Astronomia e Astrofisica con Neutrini di Alta Energia

Giulia De Bonis

giulia.debonis@roma1.infn.it

http://www.roma1.infn.it/people/debonis/

http://www.roma1.infn.it/km3/

Stanza 316 (Edificio Marconi)

Corso di LABORATORIO di ASTROFISICA

Corso di Laurea in Fisica e Astrofisica, III anno

Docente: Corinne Rossi

30/05/2014

Outline

- Neutrinos in Particle Physics
- Neutrinos in Astronomy & Astrophyisics → UHE Neutrinos

  - Candidate Neutrino Sources; Scientific Goals
- Neutrino Detection: Cherenkov Telescopes
- A new era in UHE Neutrino Astronomy: the IceCube Results
- ANTARES – Detector Setup

  - ANTARES Control Room
- ANTARES – Selected Results (point-like sources, diffuse flux, dark matter, exotic matter, multi-messenger approach)
- NEMO & KM3NeT
- ANTARES-NEMO-KM3NeT @Sapienza-Roma
- Conclusions & Perspectives

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"Un Tuffo nel Cosmo"
http://www.accastampato.it/wp-content/uploads/Giulia-De-Bonis-Antares.pdf

Neutrinos in Particle Physics

- Neutrinos in the Standard Model

- no electric charge, no mass;
- weak interactions only;
- fermions, leptons and the three generations (flavours) → weak isospin doublet and conservation of the lepton number

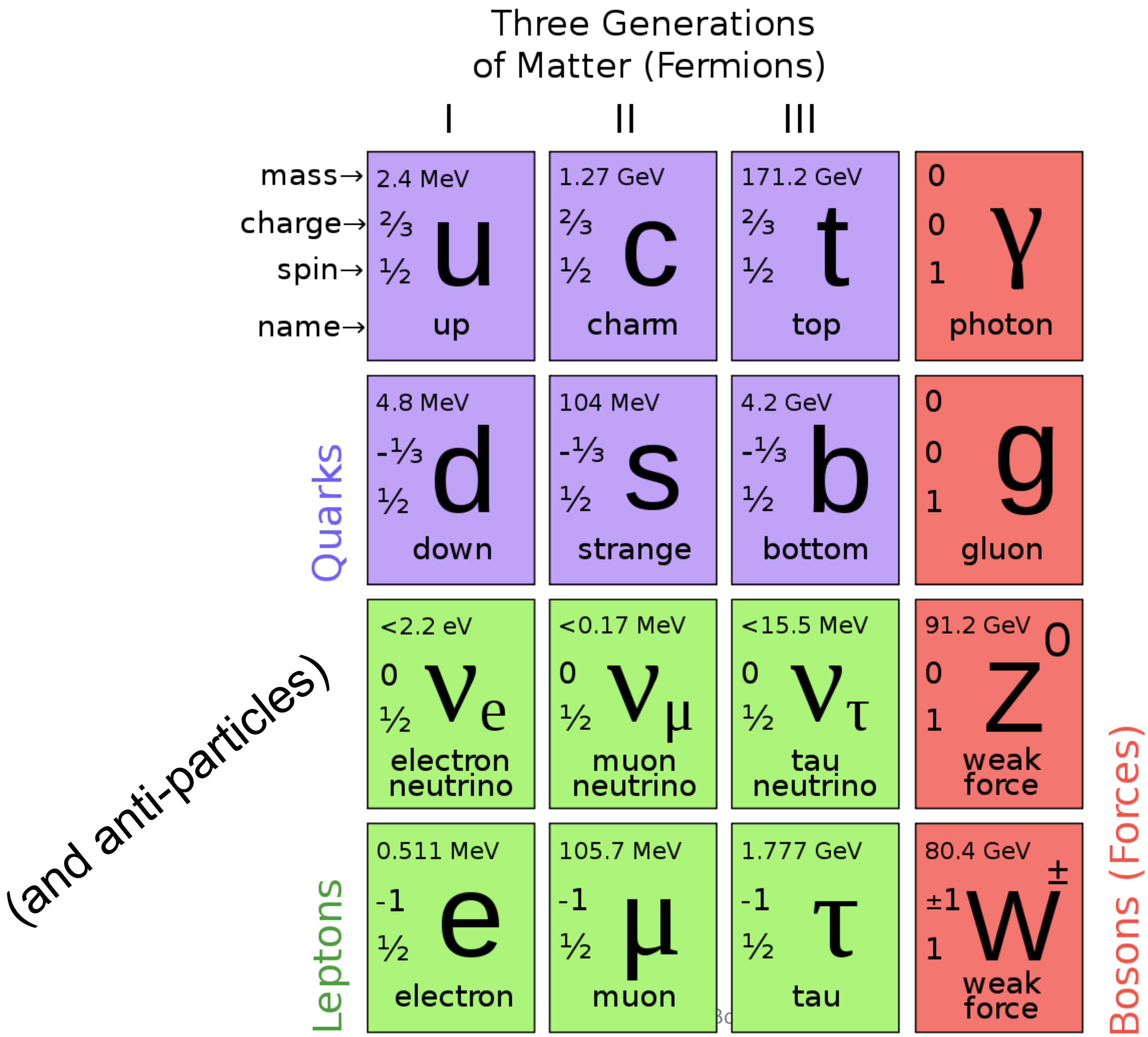
- Neutrino Interactions with matter

$$\overset{(-)}{\nu}_l + \mathrm{N} \to l^{\pm} + \mathrm{X} \qquad \text{(CC)} \qquad\qquad \overset{(-)}{\nu}_l + \mathrm{N} \to \overset{(-)}{\nu}_l + \mathrm{X} \qquad \text{(NC)}$$

- Neutrinos beyond the Standard Model:
  Neutrino mass and Neutrino Oscillations (flavour mixing)

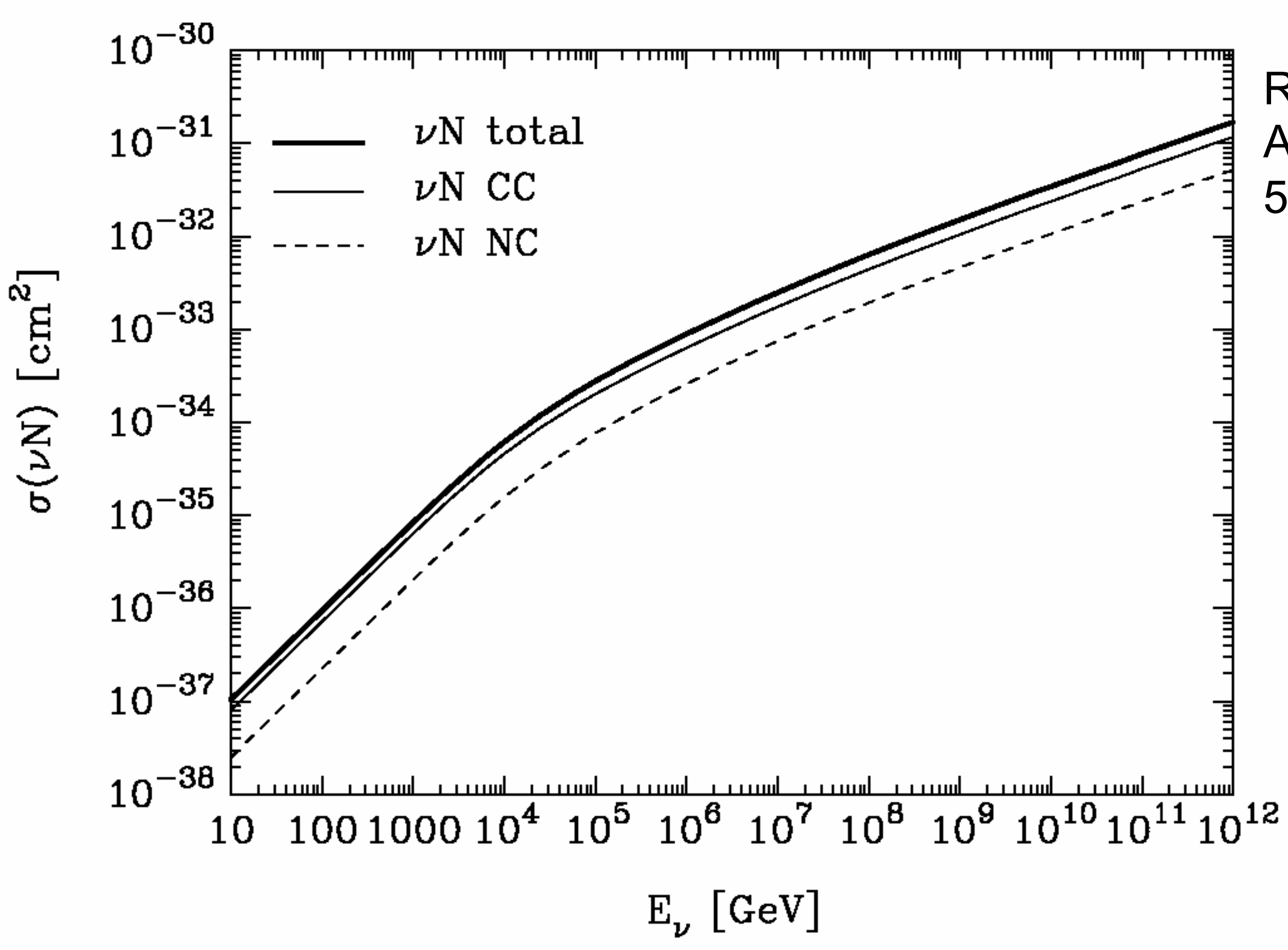
$$|\nu_\alpha\rangle = \sum_j U^*_{\alpha j} |\nu_j\rangle$$

P. Lipari, *Introduction to Neutrino Physics*, https://cds.cern.ch/record/677618



Three Generations of Matter (Fermions)
I
II
III
mass→
charge→
spin→
name→
2.4 MeV
⅔
½
u
up
1.27 GeV
⅔
½
c
charm
171.2 GeV
⅔
½
t
top
0
0
1
γ
photon
4.8 MeV
-⅓
½
d
down
104 MeV
-⅓
½
s
strange
4.2 GeV
-⅓
½
b
bottom
0
0
1
g
gluon
<2.2 eV
0
½
νe
electron neutrino
<0.17 MeV
0
½
νμ
muon neutrino
<15.5 MeV
0
½
ντ
tau neutrino
91.2 GeV
0
1
Z0
weak force
0.511 MeV
-1
½
e
electron
105.7 MeV
-1
½
μ
muon
1.777 GeV
-1
½
τ
tau
80.4 GeV
±1
1
W±
weak force
Quarks
Leptons
Bosons (Forces)
(and anti-particles)

Neutrino-Nucleon Cross Section



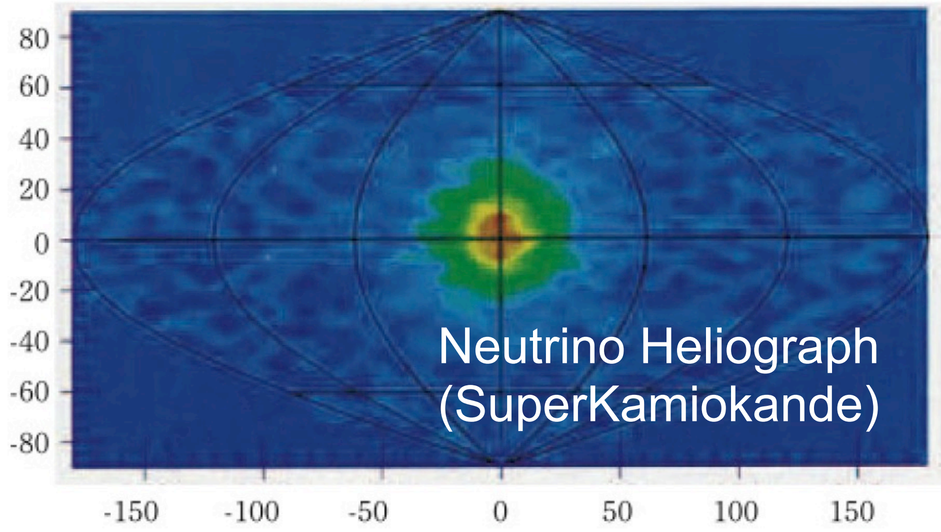
R. Gandhi *et al.*, Astropart. Phys. 5 (1996) 81

$$\frac{d^2\sigma}{dxdy} = \frac{2 \cdot G_F{}^2 \cdot M \cdot E_\nu}{2 \cdot \pi} \cdot \left(\frac{M^2_{W,Z}}{Q^2 + M^2_{W,Z}} \right)^2 \cdot \left[x \cdot q\left(x, Q^2\right) + x \cdot \overline{q}\left(x, Q^2\right) \cdot (1-y)^2 \right]$$

Neutrinos are produced in astrophyisical sites!

- Low Energy Neutrinos

- The SUN (solar neutrinos)



- SuperNovae Explosions → SN1987A, a.k.a

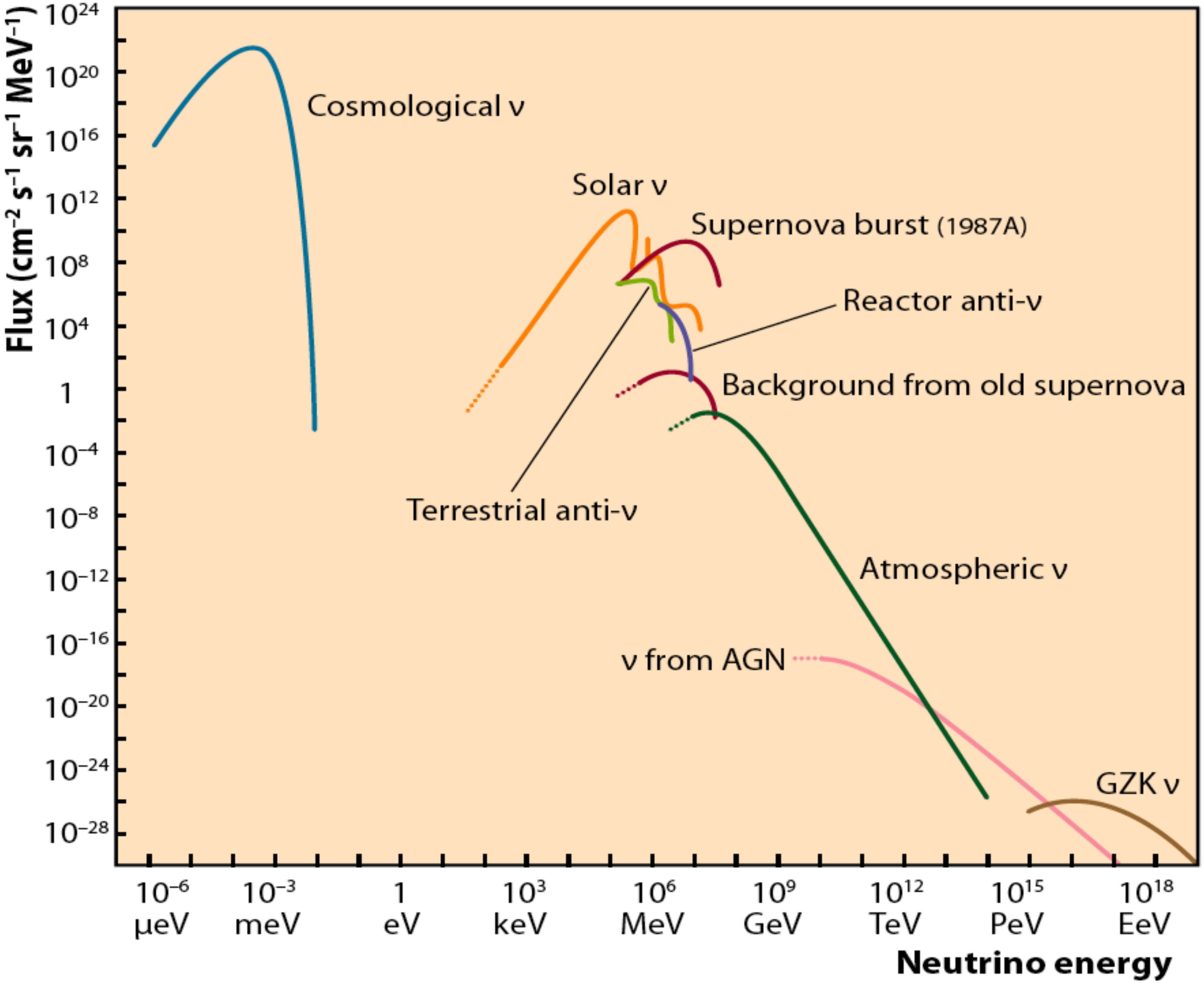
The Beginning of Neutrino Astronomy

- (U)High Energy Neutrinos

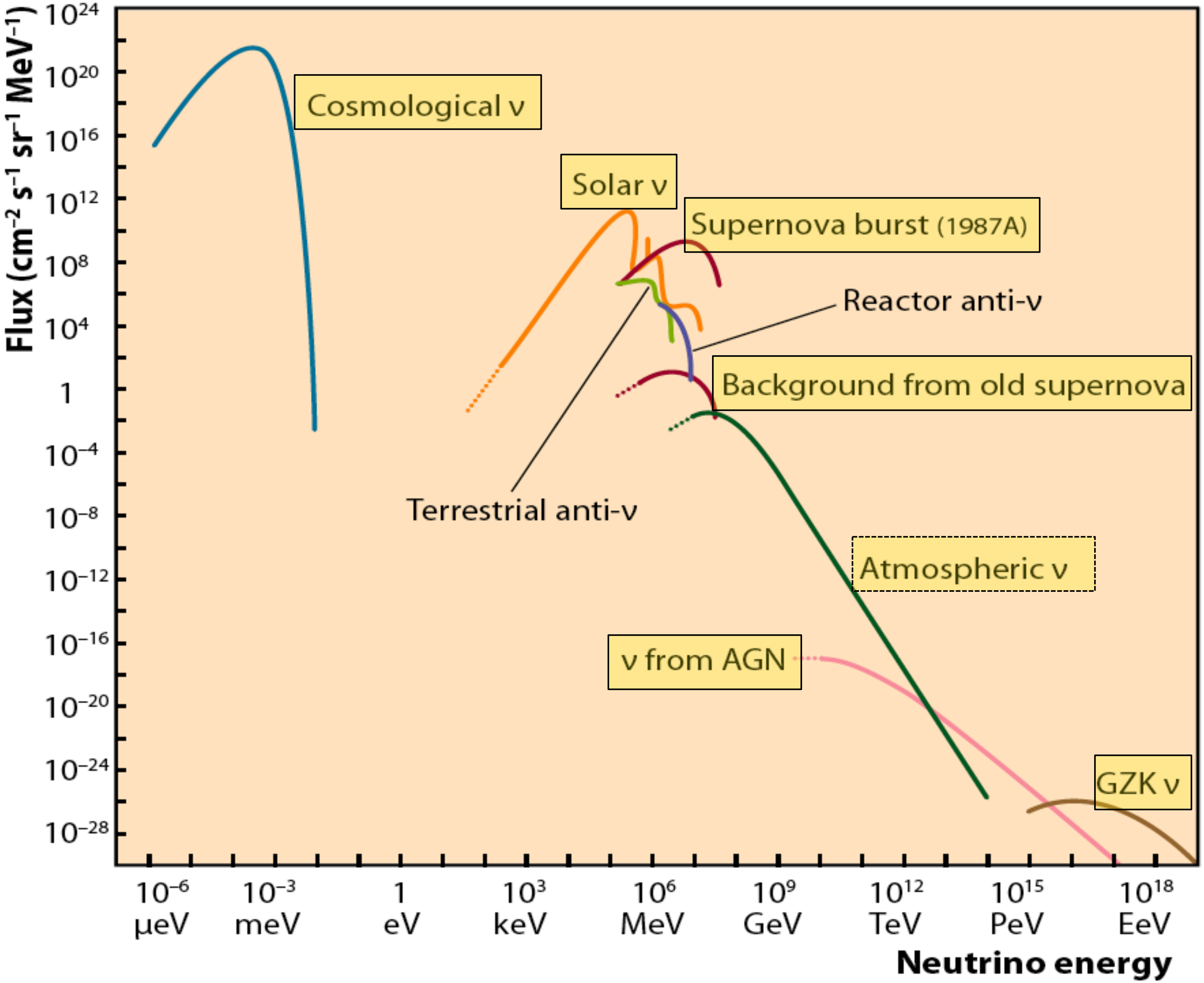
- Cosmic Accelerators

- Correlation with Cosmology (relic neutrinos, dark matter, top-down models)

