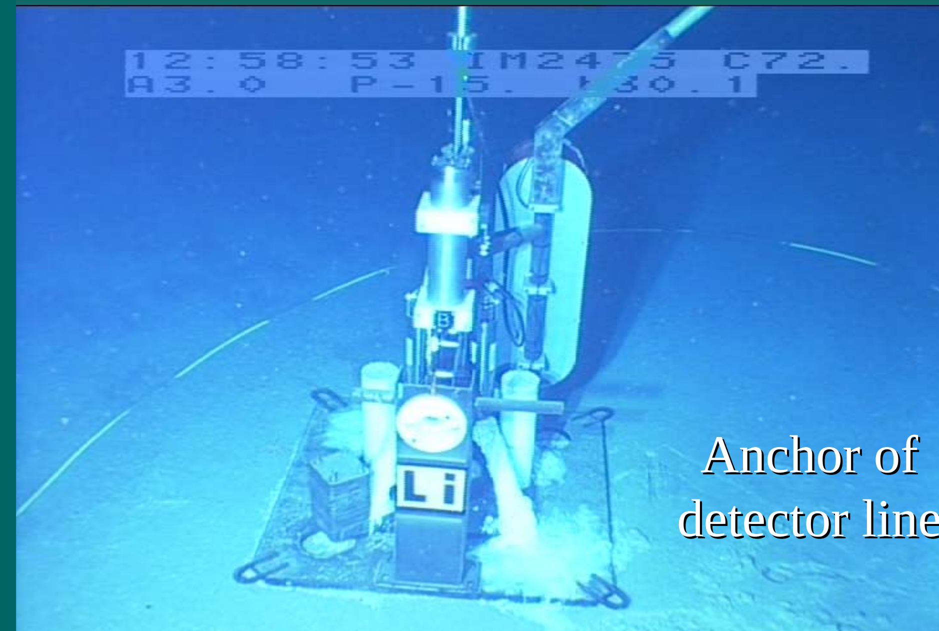
Deployment of Junction Box, Dec 2002




Sea bed situation
March 2003
5 storey
optical
detector
line
(PSL)
instrumentatio
Line
(MIL)
Ph. LAGIER

