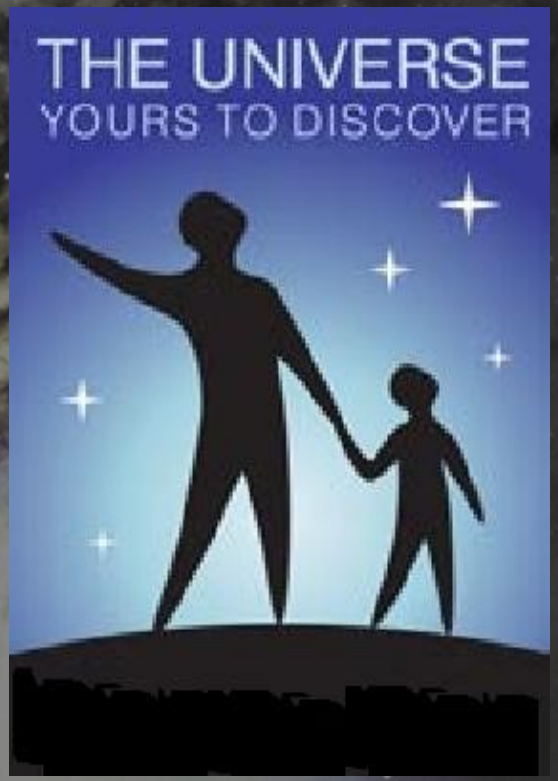
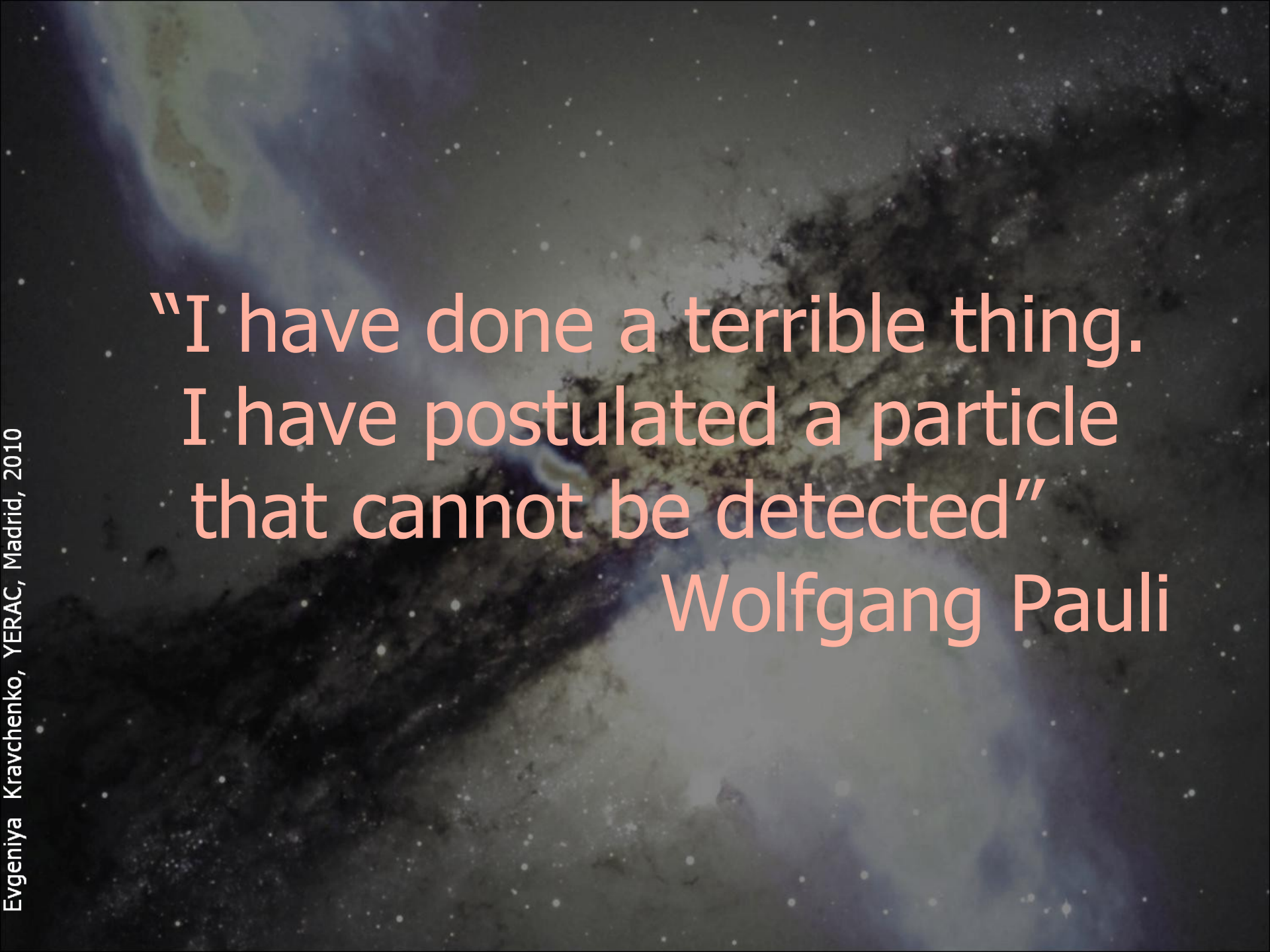