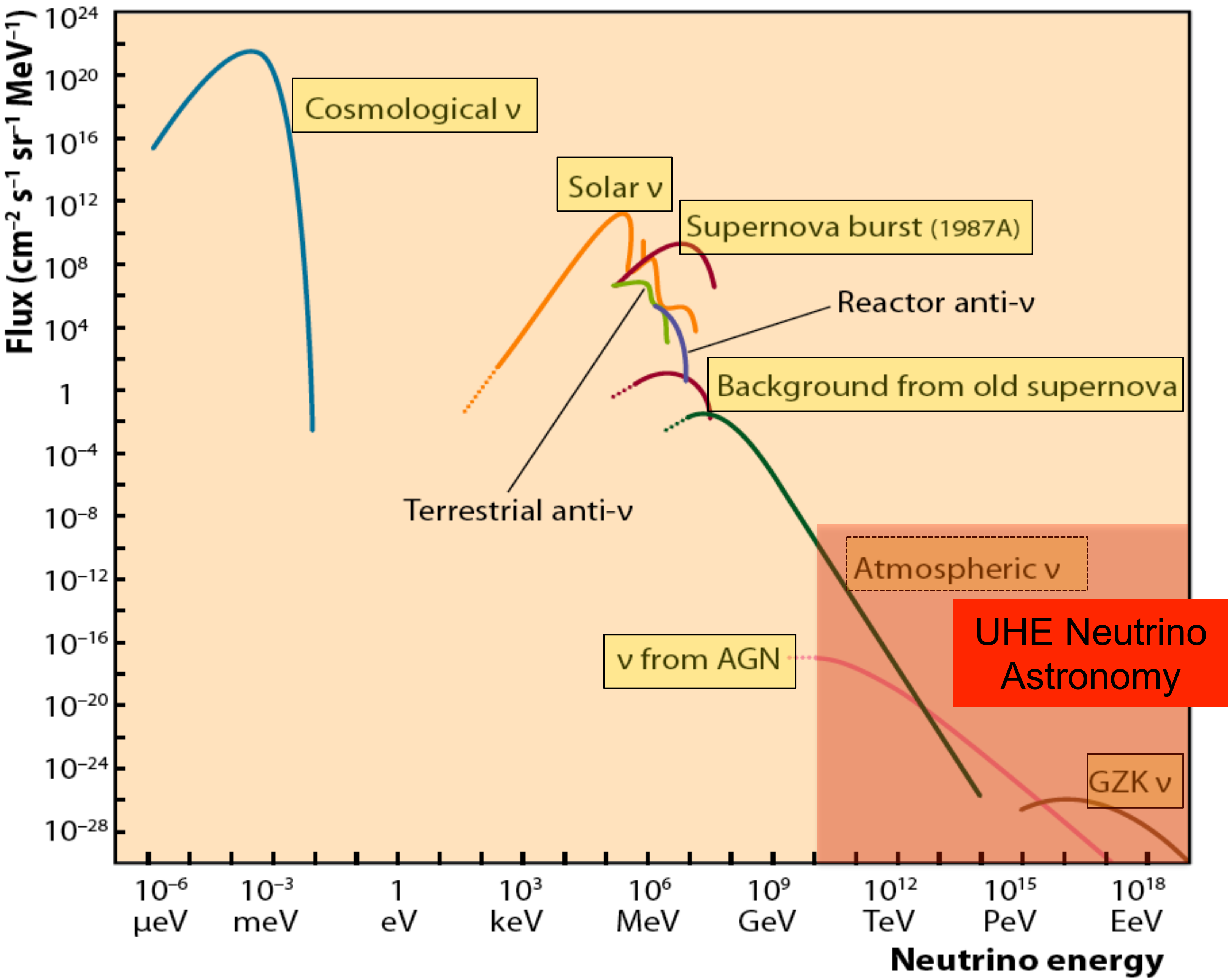
Flux of Neutrinos at the Surface of the Earth



Flux of Neutrinos at the Surface of the Earth

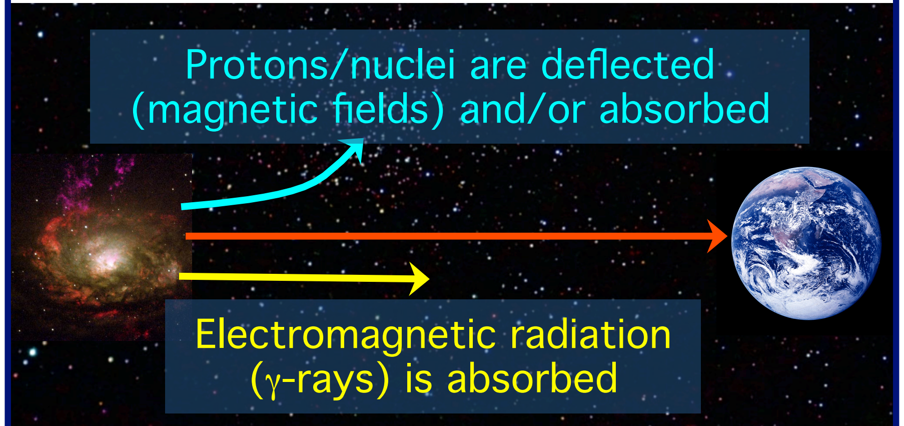


Flux of Neutrinos at the Surface of the Earth



UHE Neutrino Astronomy & Astrophysics

Why Neutrinos?



Weakly interacting **neutrinos** retain directional information, allowing deep insight into compact celestial objects (opaque to photons and protons) and at cosmological distances.

(some) References

- J. G. Learned, K. Mannheim, "High-Energy Neutrino Astrophysics", *Annu. Rev. Nucl. Part. Sci.* 50, 679 (2000)
- T. Chiarusi, M. Spurio, "High Energy Astrophysics with Neutrino Telescopes", Eur.Phys.J.C65 (2010) 649, arXiv:0906.2634v2 [astro-ph.HE]
- L. A. Anchordoqui et al., "Cosmic Neutrino Pevatrons: A Brand New Pathway to Astronomy, Astrophysics and Particle Physics ", arXiv:1312.6587v3 [astro-ph.HE]

UHEν_s Production

Bottom-Up Models (Acceleration)	**Galactic** Sources (SNRs, PWNae, μQs) **Extra-Galactic** Sources (AGNs, GRBs)
Top-Down Models (Annihilation/Decay)	WIMPs, TDs
GZK ν_s (cosmogenic flux)	

Astronomy

Search for Neutrino sources (**Neutrino Sky Map**)

Astrophysics

UHEν_s as a diagnostic of astrophysical processes

- astrophysical sources, acceleration engines
  - neutrino observations can discriminate between different acceleration mechanisms (hadronic vs leptonic)
- CRs propagation ➔ GZK cut-off [cosmogenic ν flux]

Particle Physics

- Neutrino Physics
- $\sigma_{\nu N}$ at $E>E_{LAB\_accelerators}$
- NewPhysics beyond SM

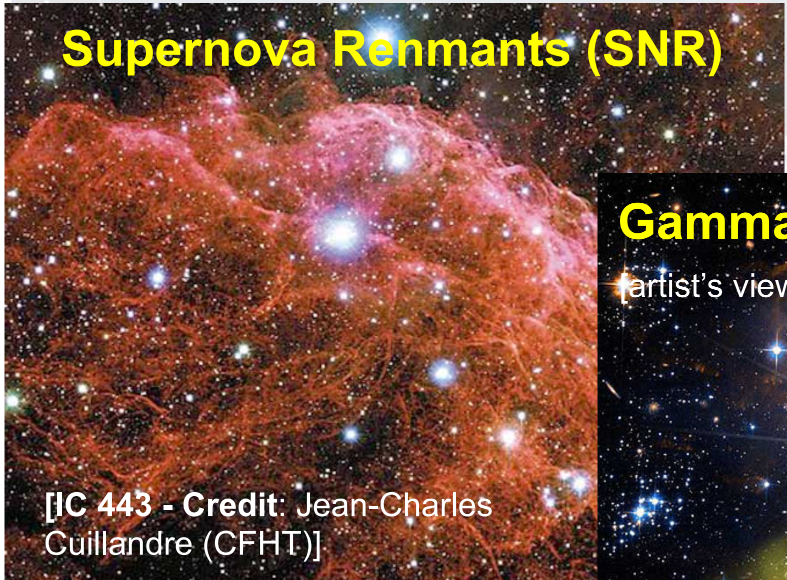
Cosmology

- top-down models (TDs, WIMPs – indirect dark matter search)

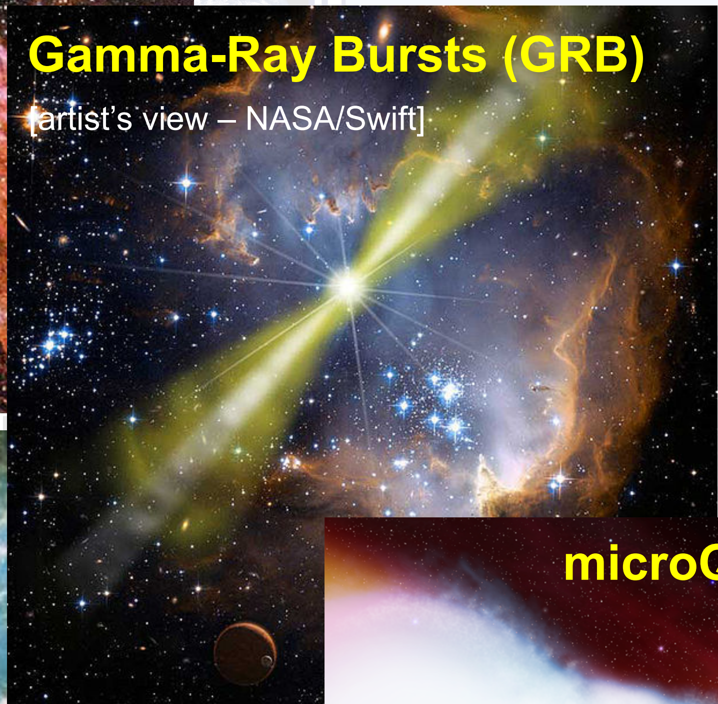
Candidate Sources

The most fascinating objects in the Sky are possible neutrino emitters

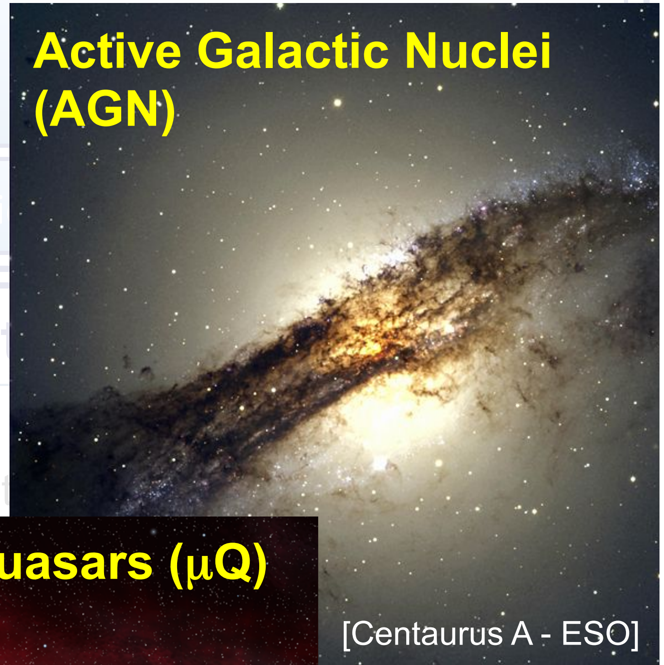
Bottom-Up Models (Acceleration)	**Galactic** Sources (SNRs, PWNae, μQs) Ex**tra-Galactic** Sources (AGNs, GRBs)



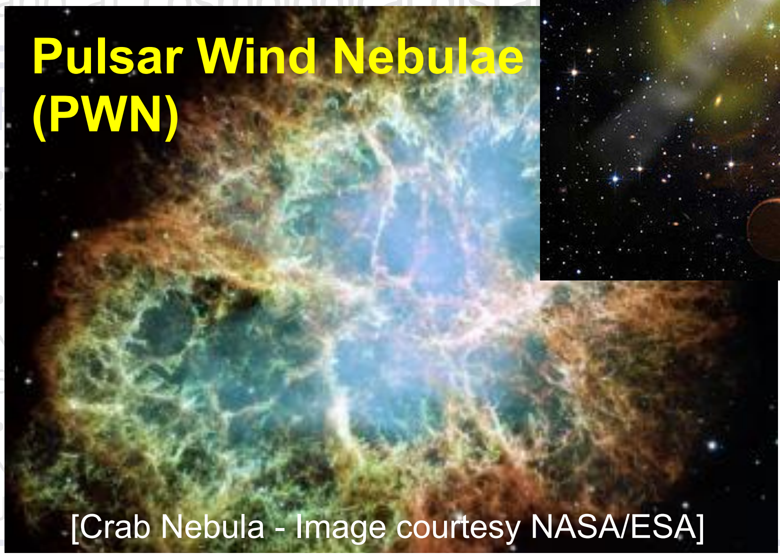
[**IC 443 - Credit**: Jean-Charles Cuillandre (CFHT)]



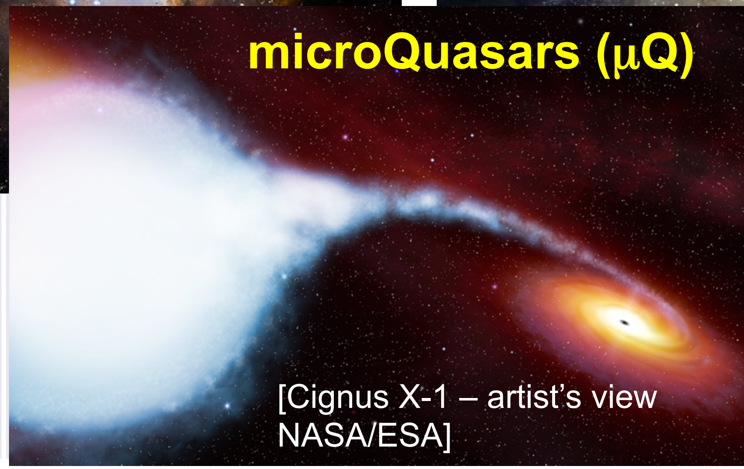
[artist's view – NASA/Swift]



[Centaurus A - ESO]



[Crab Nebula - Image courtesy NASA/ESA]



[Cignus X-1 – artist's view NASA/ESA]

UHEν's Production: Acceleration
(*bottom-up* model)

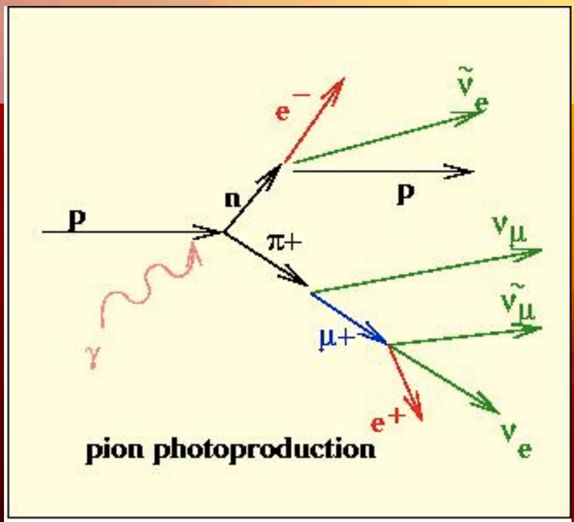
Fermi engine (AGNs, SNRs)

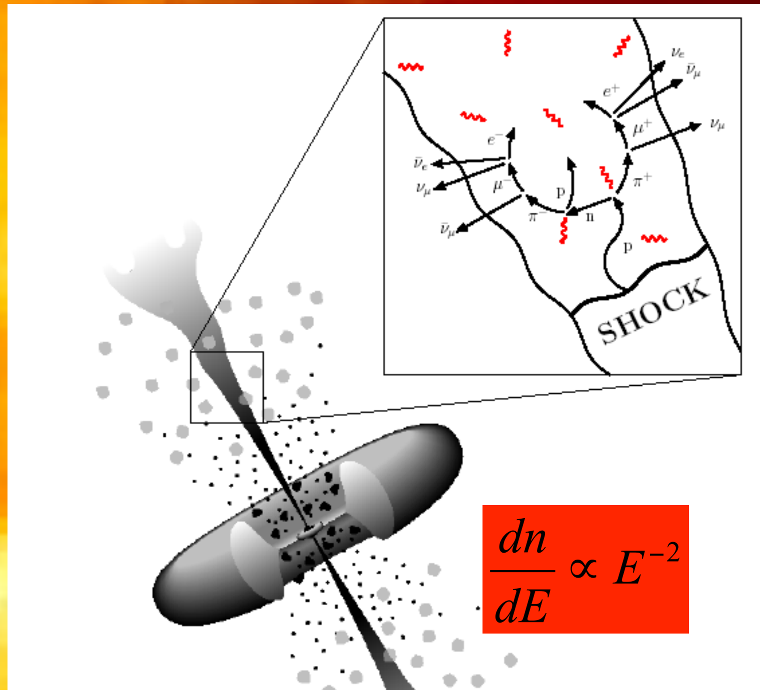
- *protons*, confined by magnetic fields, are accelerated through repeated scattering by **plasma shock front**;

- collisions of trapped protons with ambient plasma produce **γs** and **νs** through **pion photoproduction** mechanism:

$$p + N,\gamma \rightarrow X + \left.\begin{matrix} \pi^{\pm} \rightarrow \text{neutrinos} \\ \pi^{o} \rightarrow \gamma - \text{rays} \end{matrix}\right\}$$

$E_{\nu} \sim 0.05\ E_{p}$





[A. Ringwald]

core of Galaxy NGC 4261
Hubble Space Telescope

CR Propagation → GZK cut-off

[Greisen – Zatsepin – Kuzmin]

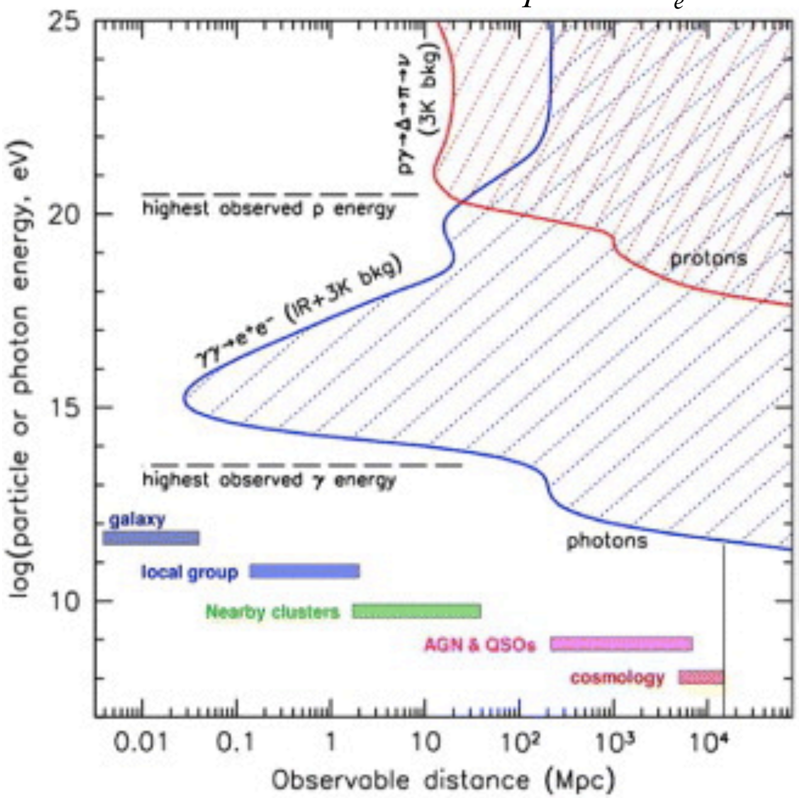
The UHE CR horizon is limited by interactions with low energy background radiation

→ Pion Photoproduction

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow \begin{cases} p + \pi^{0} \\ \quad \hookrightarrow \gamma\gamma \\ n + \pi^{+} \\ \quad \hookrightarrow \mu^{+} + \nu_{\mu} \\ \qquad \hookrightarrow e^{+} + \overline{\nu_{\mu}} + \nu_{e} \\ \hookrightarrow p + e^{-} + \overline{\nu_{e}} \end{cases}$$