Undersea images of detector elements





“Line 0” : In-situ final test of line cables

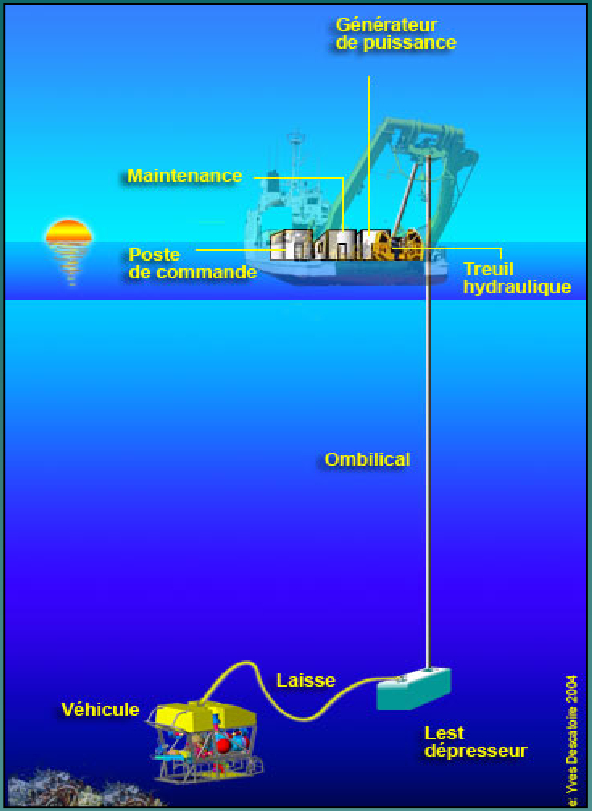
Deployment Line0

March 16 2005

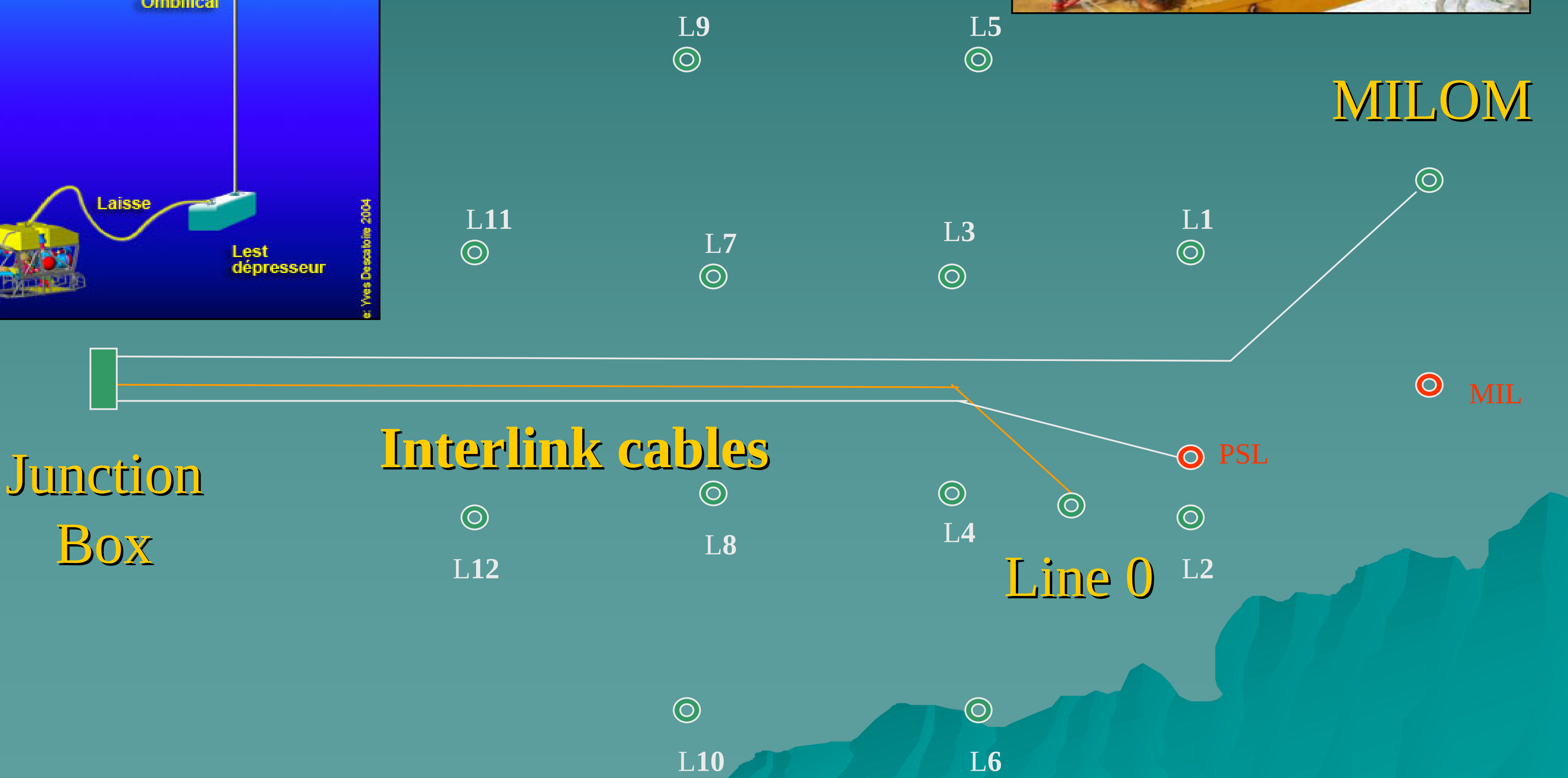
MILOM : Real instrumentation line for calibration