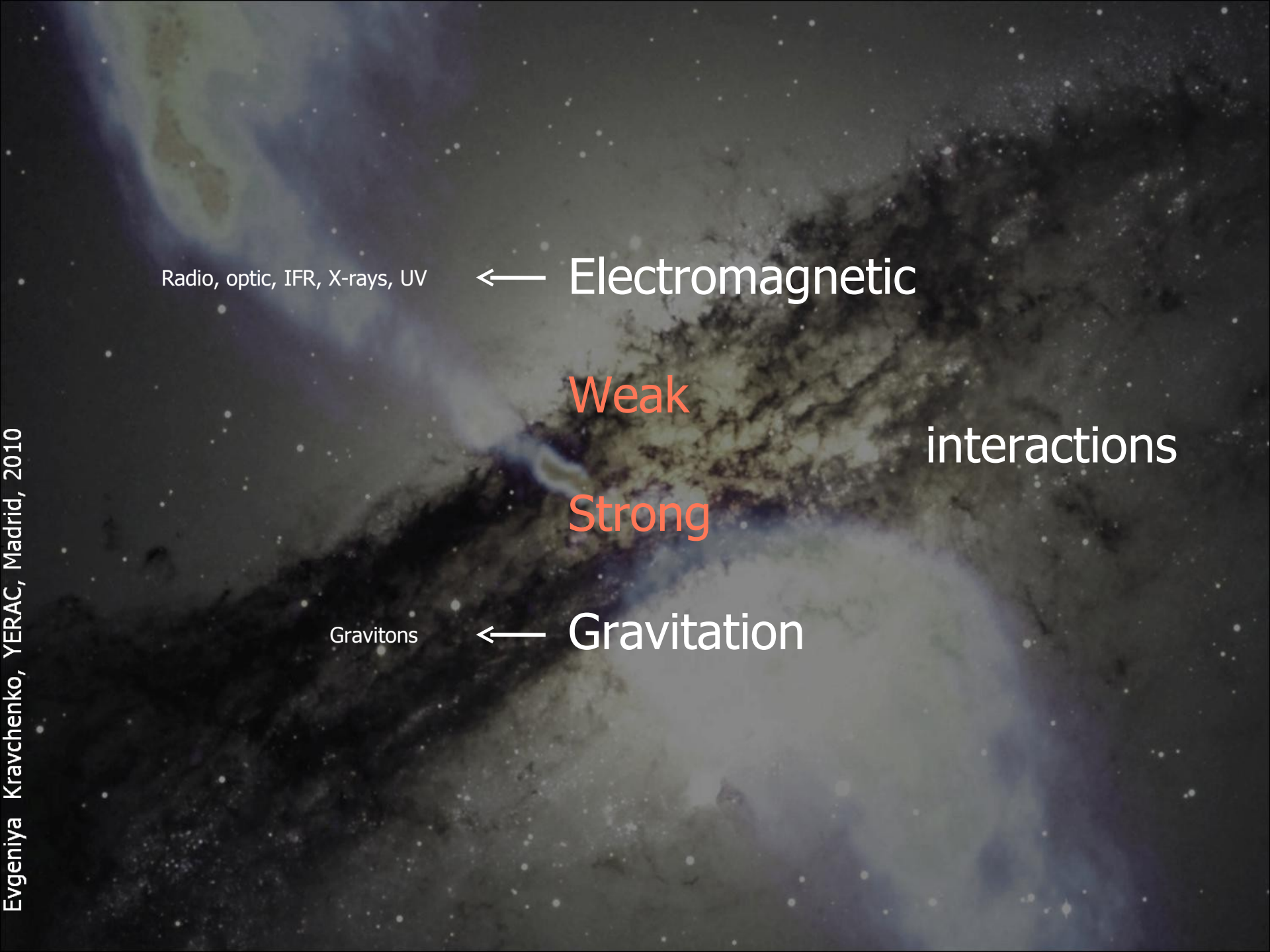
Ultra High Energy Neutrinos