$E\gamma \sim 10^{-4}$ eV
(T~2.7 K)
⇒ $E_{th} \sim 3\times10^{19}$ eV

$n_{CMBR} \sim 400$ cm^{-3}
$\sigma_{p\gamma} \sim 100$ μbarn
⇒ $$\lambda^{pCMBR}_{att} = \frac{1}{\sigma_{p\gamma} n_{CMBR}} < 50 \text{ Mpc}$$



GZK NEUTRINOS (cosmogenic neutrino flux)

Neutrinos at $10^{17\text{-}19}$ eV predicted by standard-model physics through the GZK process. **Observing them is crucial to solve the GZK puzzle**

K.D. Hoffman, *High energy neutrino telescopes*, New J. Phys. 11 (2009) 055006

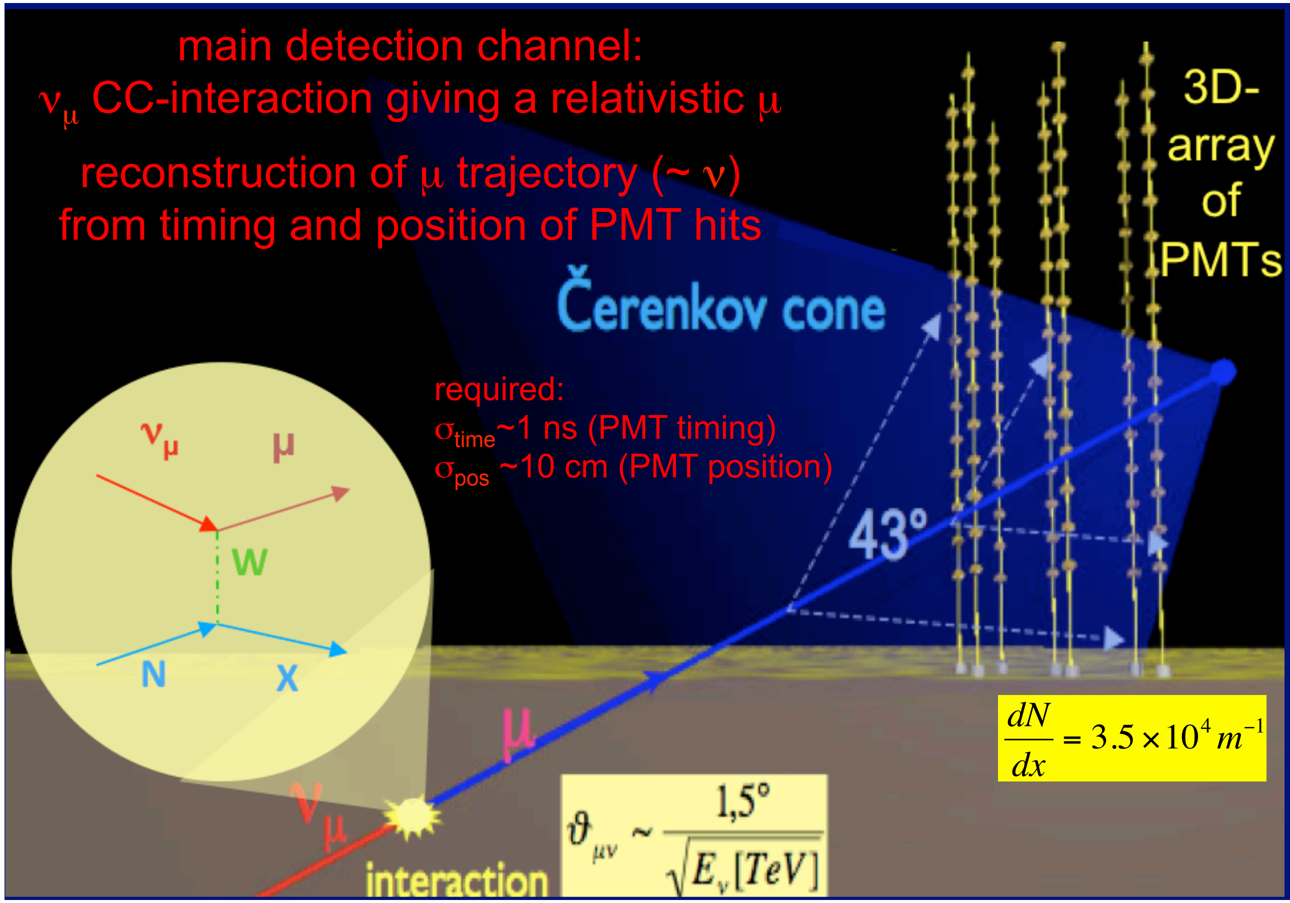
… the other side of the coin: Neutrino Detection

Weak-interacting is hard-detecting

(and very **low fluxes** are expected from the sources)

large detection volume ($\sim km^3$) is required

Cherenkov Telescopes



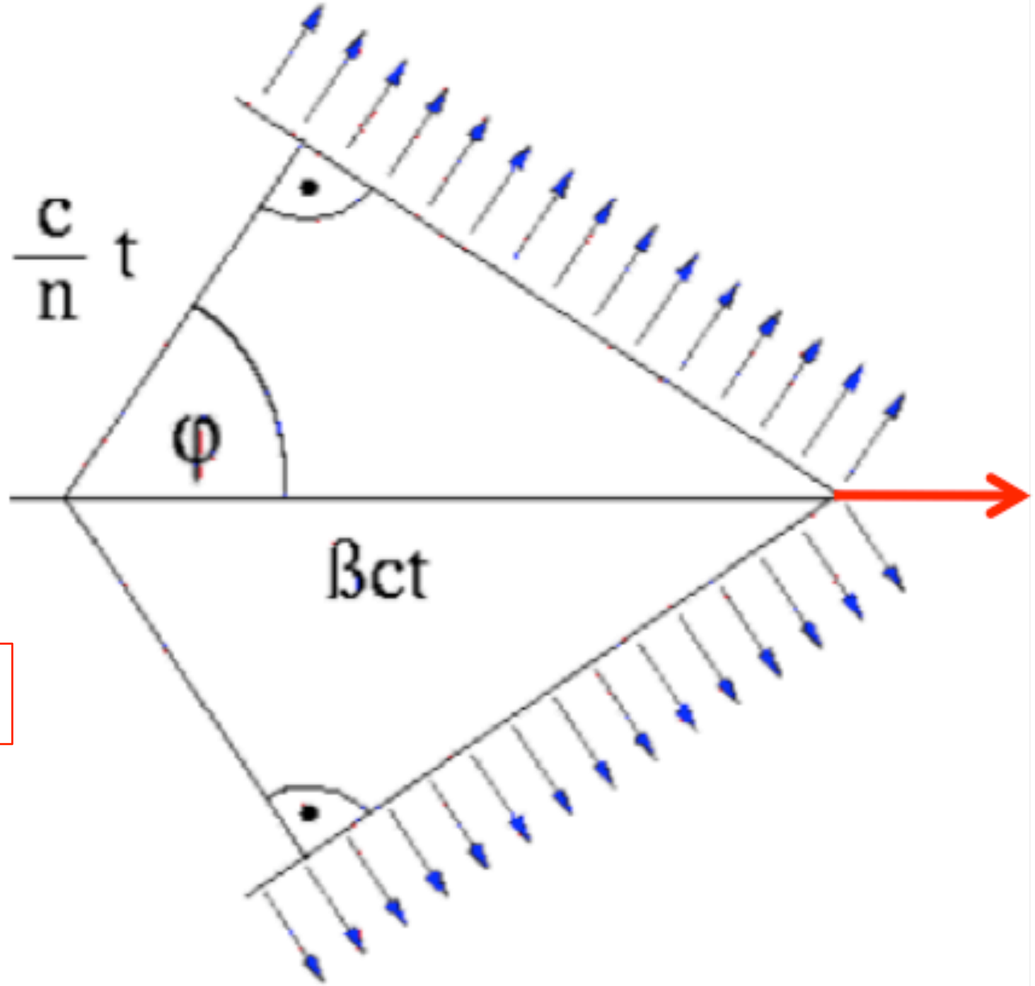
NATURAL TARGET

- sea water (ANTARES)
- Antarctic ice (IceCube)

Detection Principle

Neutrinos (E>100 GeV) can be detected collecting the visible Cherenkov radiation produced as the high-energy charged leptons (final state of CC interactions) propagate through a transparent medium with superluminal velocity.

Cherenkov Effect



$\beta ct\cos(\phi) = c/n\, t$

$\cos(\phi) = 1/(n\beta)$

- For ultra-relativistic particles: $\beta \sim 1 \rightarrow \cos(\phi) = 1/n$
- In water: $n = 1.33 \rightarrow \phi \sim 41°$

signal vs background

down-going μ from atmo. showers

$\mu_{upgoing} / \mu_{atm} \sim 10^{-4}$ at 3500m w.e. depth

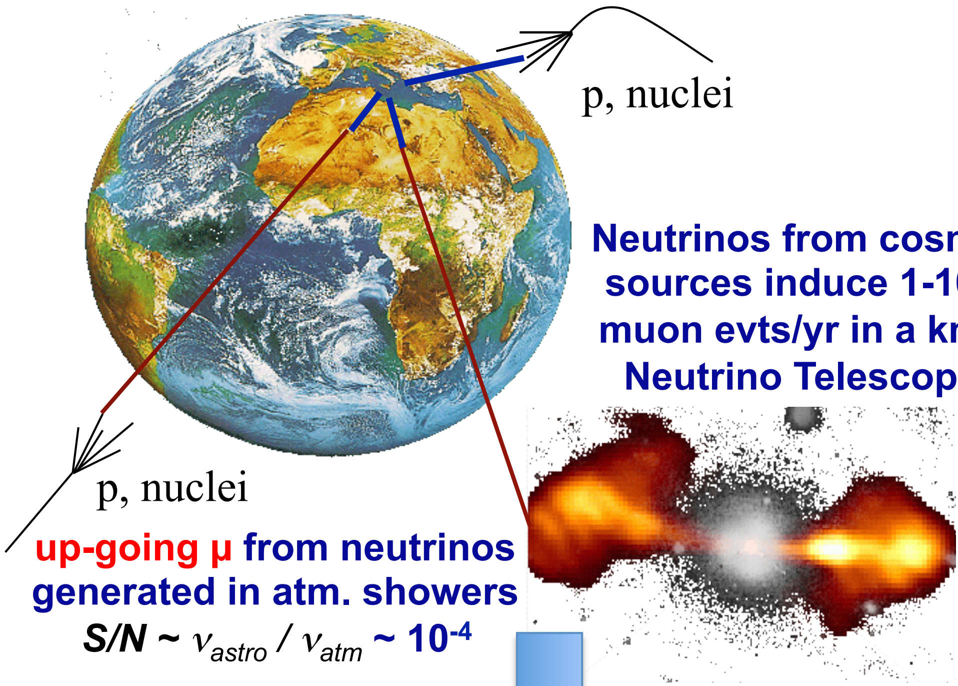
$S/N \sim 10^{-8}$

the deeper, the better

screen the atmospheric muon flux

(the most abundant source of bkg)

search for up-going events



Neutrinos from cosmic sources induce 1-100 muon evts/yr in a km3 Neutrino Telescope

up-going μ from neutrinos generated in atm. showers

$S/N \sim \nu_{astro} / \nu_{atm} \sim 10^{-4}$

atmospheric neutrino flux (an irreducible bkg)

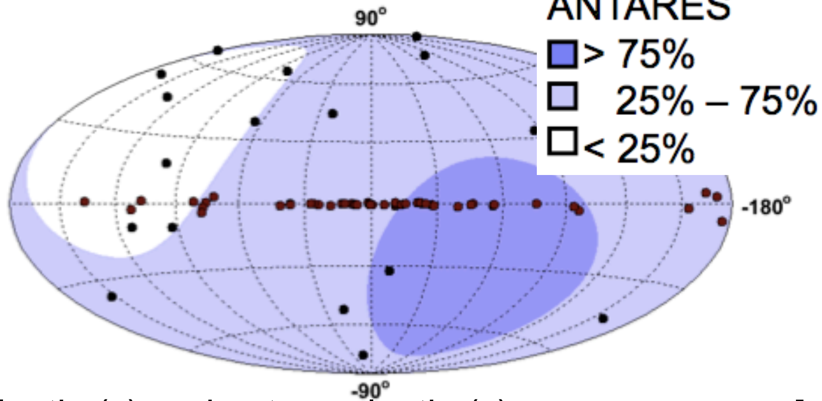
→ Energy Reconstruction

- Atmospheric neutrino flux ~ $E_\nu^{-3.5}$
- Neutrino flux from cosmic sources ~ E_ν^{-2}

search for ν with E_ν>1-10 TeV

→ Event Clustering (Point Sources)

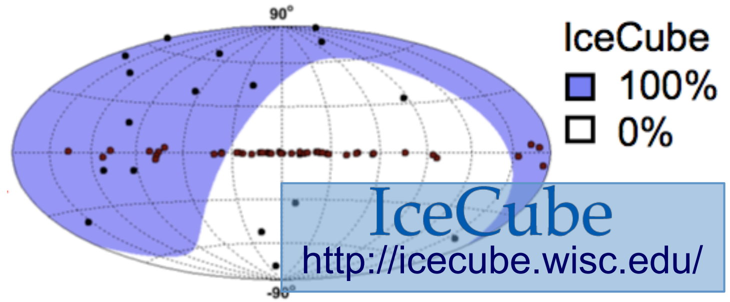
Visibility



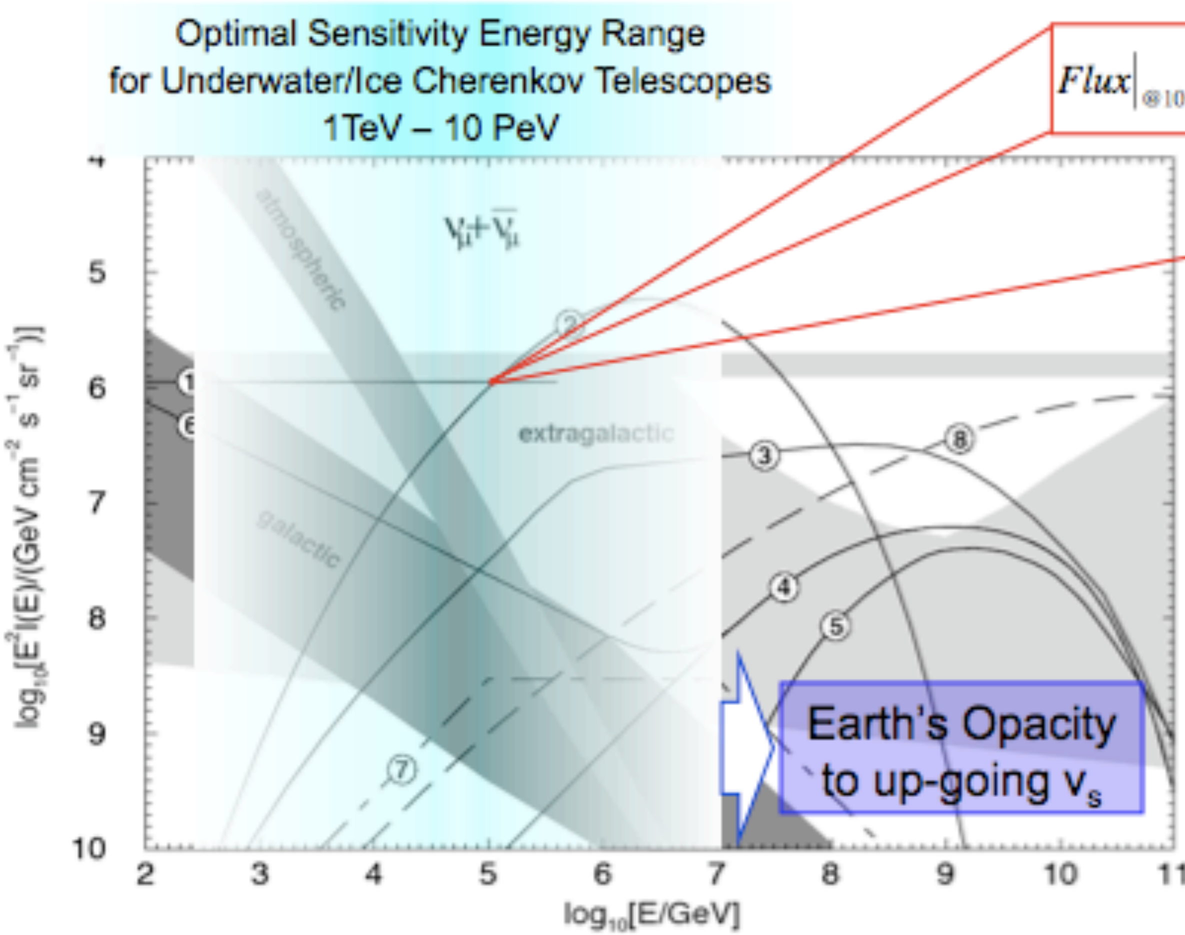
[galactic (•) and extra-galactic (•) gamma sources]

Sky Coverage

Complementarity to IceCube



… summing up
Neutrino Fluxes and Neutrino Detectors



(1-4 and 6) AGN models; *(5)* GZK; *(7)* GRB; *(8)* topological defects
[adapted from Learned and Mannheim, *Annu. Rev. Nucl. Part. Sci.* 50 (2000)]

$$Flux\Big|_{@10^5 GeV} \sim \frac{3\cdot 10^{-5}}{GeV\cdot m^2\cdot yr\cdot sr} \sim \frac{3\cdot 10^{1}}{GeV\cdot km^2\cdot yr\cdot sr}$$

Predicted neutrino fluxes are very **LOW**

\+

weak interactions

↓

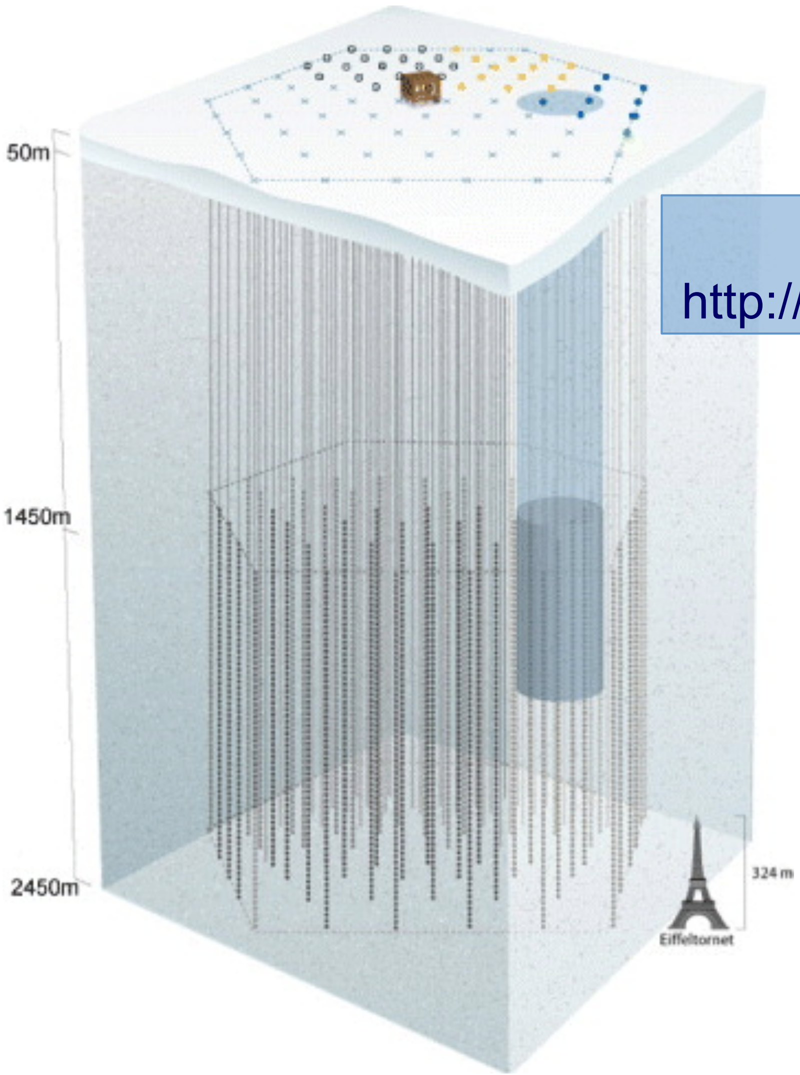
Cubic kilometer scale detectors are required