Deployment March 18 2005

Line0 / MILOM Connection with ROV Victor

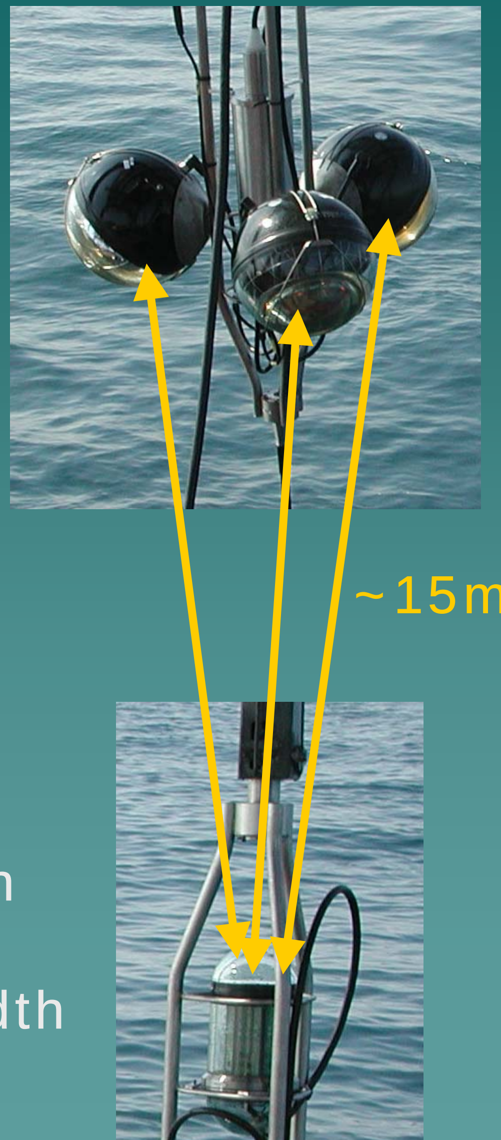


April 2005



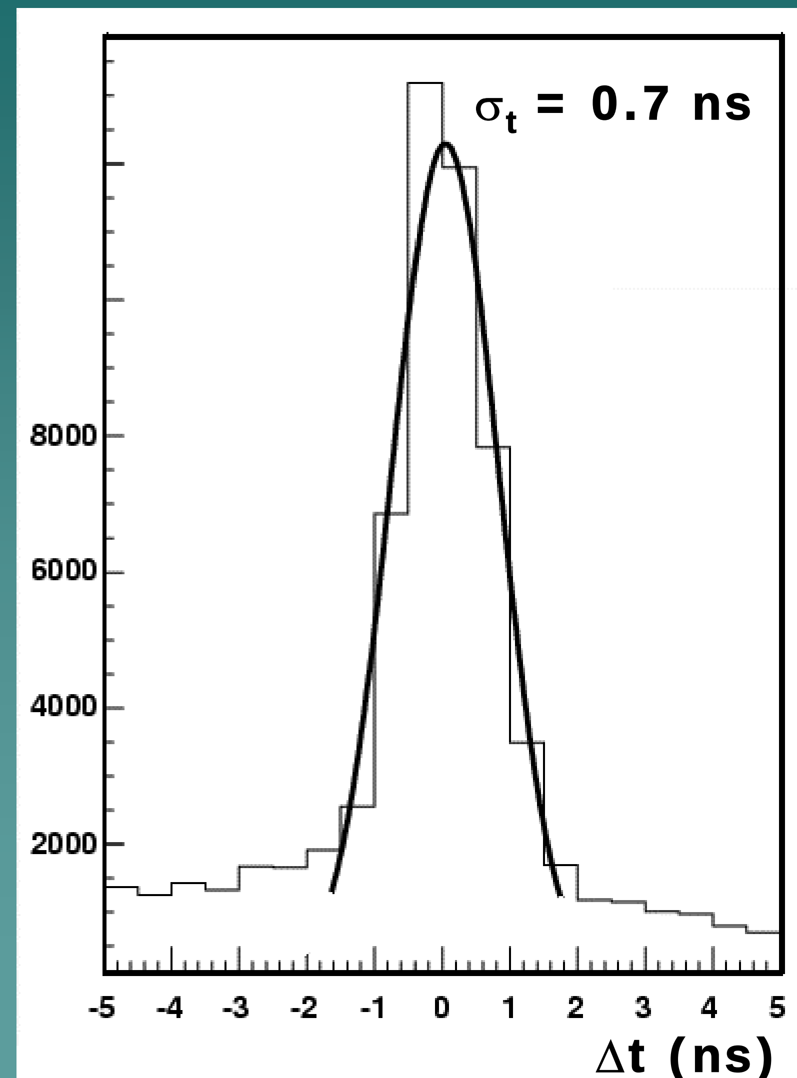
Timing resolution in the Sea

Optical Modules