Evgeniya Kravchenko
Puschino Radio Astronomy Observatory, Russia
40 YERAC, Madrid, July 5-8 2010

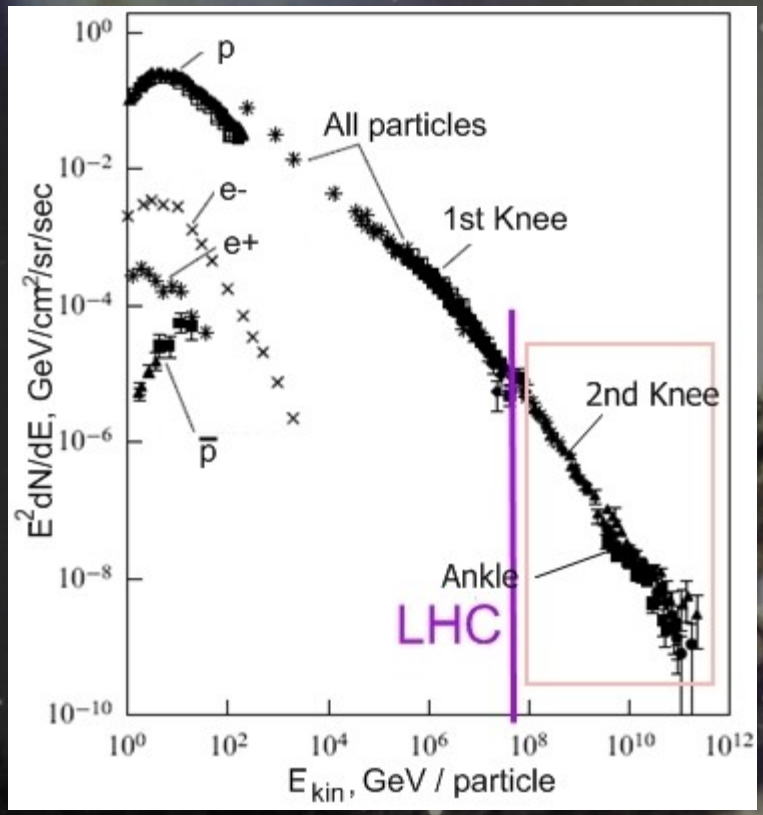



"I have done a terrible thing.
I have postulated a particle
that cannot be detected"
Wolfgang Pauli