↓

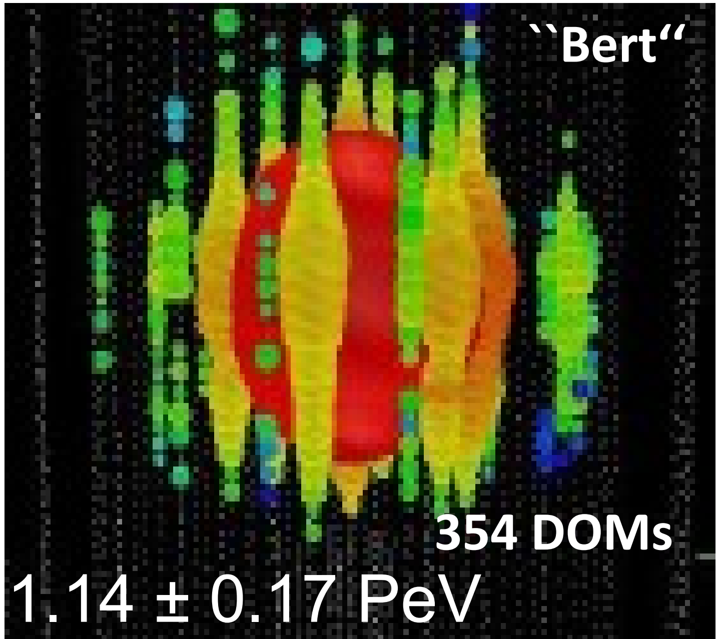
Natural Target (ICE, WATER)

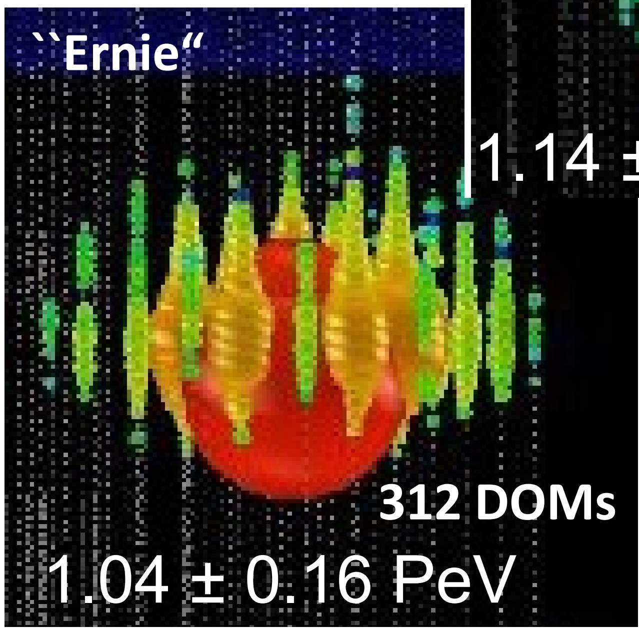
DEPTH → prevent atmo. μ contamination

IceCube Results and the New Era in Neutrino Astronomy



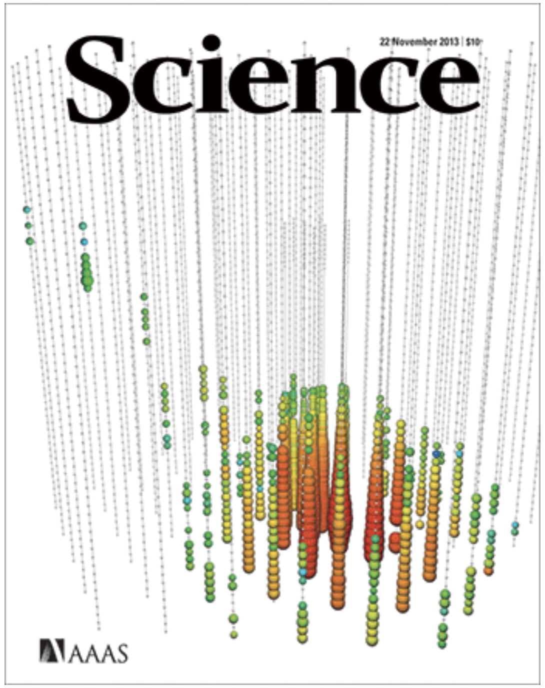
IceCube
http://icecube.wisc.edu/





(announced in Summer 2012)

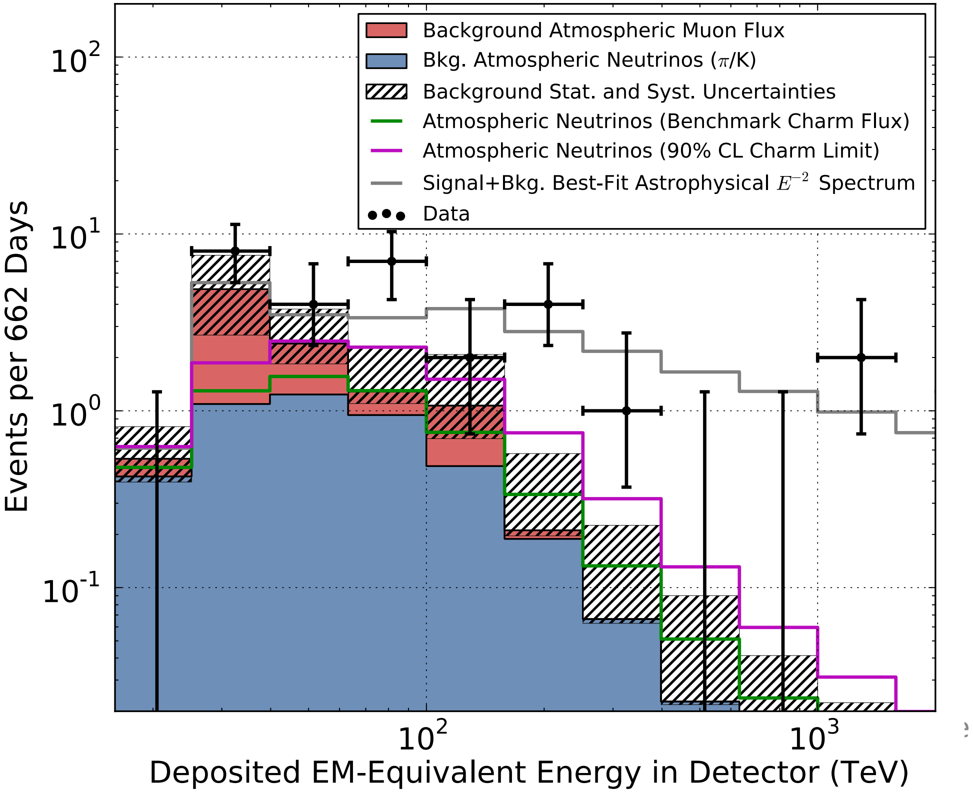
shower-like events

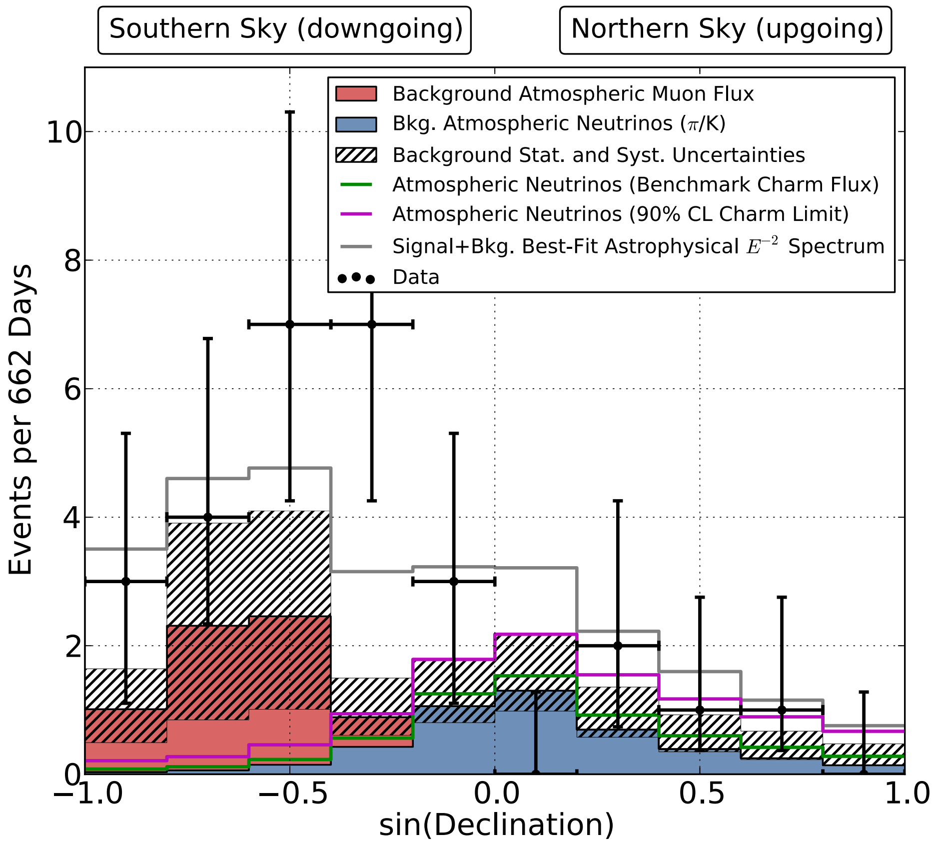


IceCube Results

Science 22 Nov. 2013
Vol. 342 no. 6161

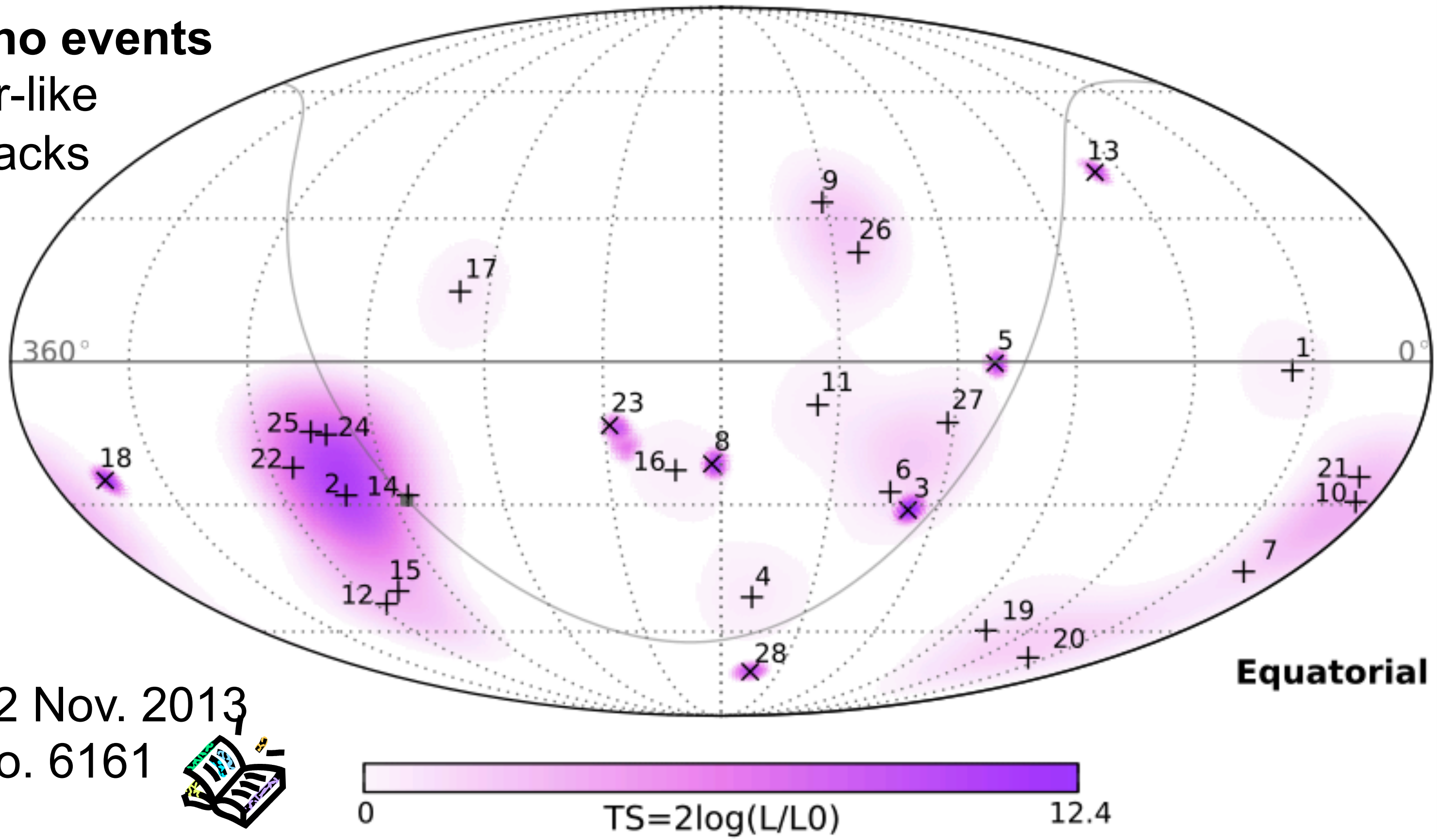
Observed **28 neutrino events** with **energy distribution harder than** any expected **atmospheric background**.
Measured event sample is compatible with **isotropic neutrino flux** (no cluster/candidate source)





IceCube Neutrino Sky Map

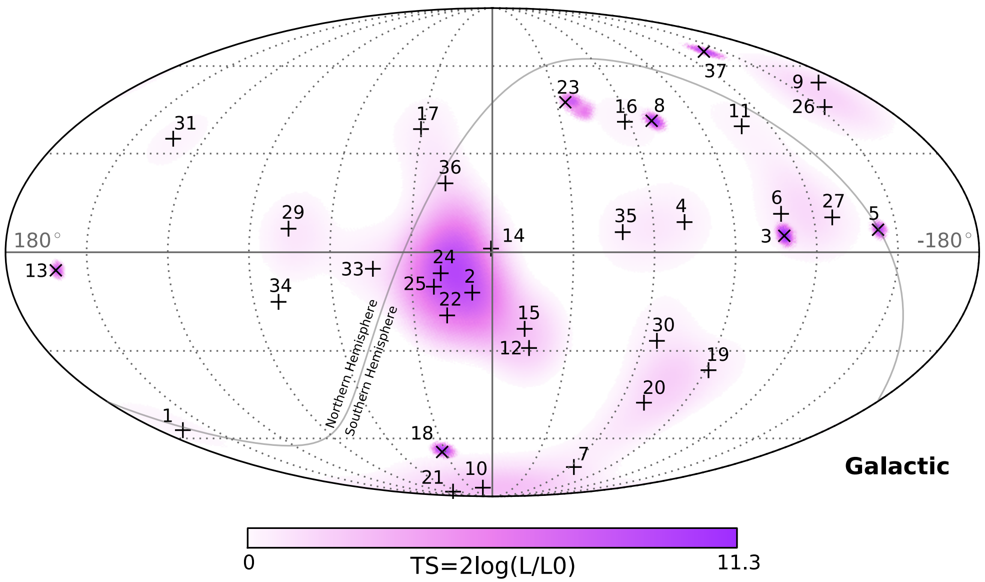
28 neutrino events
21 shower-like
7 muon tracks



Science 22 Nov. 2013
Vol. 342 no. 6161

Skymap in **equatorial coordinates** of the Test Statistic value (TS). The most significant cluster consists of 5 events (all showers and including the second-highest energy event in the sample) with a final significance of 8%. Best-fit locations of individual events are indicated with vertical crosses (+) for showers and angled crosses (x) for muon tracks.

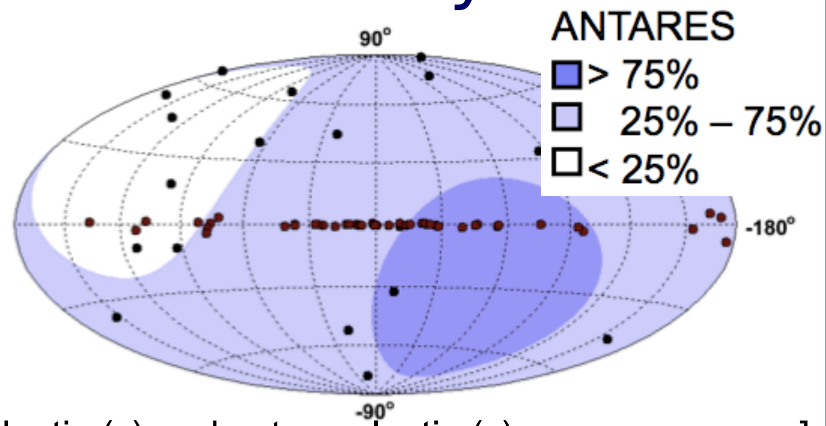
Data Analysis is in progress... updates



Observation of High-Energy Astrophysical Neutrinos in Three Years of IceCube Data, arXiv:1405.5303 [astro-ph.HE], submitted to PRL

compelling interest for a **Neutrino Telescope** in the **Northern Emisphere**

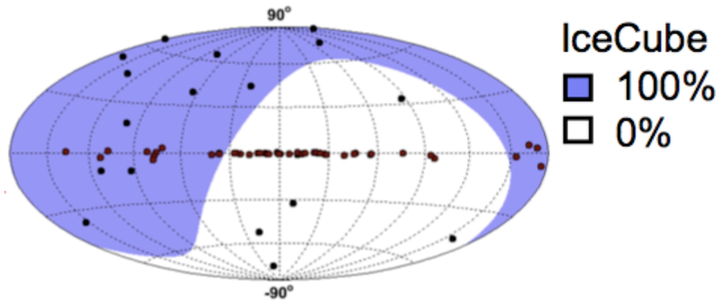
Visibility

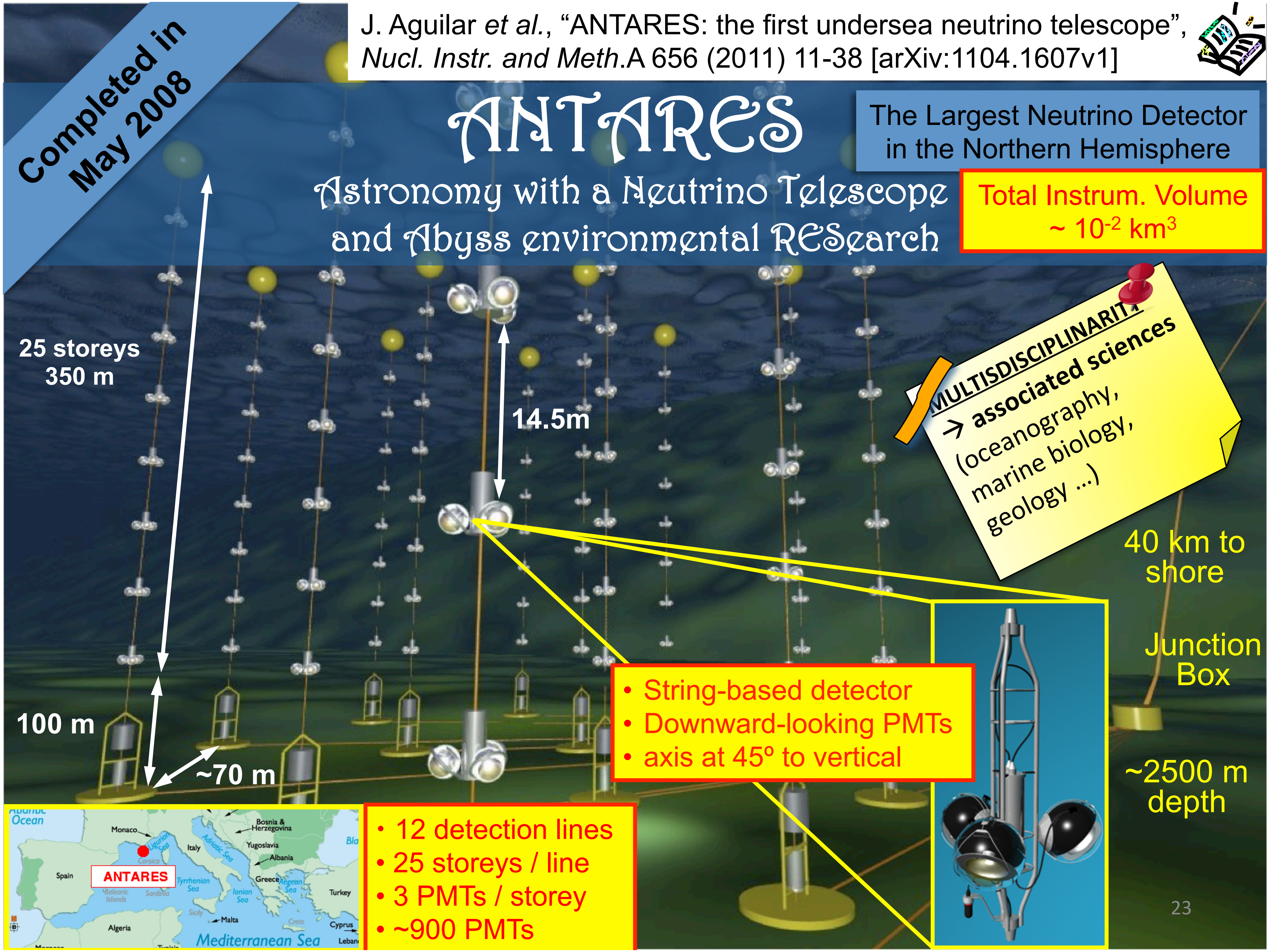


[galactic (•) and extra-galactic (•) gamma sources]