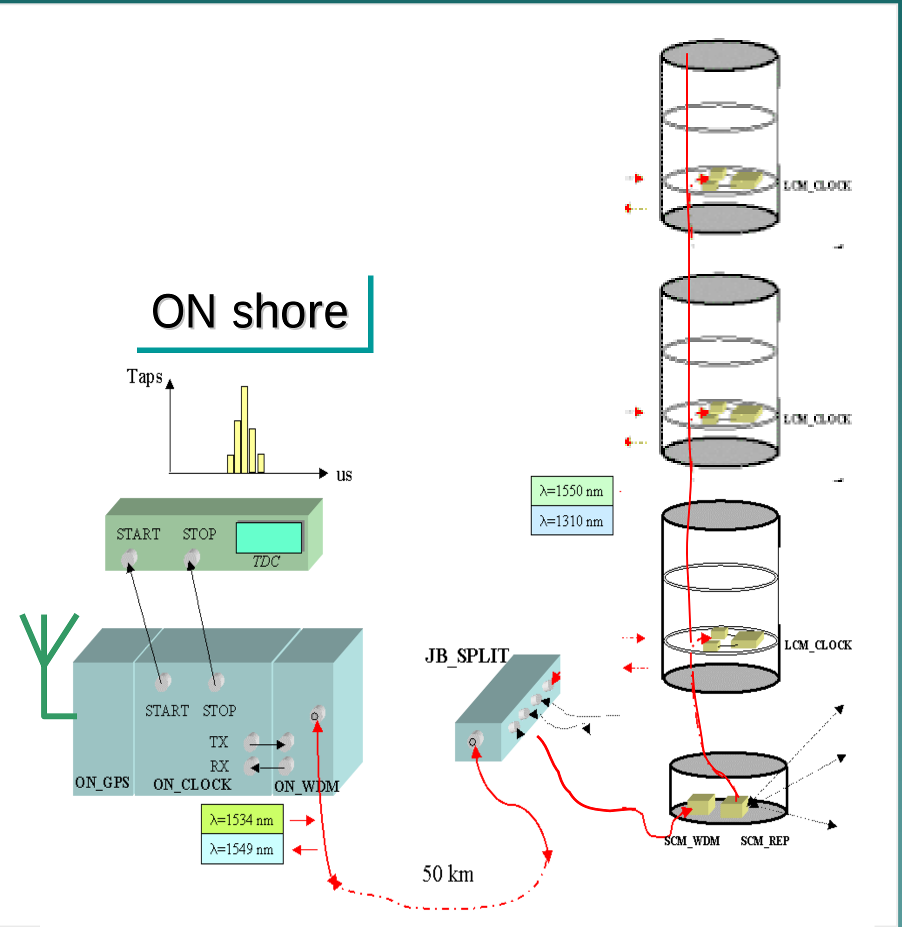


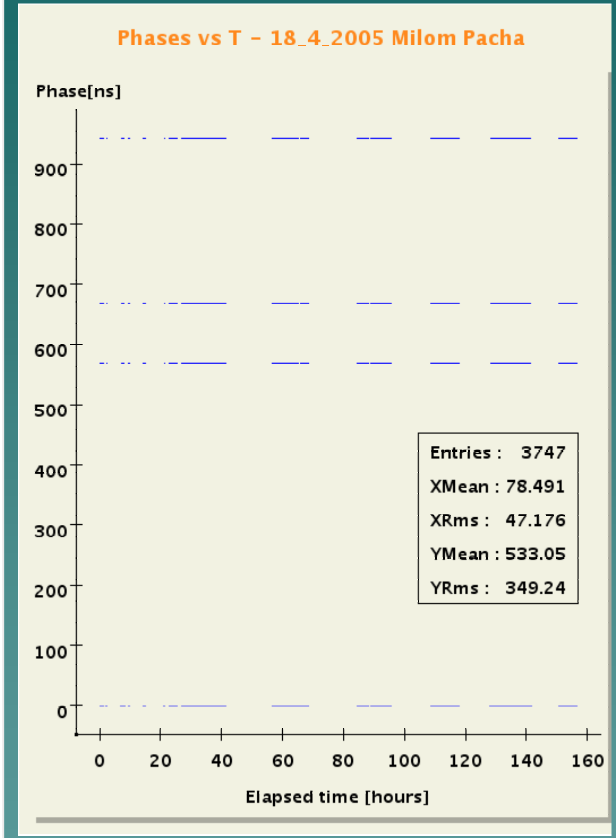
Optical Beacon
60 LED
~10ns pulse width

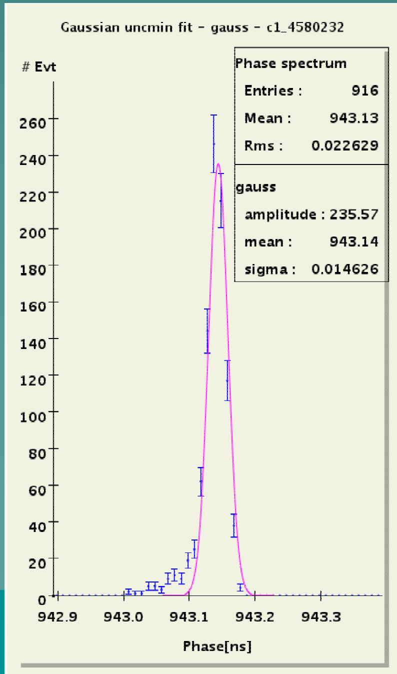
Time difference between pairs of optical modules