Evgeniya Kravchenko, YERAC, Madrid, 2010

Cosmic Rays



Cosmic rays with $2*10^{20}$ eV according
$\sqrt{s}$ = 700 TeV
LHC work up to 14 TeV according
$8*10^{16}$ eV

e^-

e^+

p

$\overline{p}$

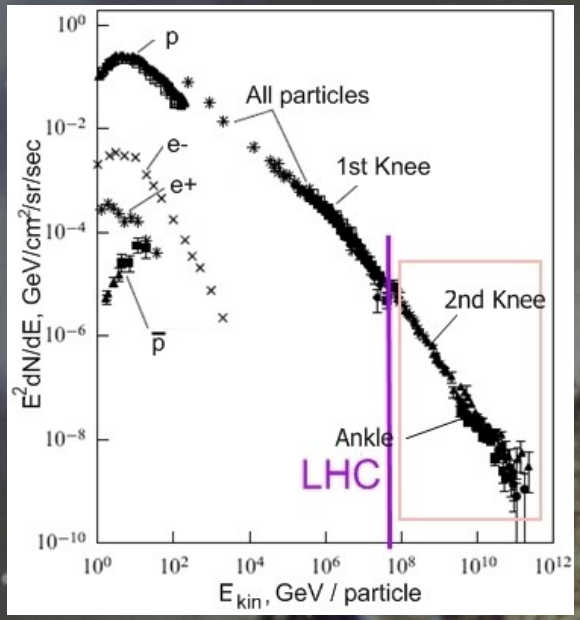
N^+

γ

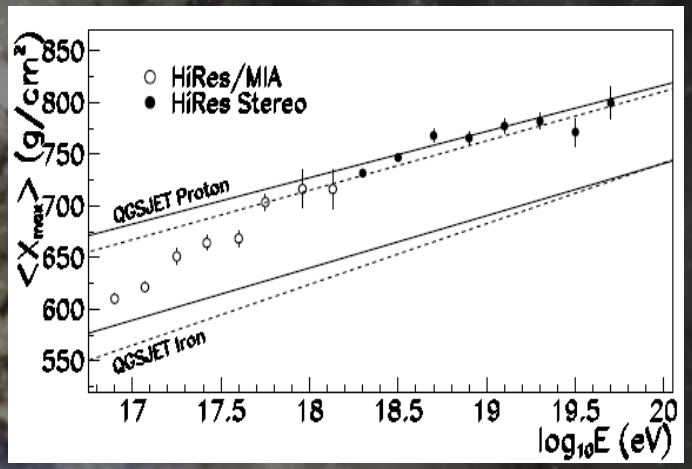
ν

Evgeniya Kravchenko, YERAC, Madrid, 2010