Sky Coverage

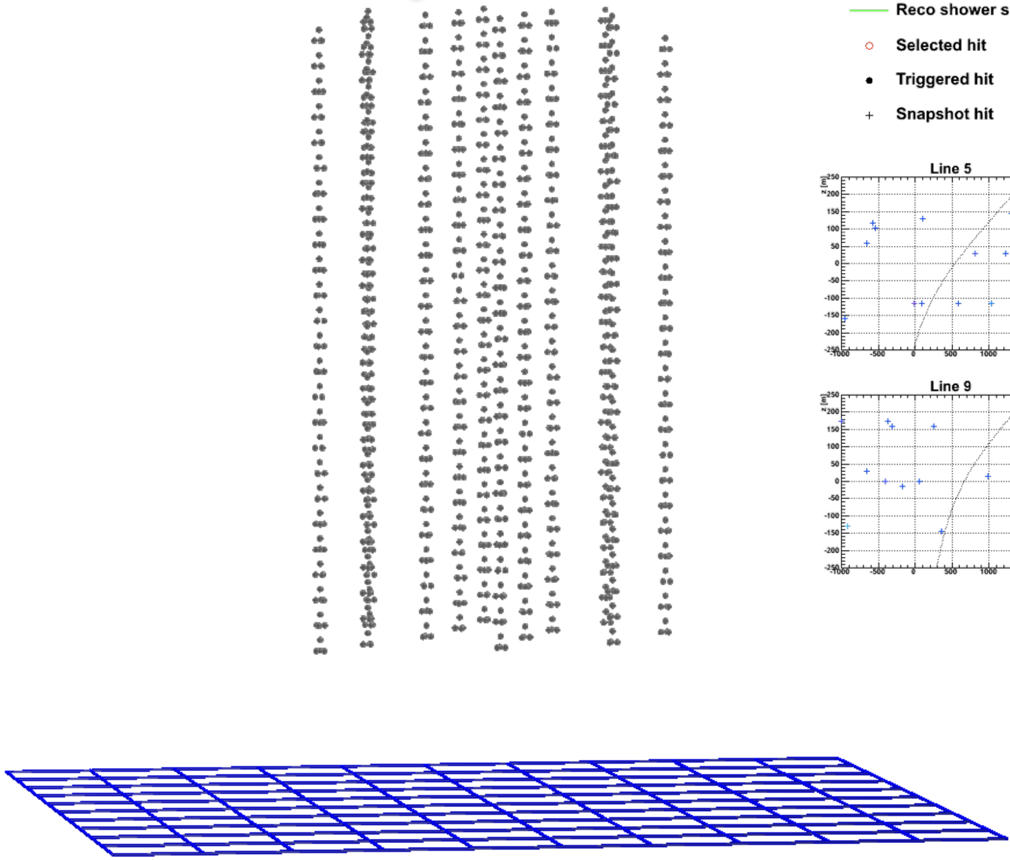
Complementarity to IceCube

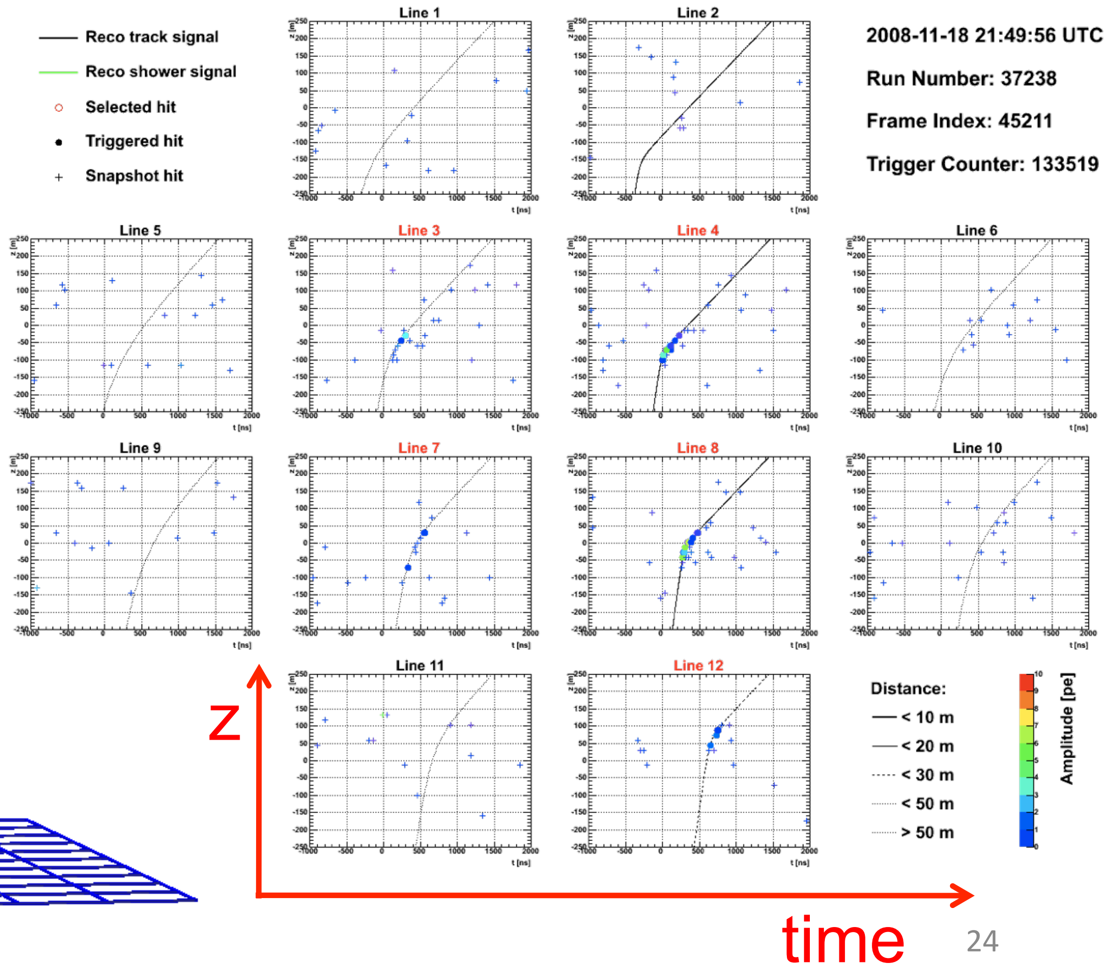



Completed in May 2008
J. Aguilar *et al.*, "ANTARES: the first undersea neutrino telescope",
*Nucl. Instr. and Meth.*A 656 (2011) 11-38 [arXiv:1104.1607v1]
ANTARES
Astronomy with a Neutrino Telescope
and Abyss environmental RESearch
The Largest Neutrino Detector
in the Northern Hemisphere
Total Instrum. Volume
~ 10^{-2} km^3
MULTISDISCIPLINARITY
→ associated sciences
(oceanography,
marine biology,
geology ...)
25 storeys
350 m
14.5m
100 m
~70 m
40 km to
shore
Junction
Box
~2500 m
depth
• String-based detector
• Downward-looking PMTs
• axis at 45° to vertical
• 12 detection lines
• 25 storeys / line
• 3 PMTs / storey
• ~900 PMTs
Ocean
Monaco
Ligurian Sea
Corsica
Italy
Adriatic Sea
Bosnia & Herzegovina
Yugoslavia
Albania
Spain
ANTARES
Balearic Islands
Sardinia
Tyrrhenian Sea
Ionian Sea
Greece
Aegean Sea
Turkey
Sicily
Malta
Crete
Cyprus
Algeria
Mediterranean Sea

ANTARES Event Display
a Neutrino Candidate

reco. μ energy: 5-10 TeV
decl.: -6°23'20.98''
RA: 12h57 23.18





The ANTARES Control Room

- Run Control
- On-Line Monitoring of the Apparatus

(hit rates, trigger rates, sea current [speed and direction], …)

- On-Line Event Display

ANTARES
Selected Results

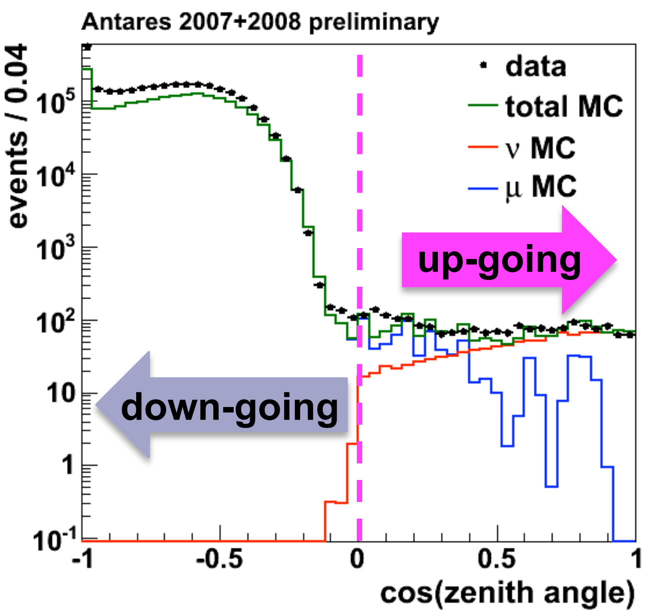
S. Adrian-Martinez, et al., *Astroph. J. Lett.*743 (2011) L14-L19

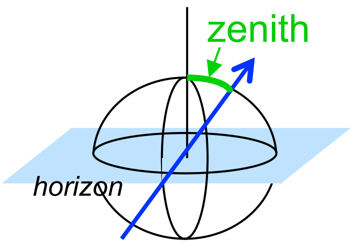
Point-like Sources

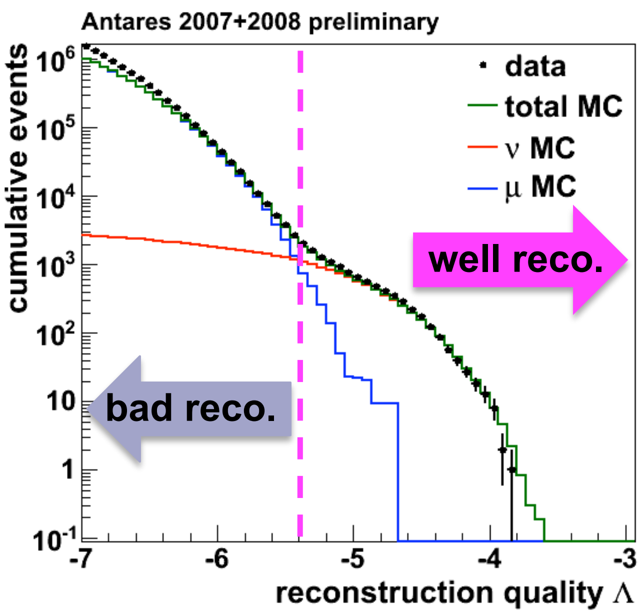
Detector Performance & Data/MC Comparison

μ tracks reconstructed using a likelihood-based algorithm

2007-2008 data
Integrated Live Time: 304 days

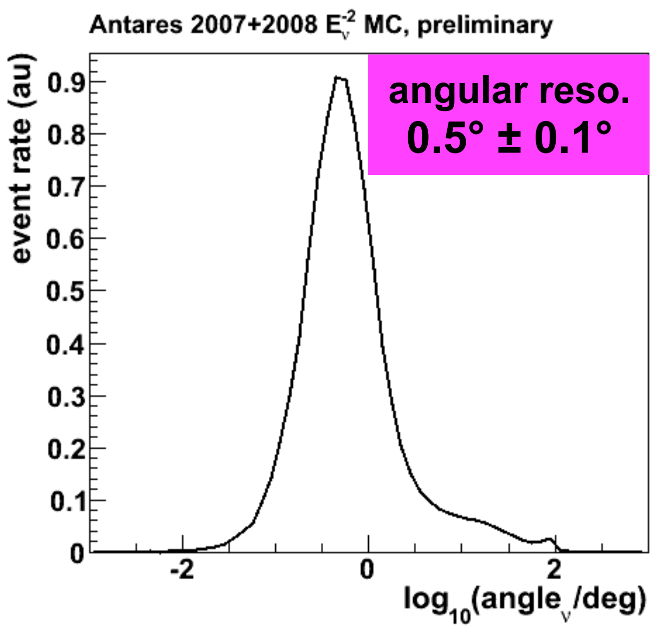






Λ distribution for the up-going selected events

Λ>-5.4 → selected 2040 events



MC studies: angle between the true ν direction and the reconstructed μ direction.

Point-like Sources

Larger Data Sample and Improved Analysis

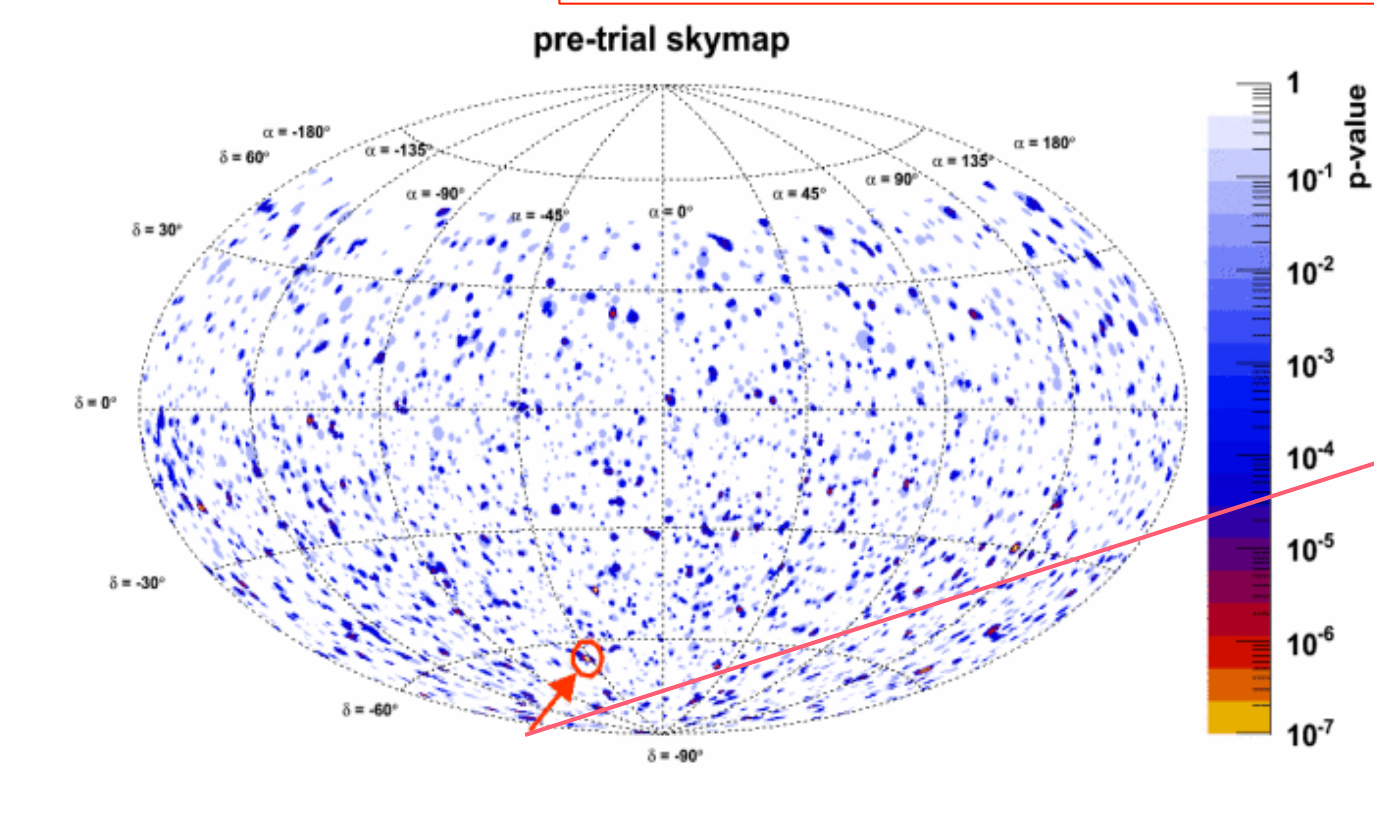
2007-2010 data
Integrated Live Time: 813 days
3058 neutrino candidates

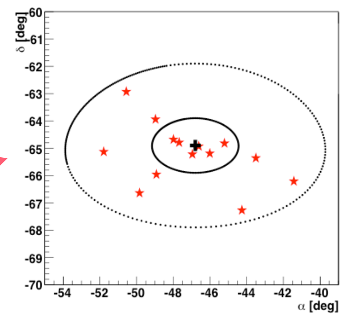
ApJ. 760:53 (2012)

2007-2012 data
Integrated Live Time: 1340 days
5516 neutrino candidates

ApJ-L. 786:L5 (2014)

No statistically significant excess
"Best" cluster at (-46.5°, -65.0°)

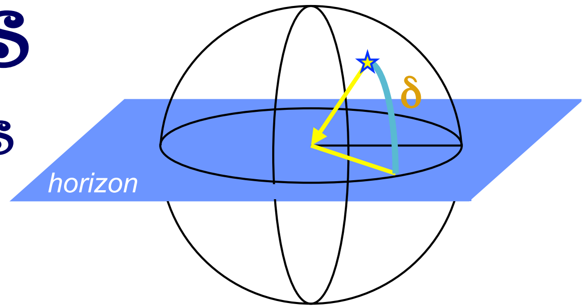


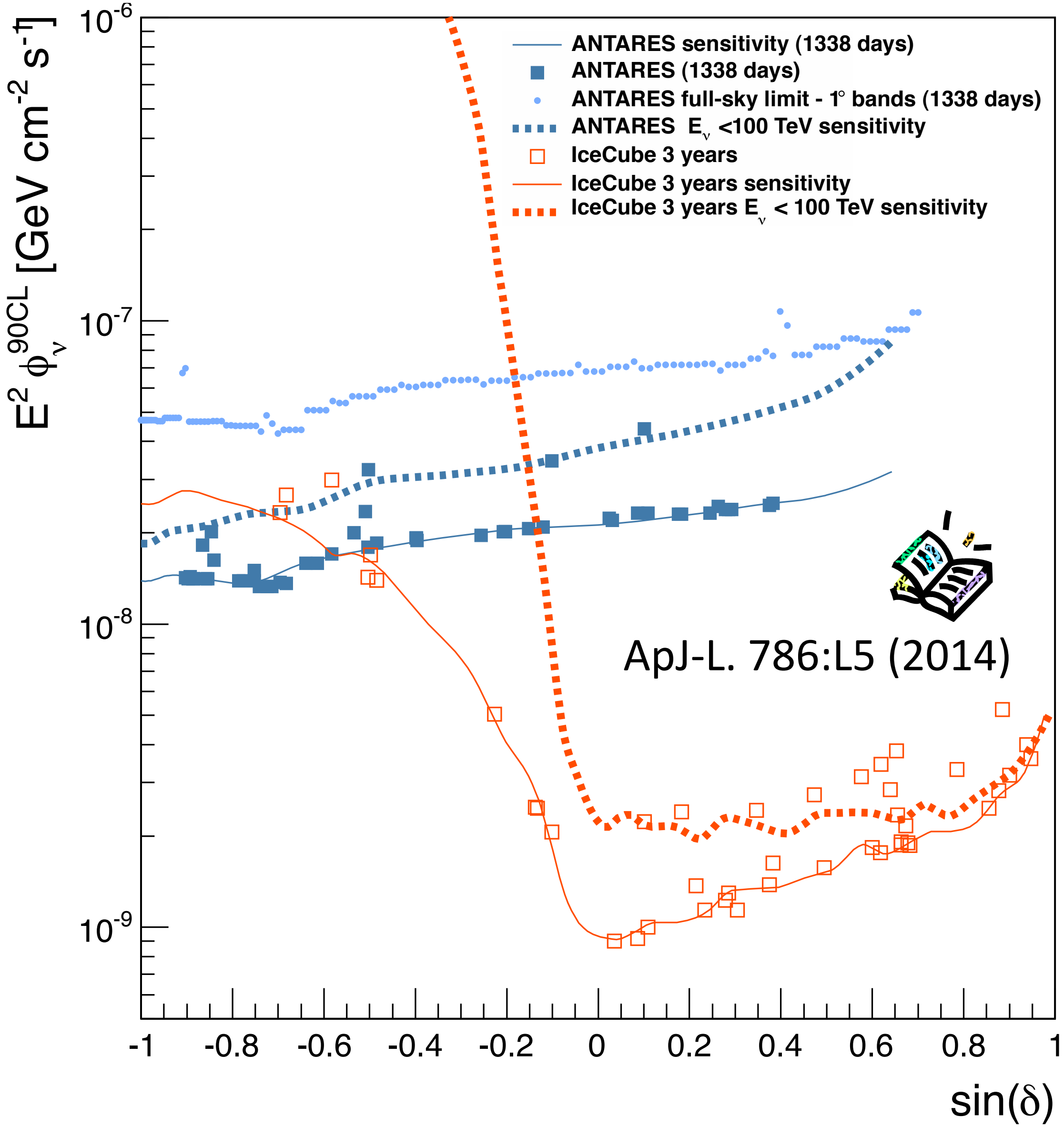


N_{sig}=6.2
p-value =2.7%
signal signif. 2.2 σ

Point-like Sources

Upper Limits and Sensitivities





ANTARES data provide the most stringent limits to flux of neutrinos from point-like sources for a large part of the Southern Sky in the TeV region.