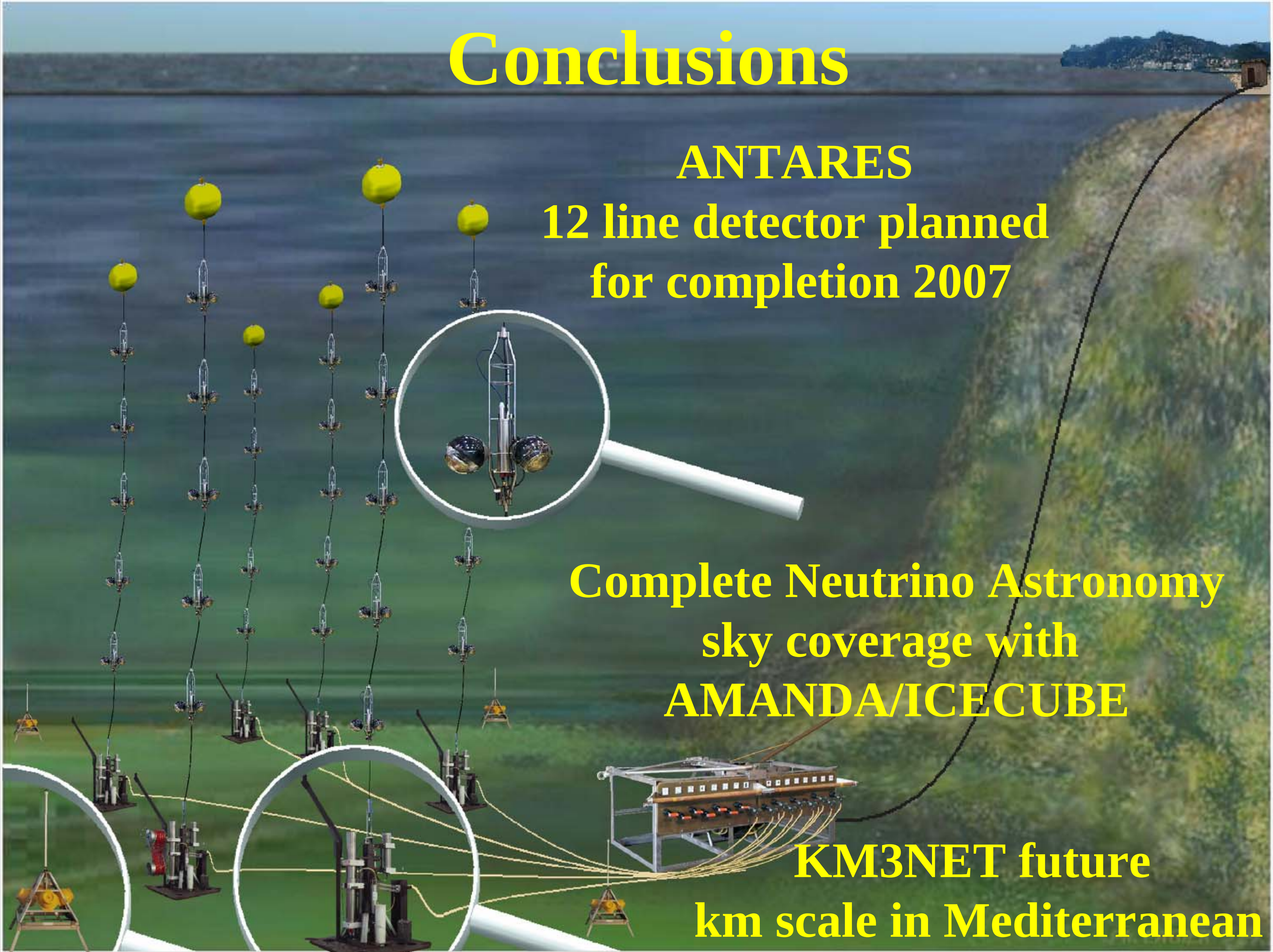
Reference time clock system







Conclusions



ANTARES
12 line detector planned
for completion 2007

Complete Neutrino Astronomy
sky coverage with
AMANDA/ICECUBE

KM3NET future
km scale in Mediterranean