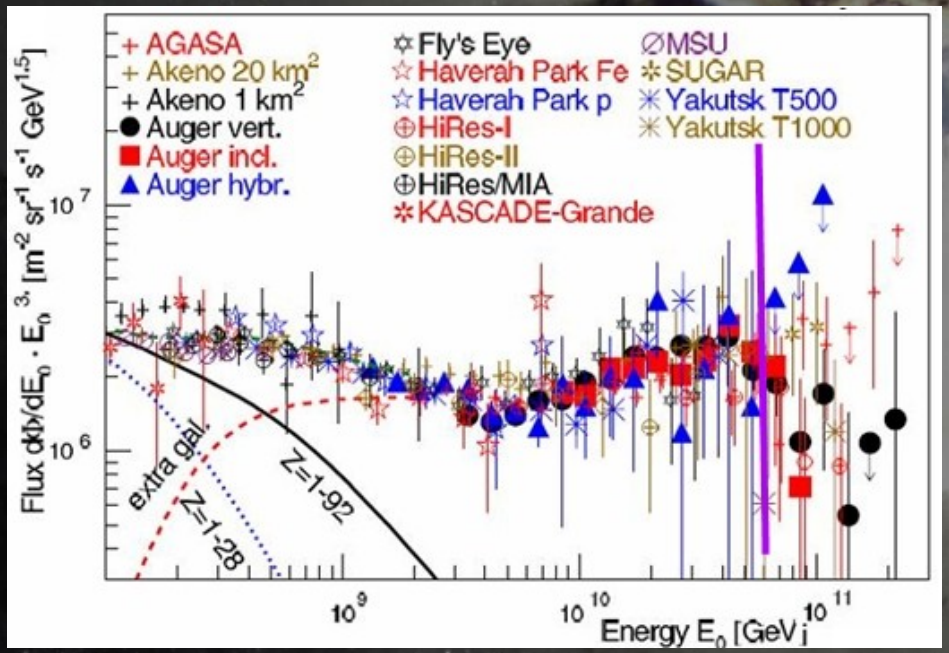
Cosmic Rays

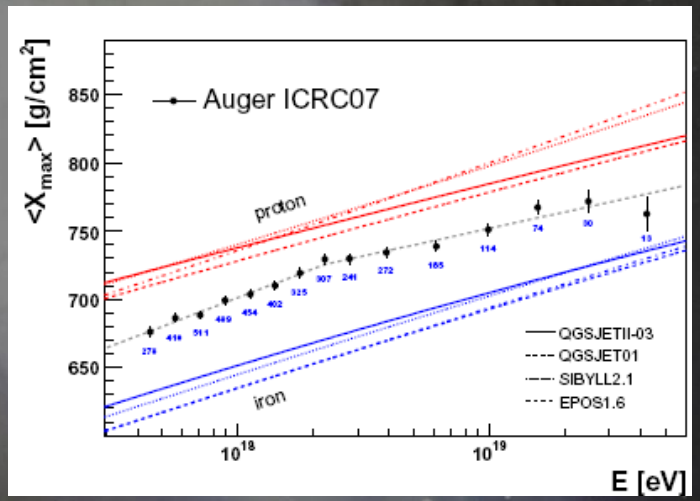


HiRes
AGASA
Pierre Auger Observatory
Yakutsk



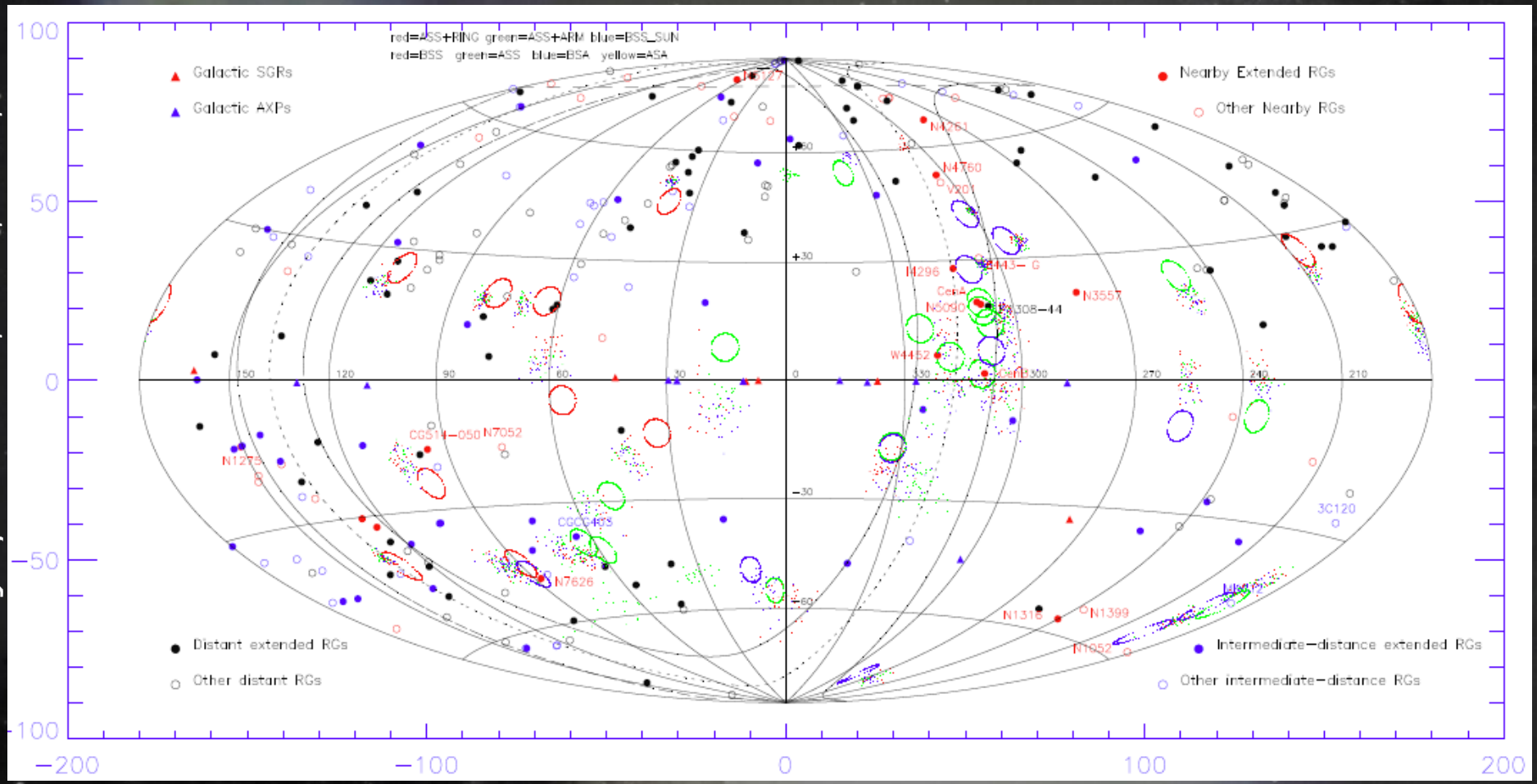
"Evidence for proton-dominated cosmic ray composition above 1.6 EeV" ,The HiRes collaboration, arXiv:0910.4184