IceCube sensitivity to point-like sources in the Southern Sky improves for $E_n > 100$ TeV (downgoing tracks)

Diffuse Cosmic ν Flux
the method

idea:

- Background atmospheric neutrinos have steeply falling energy spectrum : $N \propto E^{-3.5}$
- Many cosmic neutrino models predict much harder spectra, typically $N \propto E^{-2}$
  => *Look for High-energy diffuse flux component*

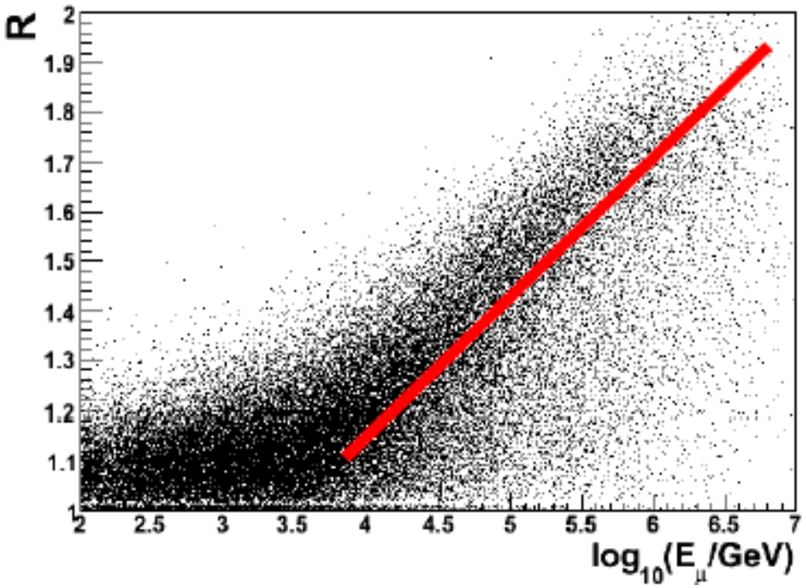
analysis:

- Live time: 334 days
- Stringent selection: 134 high energy ν candidates, no atmospheric muons
- Energy estimator R: a measure of the number of delayed photons

energy estimate:

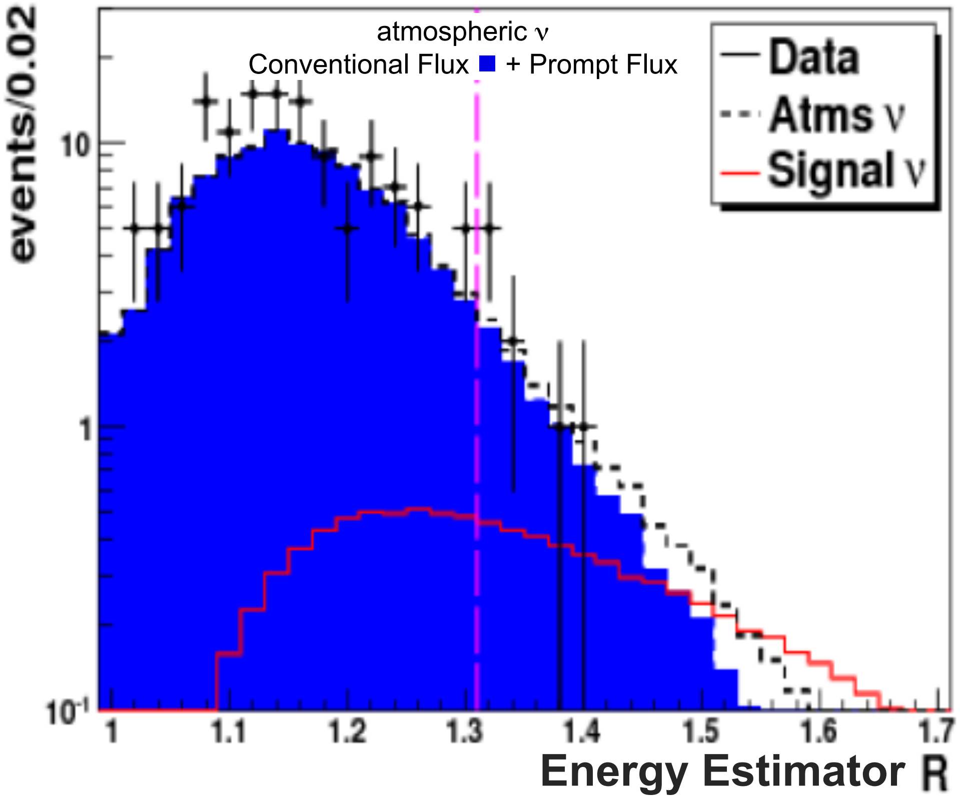
- the muon energy at the detector is correlated with the neutrino energy
- muons above 1 TeV produce additional Cherenkov light via secondaries (∝ E)
- Energy estimate R based on number of repeating hits

$$R = \frac{\sum R_i}{N_{OM}}$$

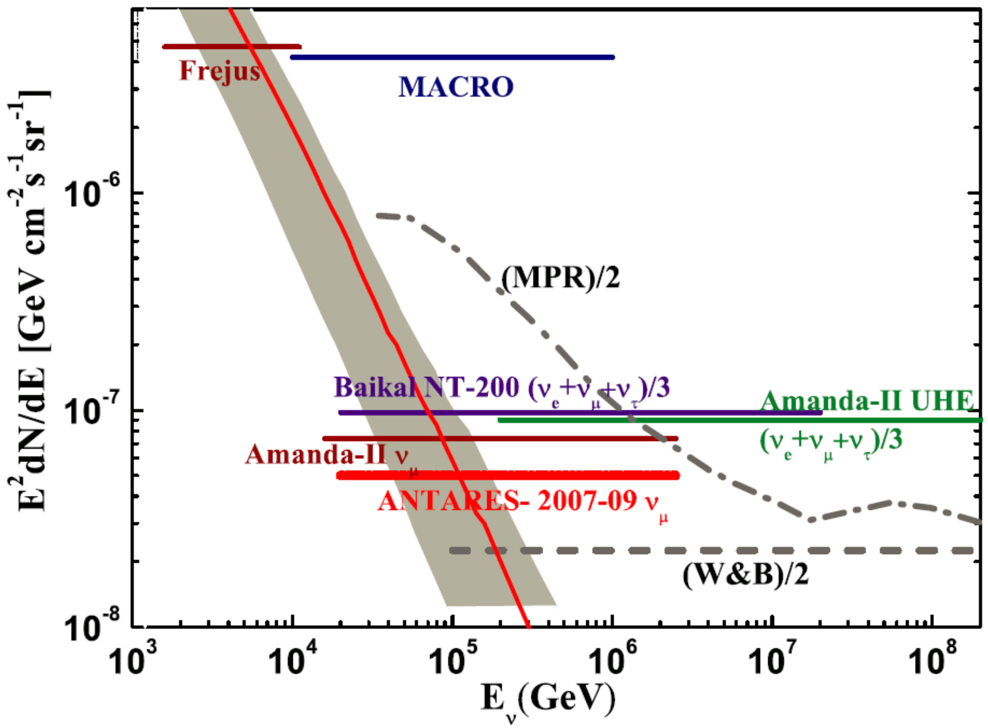


Diffuse Cosmic ν Flux

Results



No excess of high energy events found over expectation from atmospheric ν



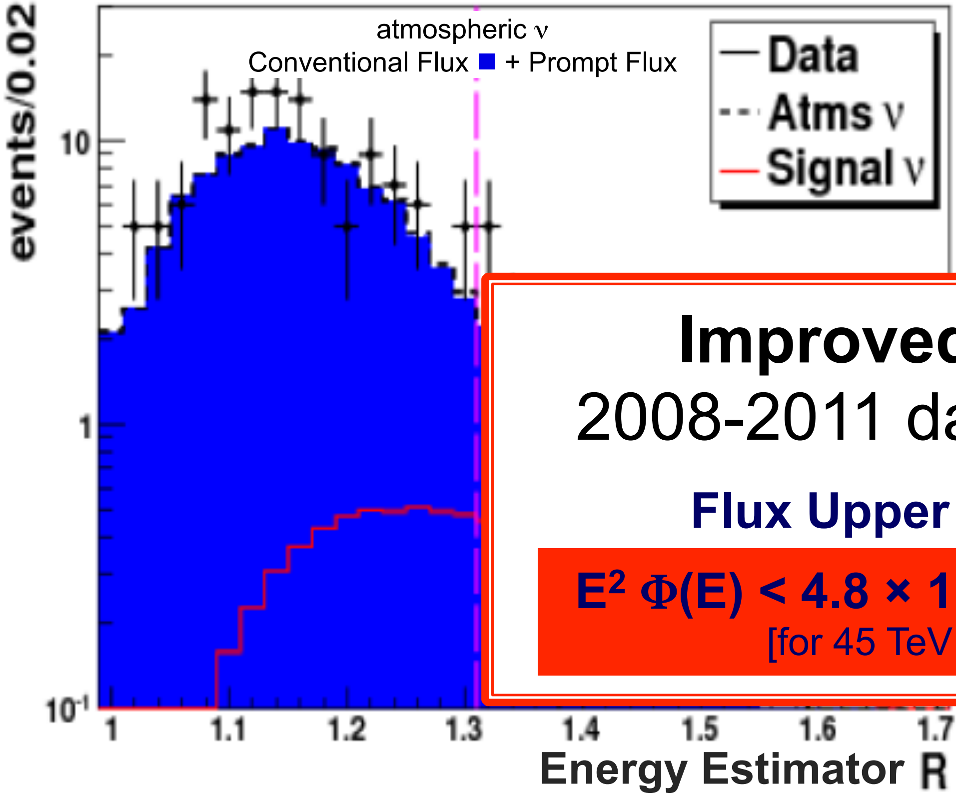
Flux Upper Limit (90% CL)

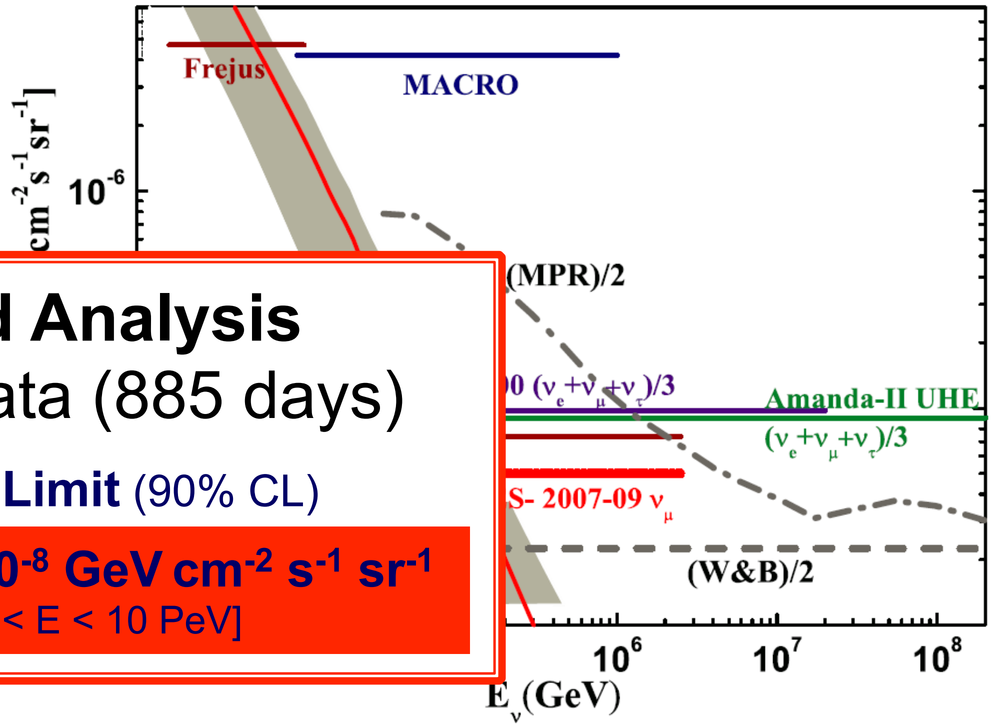
$E^2\,\Phi(E) < 5.3 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}
[for 20 TeV < E < 2.5 PeV]

J. Aguilar *et al.*, "Search for a diffuse flux of high energy ν_μ with the ANTARES neutrino telescope", *Phys. Letter B* 696, 16-22 (2011)

Diffuse Cosmic ν Flux

Results





Improved Analysis

2008-2011 data (885 days)

Flux Upper Limit (90% CL)

$E^2 \Phi(E) < 4.8 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

[for 45 TeV < E < 10 PeV]

No excess of high energy events found over expectation from atmospheric ν

Flux Upper Limit (90% CL)

$E^2 \Phi(E) < 5.3 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

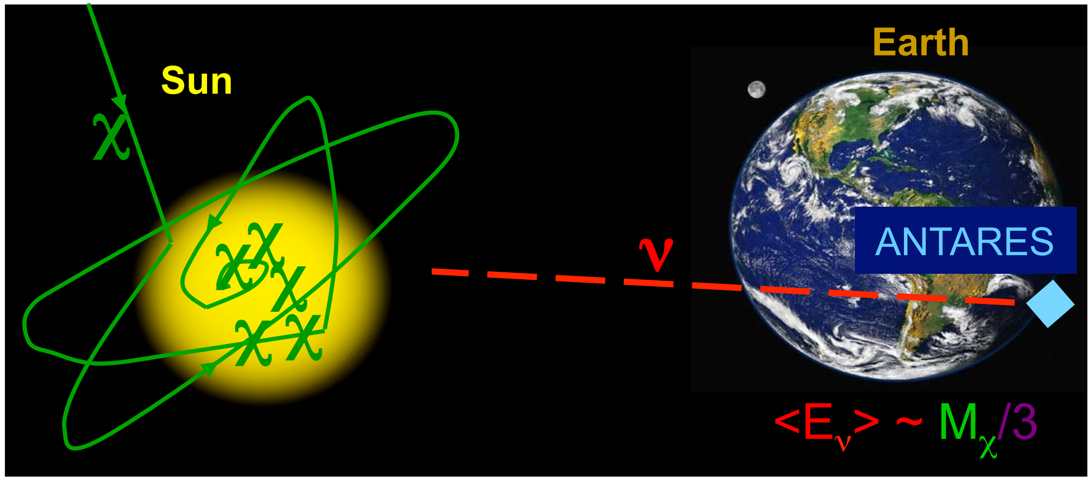
[for 20 TeV < E < 2.5 PeV]

J. Aguilar *et al.*, "Search for a diffuse flux of high energy ν_μ with the ANTARES neutrino telescope", *Phys. Letter B* 696, 16-22 (2011)

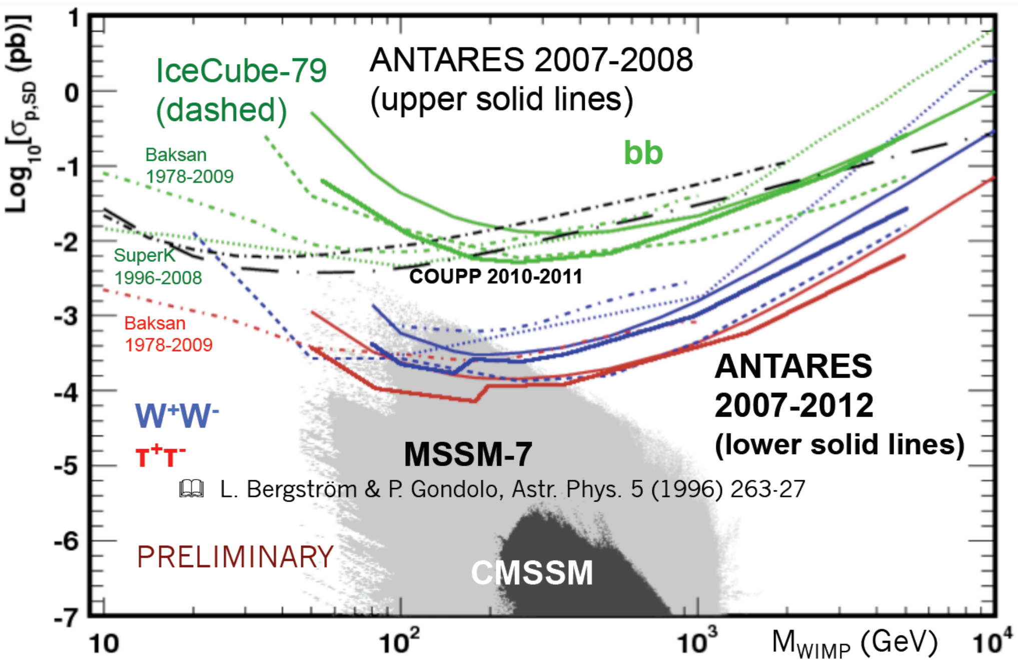
Dark Matter

WIMPs (Weakly Interacting Massive Particles) are gravitationally trapped via elastic collisions in the centre of massive object, as the Earth, the Sun or the Galactic Centre.

Indirect search for dark matter in the ANTARES telescope is possible assuming **neutrinos** (in the GeV-TeV energy range) are produced in the **WIMPs annihilation**.



$\chi\,\chi \rightarrow bb,\ WW,\ tt,\ \tau\tau,\ \nu_\mu\nu_\mu, \nu_\tau\nu_\tau \rightarrow \nu_e,\ \nu_\mu, \nu_\tau$



Upper limit on the total flux $\Phi(\nu_\mu+\nu_\mu)$ from **neutralino annihilations in the Sun** as function of mχ

Limits on the neutralino cross section

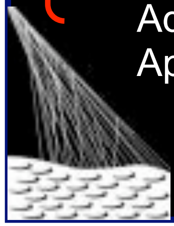
Journal of Cosmology and Astroparticle Physics, JCAP11(2013)032

Multi-Messenger Searches

Potential astrophysical sources are predicted to emit very faint neutrino signal. The Multi-Messenger Approach increases the **discovery potential**, by observing with different probes; the **significance**, by coincident detection; the **efficiency**, by relaxed cuts.

ANTARES ⟷ VIRGO LIGO

common working group (GWHEN)
S. Adrián-Martínez et al.
JCAP 06 (2013) 008



ANTARES ⟷ AUGER

Adrian-Martinez et al.,
ApJ 774 (2013) 008

Flaring Sources
(ν emission from γ-flaring blazars/μQuasars)

ANTARES ⟷ FERMI SWIFT RXTE

APP 36 (2012) 304
arXiv:1402.1600

TAToO
(Telescopes – ANTARES Target of Opportunity) **Optical follow-up** of **neutrino alerts** for transient source search (GRBs, SNae).
Analysis in progress!