"The Pierre Auger Observatory – a new stage in the study of the ultra high energy cosmic rays" ,Serguei Vorobiev, arXiv:0811.0752

Correlations?



Evgeniya Kravchenko, YERAC, Madrid, 2010

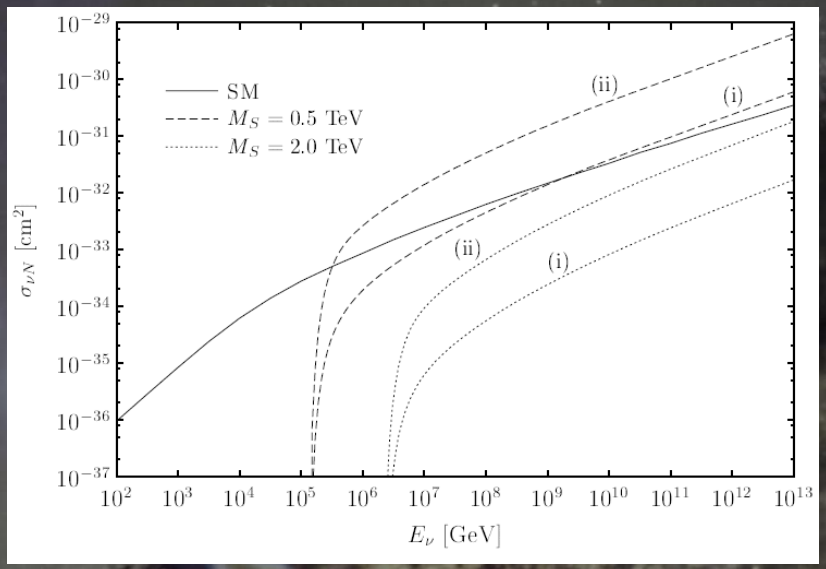
O - 56-75 10^{18} eV UHECRs by PAO
O - >75 10^{18} eV UHECRs by PAO
O - AGASA UHECRs events of radius 3.5^0

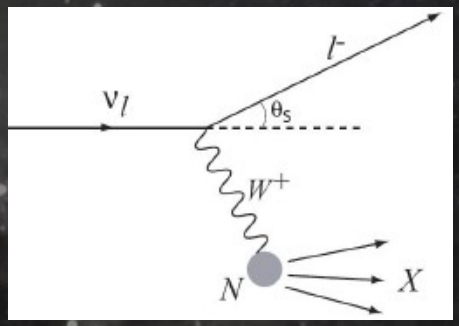
• - galaxies with radio jets at D~75 Mpc
• - galaxies with radio jets at 75 Mpc < D 200 Mpc
• - galaxies with radio jets at 200 Mpc < D 500 Mpc
Δ - Galactic SGRs
Δ - AXPs