ANTARES ⟷ Optical Telescopes
TAROT & ROSTE + more

Ageron *et al.*, *Astrop.Phys* 35 (2012) 530-536

GCN
(**GRB** Coordinat. Network)

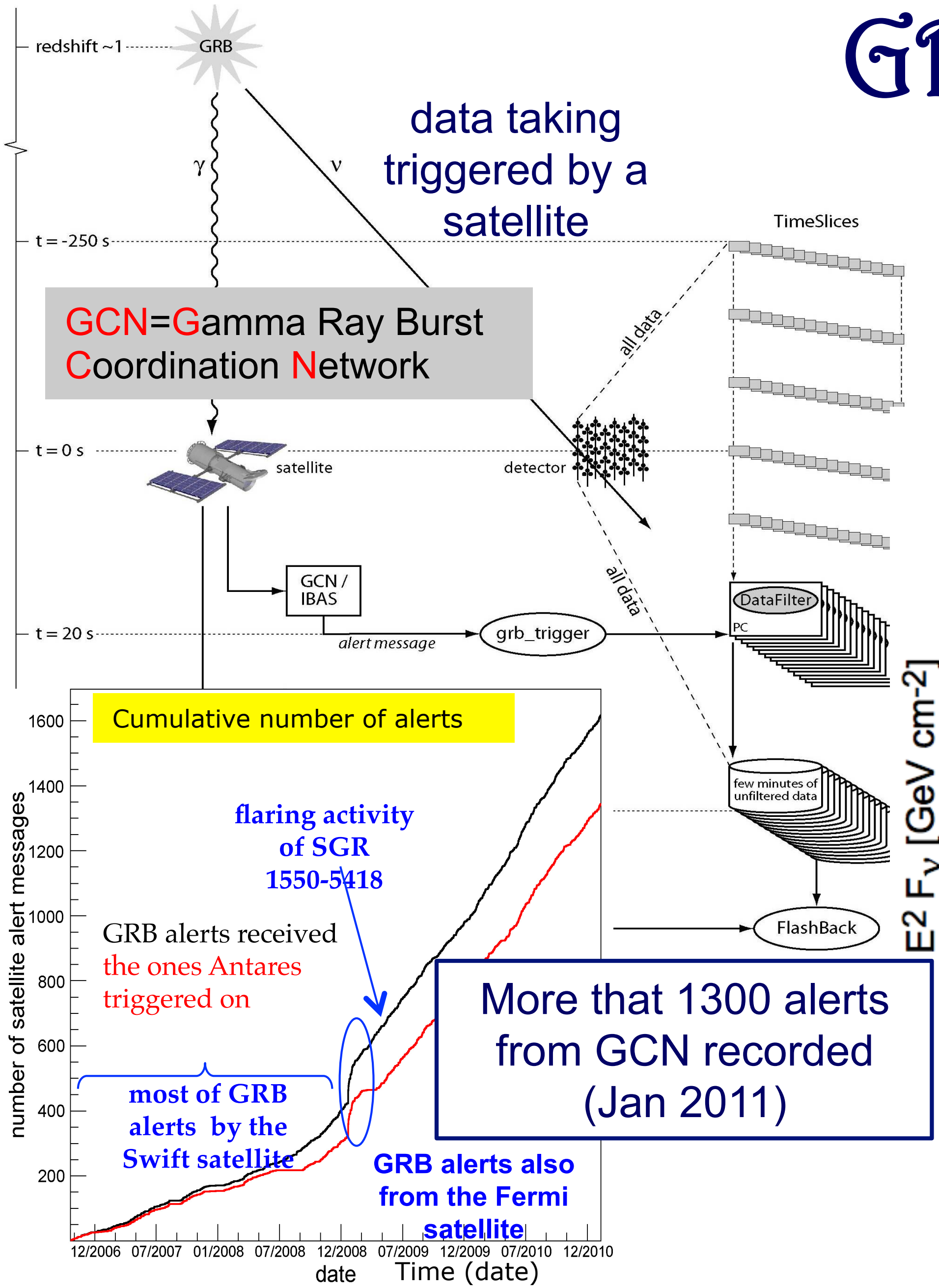
ANTARES ⟷ GCN

Adrián-Martínez et al.,
JCAP 1303 (2013) 006

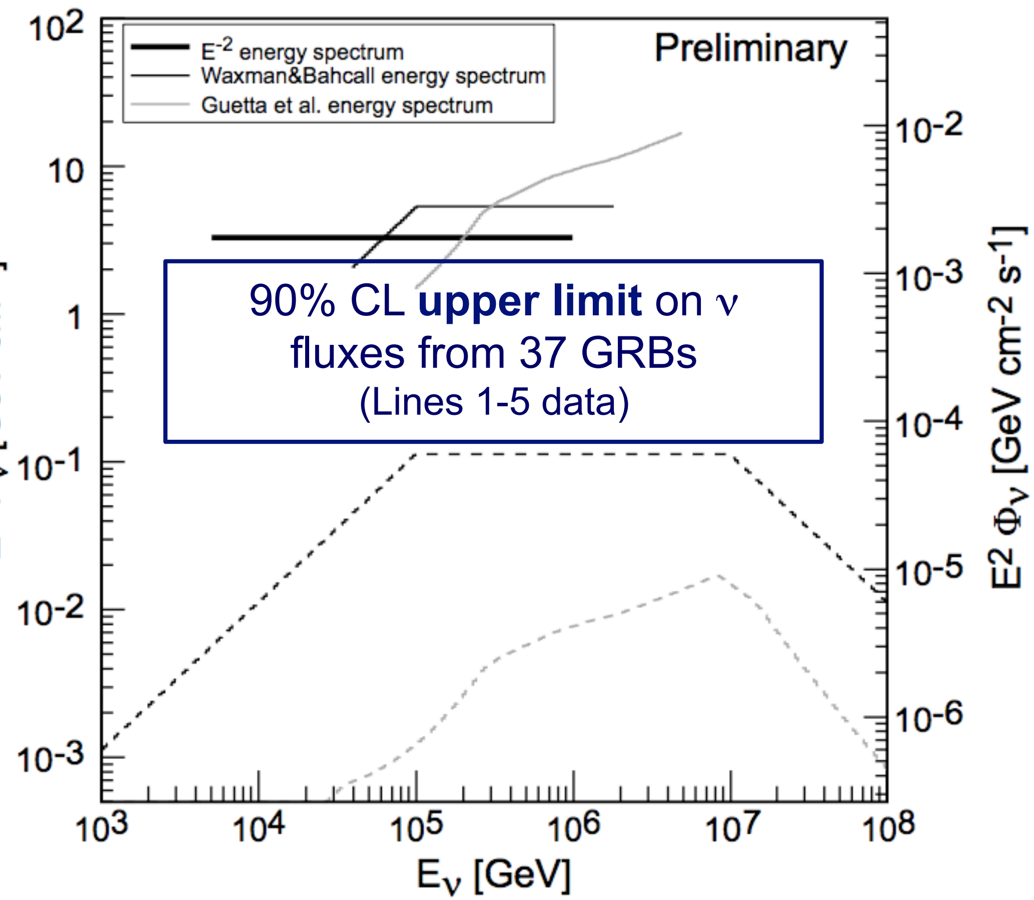
Multi-Messenger Searches

GRBs

ANTARES ⬌ GCN



Lines 1-5 data: 148 alerts received (72 above the horizon, 23 rejected by run selection, 16 false trigger) → **37 GRBs in the analysis** (exposure 1882 s)



A Multi-Messenger Search of ν from GRB

Astronomy & Astrophysics 559, A9 (2013)

2007-2011 data:
- alerts and data from FERMI – SWIFT - GCN
- analysis of 296 long GRBs (total prompt emission 6.6 hours)

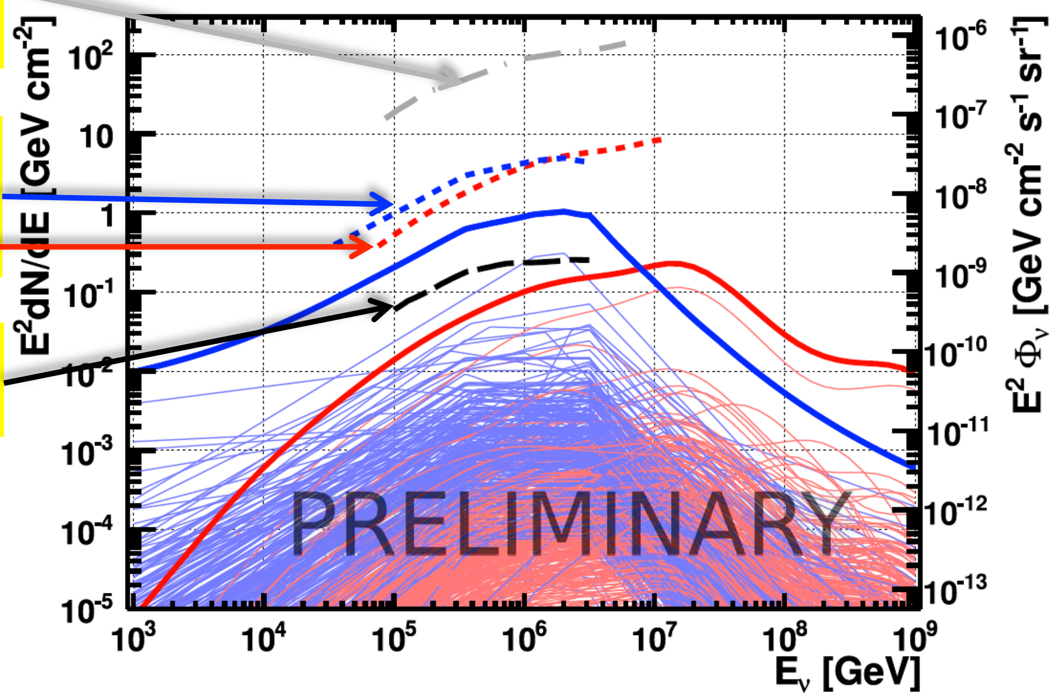
Simulation of neutrino fluxes from GRB:
- NeuCosmA (Hümmer et al 2010) → expected 0.061 events
- Guetta (Guetta et al. 2004) → expected 0.48 events
- Expected background 0.051 events

No events found in stacked GRB search within 10° window:

Previous ANTARES result, 40 GRBs
JCAP 1303 (2013) 006

ANTARES upper limits 90% C.L. for
Guetta fluxes
NeuCosmA fluxes

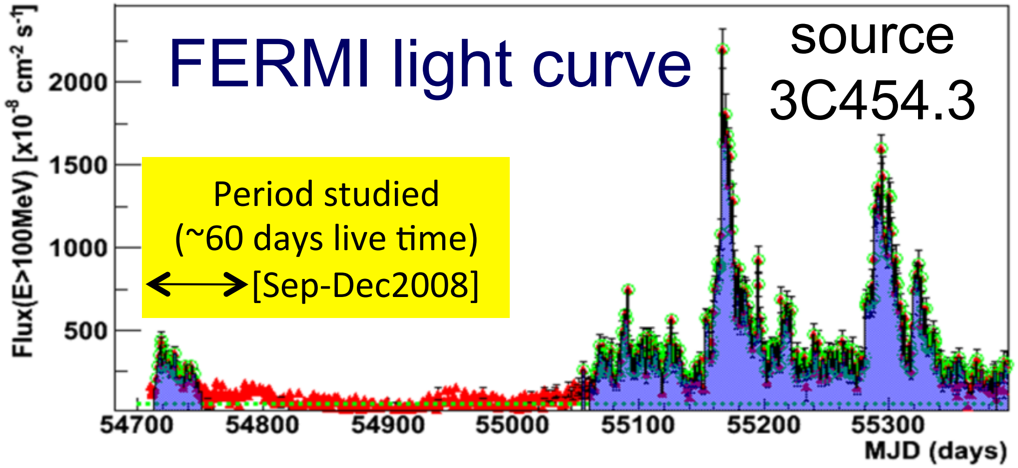
IceCube upper limits 90% C.L.
IC40+59 for 215 GRBs



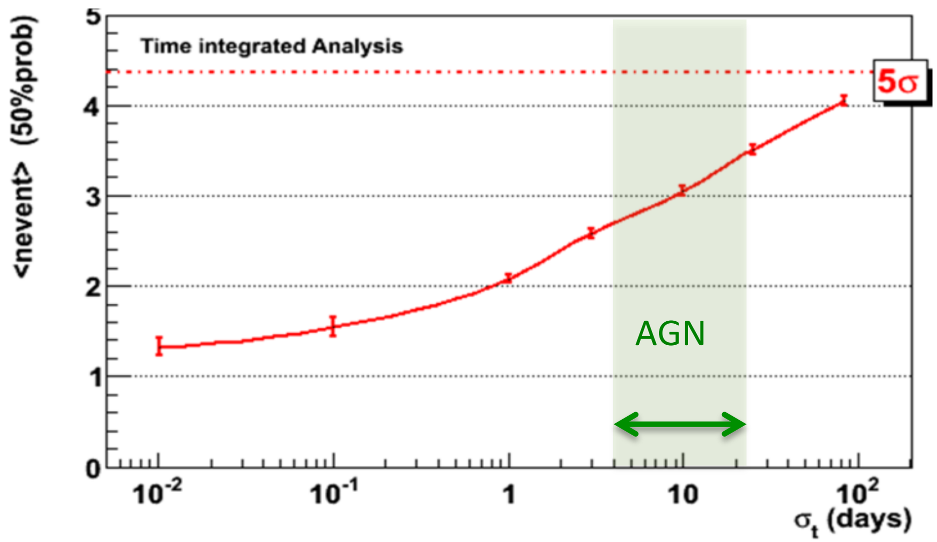
Astrop.Phys. 36 (2012) 204–210

ν emission from γ-flaring blazars

Multi-Messenger Searches
AGN Flares (ANTARES ⟺ FERMI)



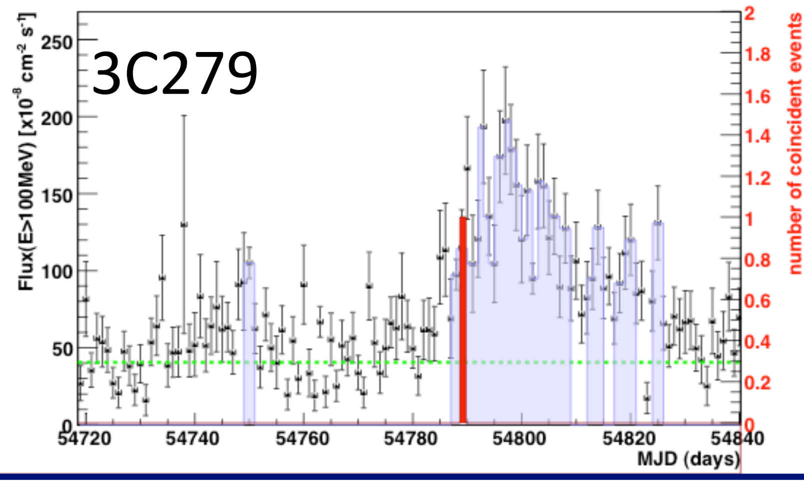
10 sources selected from the FERMI catalog, showing a large **variability** (flaring state) in the period studied for this analysis.



Performance of the **time-dependent analysis**

RESULTS

- **1 neutrino candidate event** compatible with the time/space distribution (Δα=0.56°) of 3C279 with probability (p-value) = 1% (but post trial probability = 10%) → very promising analysis → **extend the studied period** to 2009-2010 data set
- **Fluence Upper Limits** for the selected source



ANTARES ⟺ AUGER

Adrian-Martinez et al., ApJ 774 (2013) 008

Multi-Messenger Searches

Correlation with UHECRs

-Search for correlation in the arrival directions of **2190 neutrino candidate events** (detected by ANTARES in 2007-2008, effective live time: 304 days) and **69 UHECRs** (detected by Pierre AUGER Observatory in 2004-2009, E>$10^{19.74}$ eV, all the events in the ANTARES telescope field of view).

-**Source Stacking Method**.

-UHECR magnetic deflection = 3° (light composition assumed)

-Statistical significance and optimal angular search bin is determined by 10^6 pseudo-experiments, each containing the 69 AUGER events at fixed coordinates and the 2190 neutrino events scrambled in right ascension.

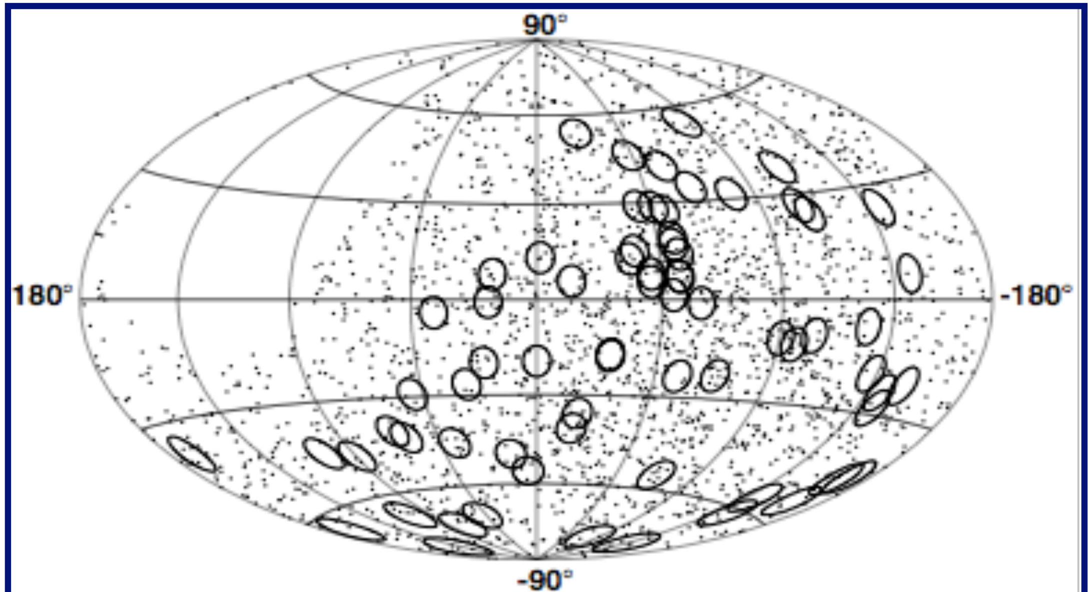
no significant correlation observed

↓

Upper Limit on the Neutrino Flux

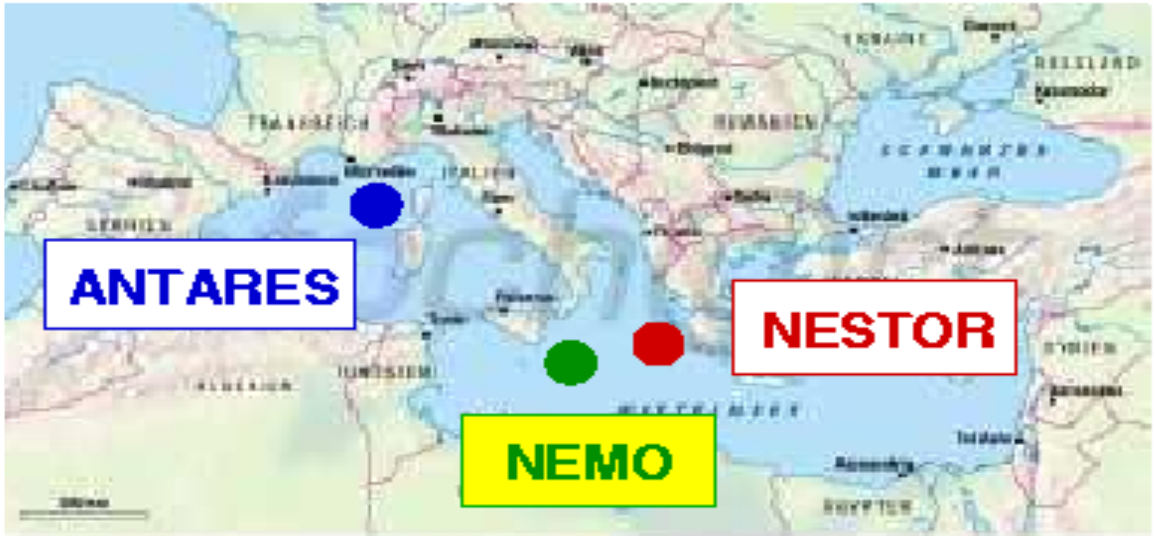
4.99 x 10^{-8} GeV cm^{-2} s^{-1}

(assuming a E^{-2} energy spectrum)



Skymap in Galactic Coordinates; neutrino events are represented with black dots and angular search bins of 4.9° centered on the observed UHECRs with black circles.

Towards the KM3…



ANTARES + NEMO + NESTOR joined their efforts to prepare a km^3-scale Cherenkov neutrino telescope in the Mediterranean →

The KM3NeT Collaboration

KM3NeT

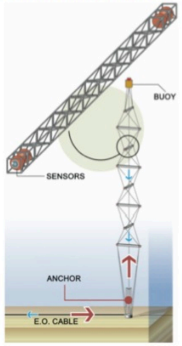
http://www.km3net.org/

È operativa la prima Torre del futuro Telescopio per neutrini astrofisici nel Mediterraneo !!!

Portopalo di Capo Passero (SR), 24 marzo 2013.

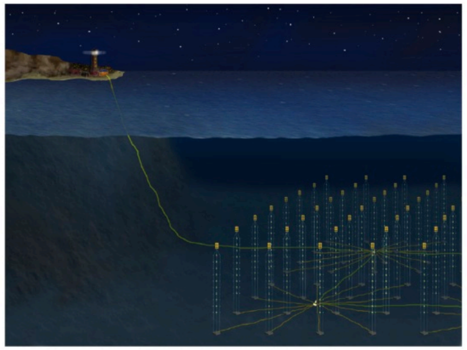
Si è svolta secondo i programmi e si è conclusa ieri con successo l'operazione di posizionamento e messa in opera nel Mar Ionio, a 3500 metri di profondità ed ad 80 km a SE di Capo Passero, del primo modulo del futuro telescopio per neutrini astrofisici di alta energia. Tale telescopio permetterà di estendere l'orizzonte osservativo verso i confini dell'Universo.

L'importante risultato della collaborazione Italiana **NEMO**, a cui partecipano nove gruppi dell'INFN (Bari, Bologna, Catania, Genova, LNF, LNS, Napoli, Pisa, Roma), è stato raggiunto grazie ad una lunga attività di ricerca e di sviluppi tecnologici il cui obiettivo finale è la realizzazione del telescopio per neutrini. Per il raggiungimento di tale risultato un ruolo importante ha rivestito la collaborazione e la sinergia con Istituti di ricerca geofisica, oceanografica di biologia marina (INGV, CNR, CIBRA, NURC).



L'apparato installato è una struttura a "torre" che consiste di otto piani, ciascuno equipaggiato con sensori ottici, acustici ed oceanografici. Le operazioni di installazione sul fondale marino sono state eseguite dalla nave "Nautical Tide" specializzata per attività a grande profondità. Mediante un ROV (Remotely Operating Vehicle), l'apparato è stato dapprima posizionato a 3500 m di profondità, con precisione di alcuni metri rispetto al punto previsto, e quindi connesso al cavo elettro-ottico sottomarino di 100 km già installato dall'INFN nel 2007. La torre, inizialmente posizionata in configurazione compatta, è stata poi aperta facendole assumere la sua configurazione finale di 400 m di altezza.

Il cavo sottomarino permette l'alimentazione, il controllo dell'apparato e l'acquisizione dei dati dal laboratorio a terra dei LNS (Laboratori Nazionali del Sud dell'INFN) situato a Portopalo di Capo Passero (SR) da cui i dati sono resi disponibili in tempo reale a tutte le componenti della collaborazione.



La realizzazione di un telescopio sottomarino per neutrini astrofisici di alta energia è l'obiettivo perseguito da ricercatori INFN nell'ambito della collaborazione europea KM3NeT supportata negli anni 2006-2012 da programmi di finanziamento FP6 ed FP7.

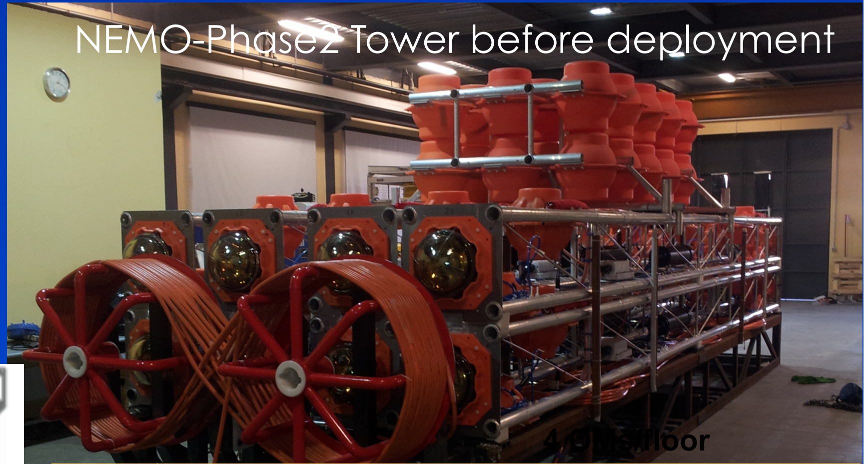
L'apparato installato costituisce il primo passo verso la realizzazione del nodo italiano del futuro telescopio per neutrini KM3NeT. La costruzione di una prima parte di questo nodo è già stata avviata grazie ad un finanziamento del MIUR su fondi del PON 2007-2013.

Per maggiori informazioni rivolgersi al Prof. Antonio Capone (antonio.capone@roma1.infn.it)
http://www.roma1.infn.it/km3/

http://www.roma1.infn.it/km3/

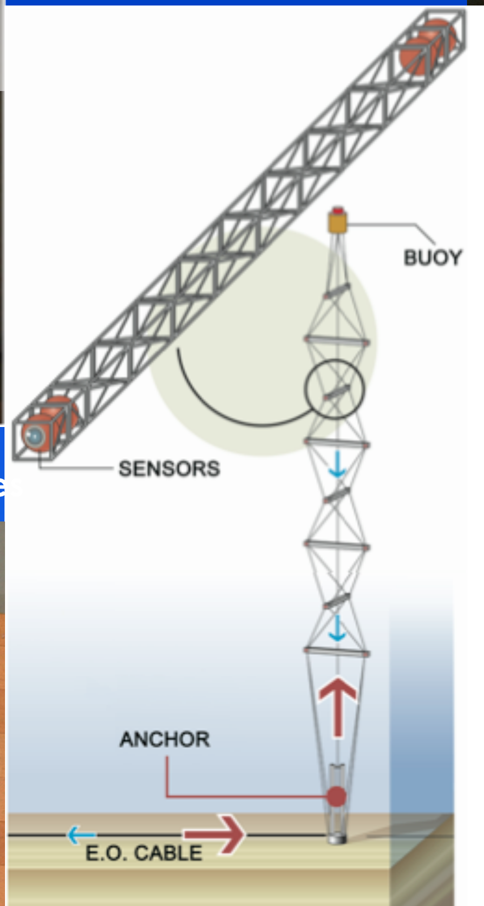
KM3NeT Phase1 and the NEMO Tower technology

NEMO – Phase2
8 floors, 4PMTs/Floor, 2 hydrophones/Floor
8 m bars, vertical dist. = 40 m, H_{tot} = 450 m
oceanographic instruments
Deployed at 3500m depth in March 2013



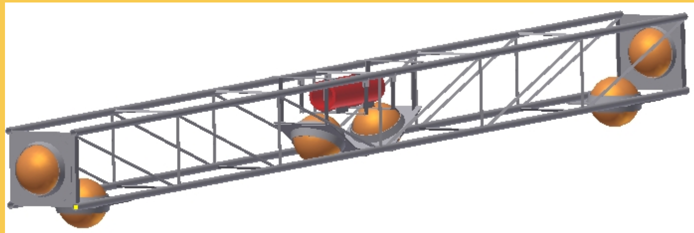
The OM: 10” Hamamatsu R7081, Front End Module, Time Calibration, LED beacons

32 OMs, all fully tested and calibrated.
2 OMs equipped with piezo-hydrophone



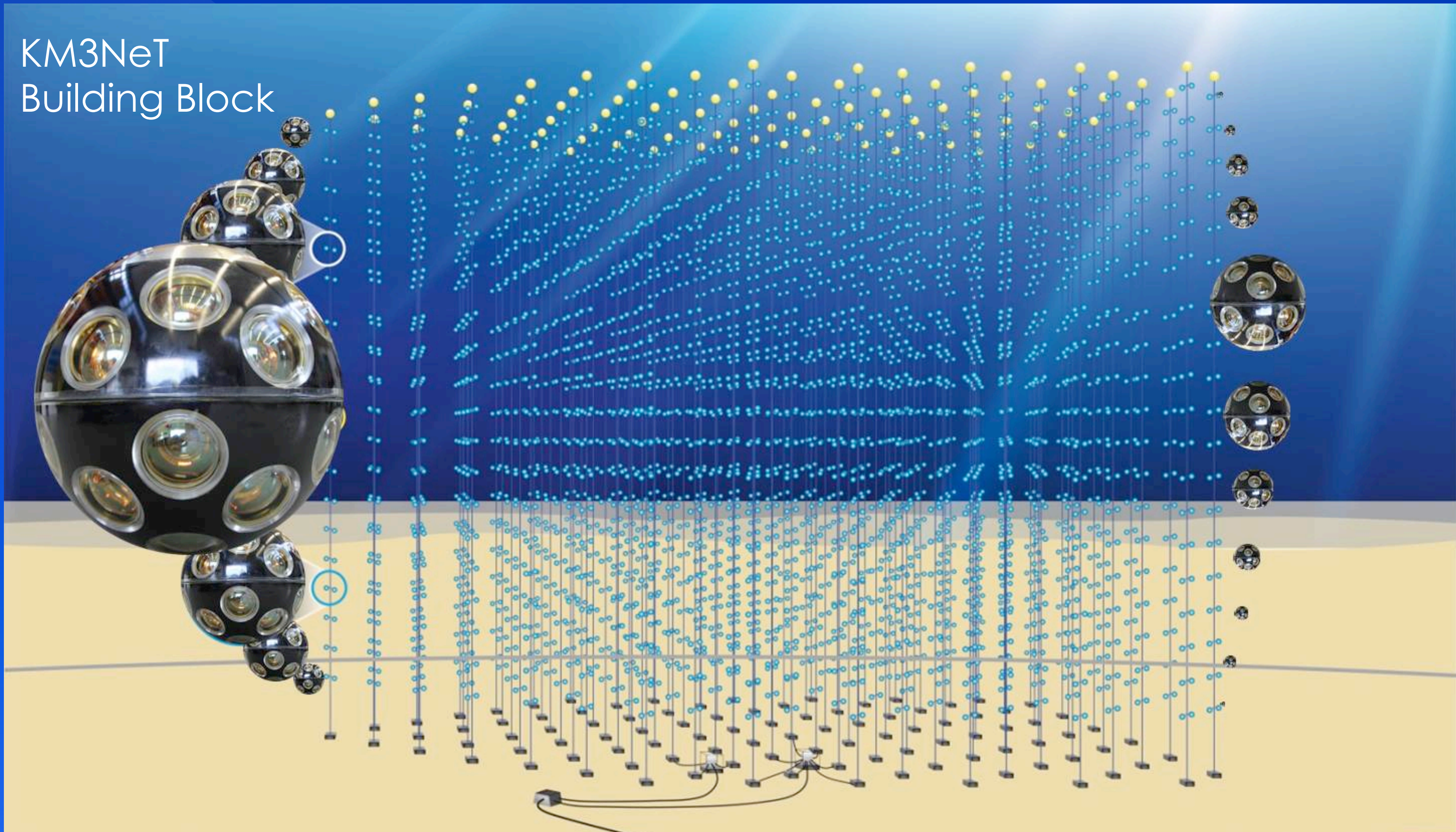
Hydrophones: acoustic positioning and bioacustics

KM3NeT – Italy Towers
14 Floors
8 m bars, vertical dist. = 20 m
H_{tot} ~ 400 m



6 OMs + 2 hydrophones / Floors
Oceanographic Instruments
Towers at ~100m hor. dist.

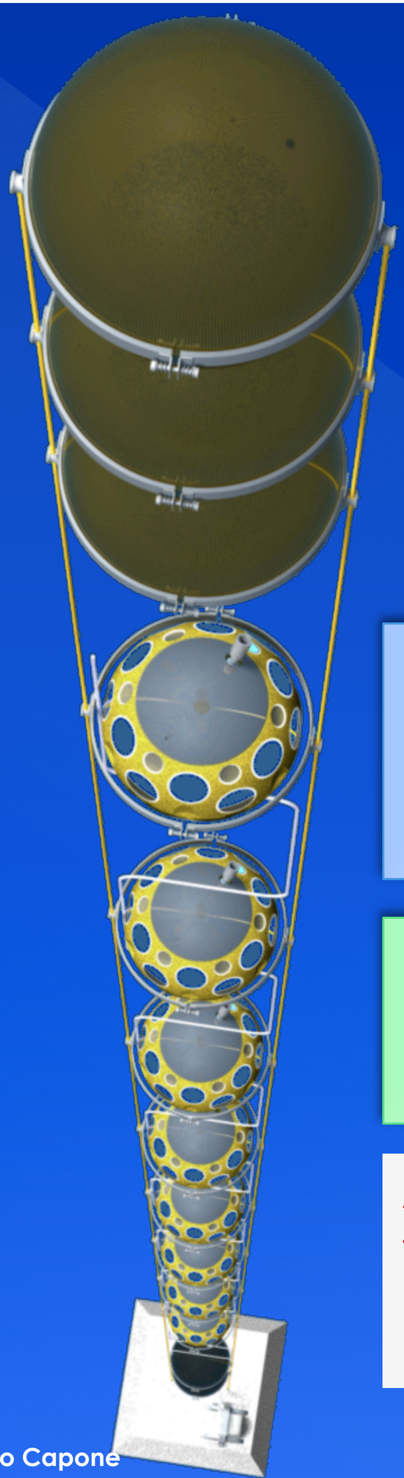
The KM3NeT Detector concept:



About 12000 KM3NeT-DOMs (Digital Optical Modules) attached to about 600 KM3NeT-DUs (string Detection Units)

Propriety KM3NeT Collaboration

The String Technology



Digital Optical Module

31 small, 3”, PMTs in one glass sphere

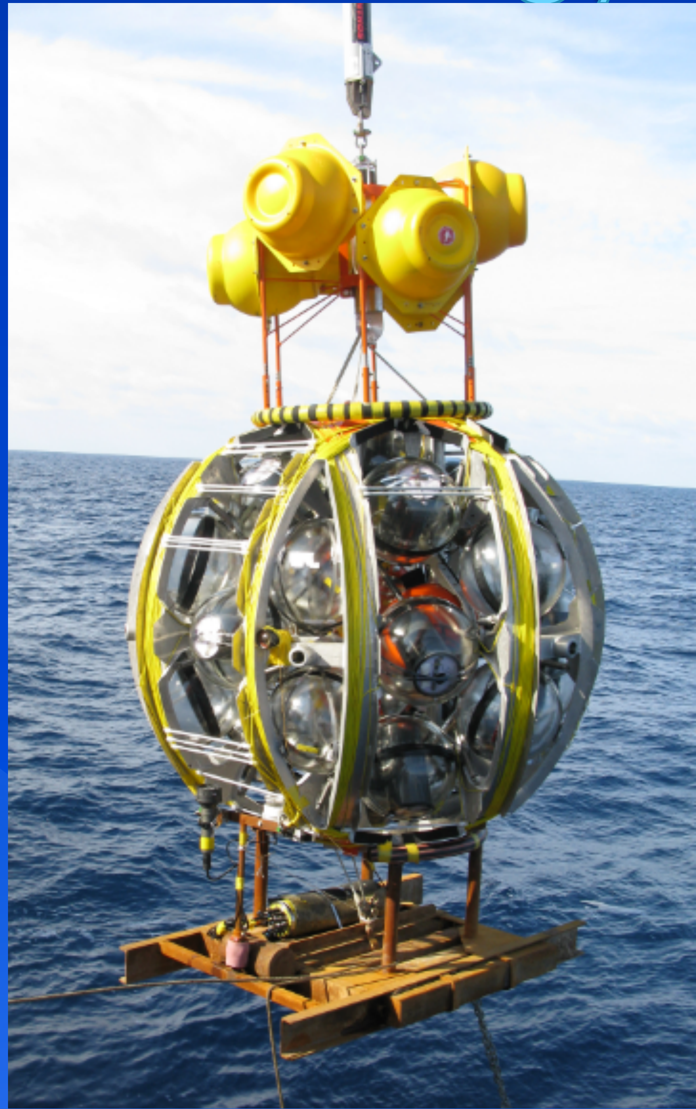
Photon counting

Detection Unit with 18 storeys

36 m inter-storey distance

Compact deployment

A multi-PMT OM mounted on the ANTARES Instrumented line allows to study its behaviour



ANTARES-NEMO-KM3NeT @Sapienza-Roma

- Capogruppo: Prof. Antonio Capone
  antonio.capone@roma1.infn.it, http://www.roma1.infn.it/people/capone/

(Edificio Marconi, Terzo Piano, Stanza 346)

Le attività del gruppo includono:

http://www.roma1.infn.it/km3/

- Elettronica (trasmissione dati)
- Strumenti oceanografici
- Test & Integrazione (KM3NeT-IT)
- Monte Carlo: simulazione di eventi di neutrino
- Studio di Algoritmi di Selezione (Trigger) e Ricostruzione
- Analisi Dati: down-going tracks, shower events, Dark Matter, CR anisotropies
- Rivelazione Acustica

[disponibilità di dissertazioni/tesi]

Conclusions

- ANTARES is **the largest neutrino telescope in the Northern Hemisphere** and the first undersea Cherenkov telescope
- Detector is completed (12 detection lines) since 2008
- **Multidisciplinary platform** for associated sea sciences
- Detector is working within design specifications - DAQ ongoing
- **Data analysis ongoing → first results published**
  → extended results forthcoming
- **Milestone towards a km^3 detector → KM3NeT**

http://www.km3net.org/

Contacts

- Prof. Antonio Capone (Edificio Marconi, terzo piano, stanza 346)
  antonio.capone@roma1.infn.it, http://www.roma1.infn.it/people/capone/
- Dr. Giulia De Bonis, (Edificio Marconi, terzo piano, stanza 316)
  giulia.debonis@roma1.infn.it, http://www.roma1.infn.it/people/deponis/

Useful Links

- IceCube, http://icecube.wisc.edu/
- ANTARES, http://antares.in2p3.fr/
- NEMO/KM3NeT-IT, http://www.roma1.infn.it/km3/
- KM3NeT, http://www.km3net.org/

References

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- Un Tuffo nel Cosmo, http://www.accastampato.it/wp-content/uploads/Giulia-De-Bonis-Antares.pdf
- poster (stanza 346)

UHE Neutrino Astronomy & Atrophysics / Neutrino Telescopes

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- T. Chiarusi, M. Spurio, *High Energy Astrophysics with Neutrino Telescopes*, Eur.Phys.J.C65 (2010) 649, http://arxiv.org/pdf/0906.2634v2.pdf
- L. A. Anchordoqui et al., *Cosmic Neutrino Pevatrons: A Brand New Pathway to Astronomy, Astrophysics and Particle Physics*, http://arxiv.org/pdf/1312.6587v3.pdf

IceCube

- *Evidence for High-Energy Extra-Terrestrial Neutrinos at the IceCube Detector*, Science 22 Nov. 2013 Vol. 342 no. 6161, http://arxiv.org/abs/1311.5238
- *Observation of High-Energy Astrophysical Neutrinos in Three Years of IceCube Data*, http://arxiv.org/abs/1405.5303

ANTARES

- *ANTARES: the first undersea neutrino telescope*, Nucl. Instr. and Meth.A 656 (2011) 11-38, http://arxiv.org/pdf/1104.1607v2.pdf

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- *First results on dark matter annihilation in the Sun using the ANTARES neutrino telescope*, JCAP11 (2013)032. http://arxiv.org/pdf/1302.6516.pdf
- *Search for muon neutrinos from gamma-ray bursts with the ANTARES neutrino telescope using 2008 to 2011 data*, A&A 559, A9 (2013), http://arxiv.org/pdf/1307.0304v2.pdf
- *Search for a Correlation between ANTARES Neutrinos and Pierre Auger Observatory UHECRs Arrival Directions*, ApJ 774 (2013) 19. http://arxiv.org/pdf/1202.6661v2.pdf
- *A first search for coincident gravitational waves and high energy neutrinos using LIGO, Virgo and ANTARES data from 2007*, S. Adrian-Martinez et al., JCAP 06 (2013) 008. http://arxiv.org/pdf/1205.3018v3.pdf
- *Search for neutrino emission from gamma-ray flaring blazars with the ANTARES telescope*, Astropart. Phys. 36 (2012) 204–210, http://arxiv.org/abs/1111.3473