"Ultra-High Energy Cosmic Rays Detected by Auger and AGASA: Corrections for Galactic Magnetic Field Deflections, Source Populations, and Arguments for Multiple-Components", Neil M. Nagar and Javier Matulich anhiarXiv:0912.2131

Peculiarities

"TeV Strings and the Neutrino-Nucleon Cross Section at Ultra-high Energies", F. Cornet, arXiv:hep-ph/0102065





m_ν<1eV
neutral
stable
weakly interacting

not deflected → point back to the source
not absorbed → travel Gpc distances

At 5 Gpc probability to interact is <5%

$\nu + \gamma_{CMB} \rightarrow \nu + \gamma$ σ=10^{-66} cm^{-2}

$\nu + \gamma_{CMB} \rightarrow \nu + \gamma + \gamma$ σ=10^{-52} cm^{-2}

$\nu + \gamma_{CMB} \rightarrow \nu + e^- + e^+$ σ=10^{-47} cm^{-2}

$\nu + \gamma_{CMB} \rightarrow l^{\mp} + W^{\pm}$ σ=$8 \cdot 10^{-34}$ cm^{-2}

relic neutrino background:

$\nu_i + \bar{\nu}_j \rightarrow \nu_i + \bar{\nu}_j$ Z^0 σ=10^{-34} cm^{-2}

$\nu_i + \bar{\nu}_j \rightarrow l_i + \bar{l}_j$

$\nu_i + \bar{\nu}_j \rightarrow f_i + \bar{f}_j$ $W^{\pm}$ σ=$4.2 \cdot 10^{-32}$ cm^{-2}

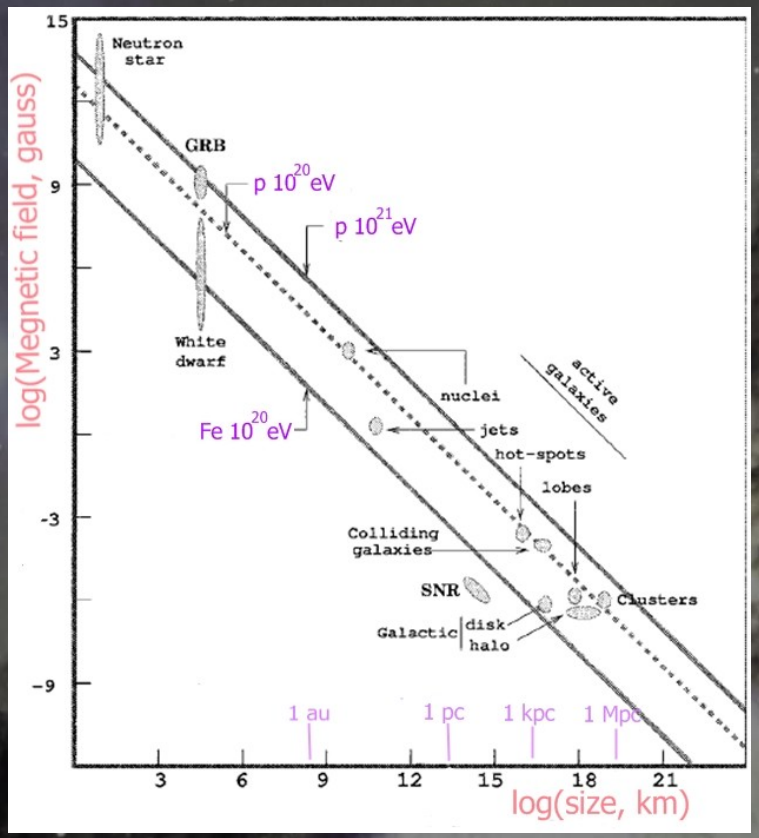
$\nu + \bar{\nu}_{CMB} \rightarrow \gamma + \gamma$ At $E_\nu \sim 10^{21}$ eV and m_ν=1eV σ~10^{-42} cm^{-2}

Sources

Scenarios

Top-down:

decay or annihilation



Bottom-up:

acceleration

Decay of massive "X" particles
Topological defects:
Cosmic strings
Superconductive strings
Magnetic monopoles
Cosmic loops
Vortons
Z-bursts

Topological defects predict that the highest-energy cosmic rays are predominantly protons

> TeV

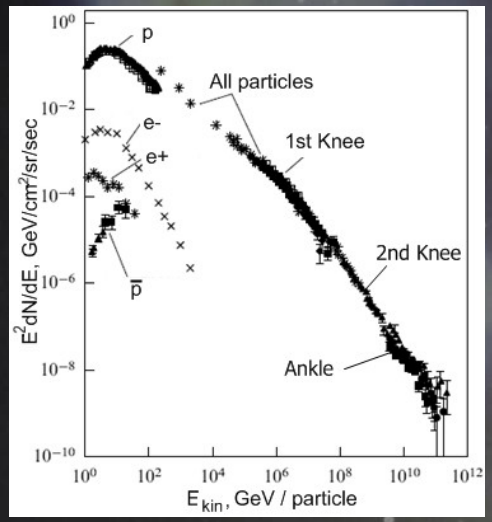
Active Galaxies Nucleus
Gamma Ray Bursts
GZK-neutrinos
Magnetars, Neutron stars

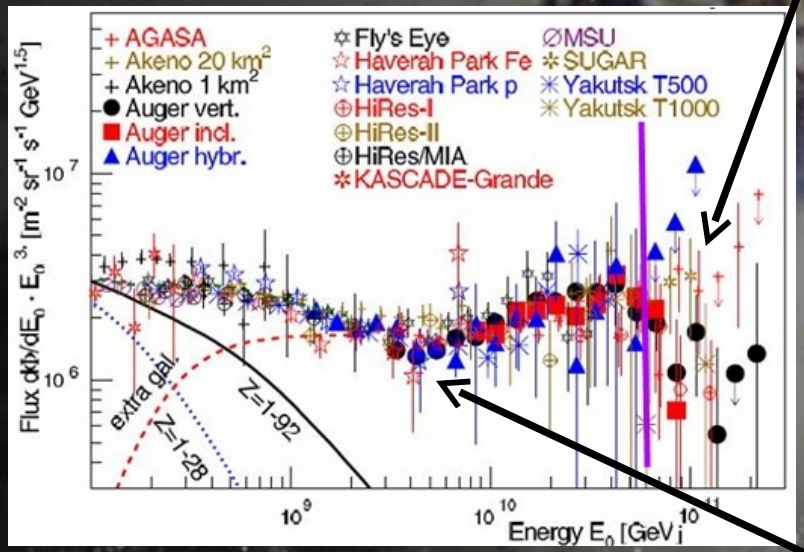
1-10 MeV

Binaries
Spiral galaxies
Supernovae explozion
Supernovae remnant
Microquasars

Evgeniya Kravchenko, YERAC, Madrid, 2010

GZK-neutrinos





412 γ_{cmb} per cm^{-3}

Greizen-Zatsepin-Kuzmin (GZK) cut-off at $6*10^{19}$ eV

Lint < 50Mpc

$$p + \gamma_{CMB} \rightarrow n + \pi^{+}$$

$$\rightarrow n + \gamma \rightarrow p + \pi^{-}$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$$

$$\mu^{\pm} \rightarrow e^{\pm} + \nu_{e} + \bar{\nu}_{\mu}$$

$$p + \gamma_{CMB} \rightarrow p + \pi^{0}$$

$$\pi^{0} \rightarrow \gamma + \gamma$$

$$p + p \rightarrow \pi^{\pm 0} K^{\pm} D^{\pm 0} \rightarrow decay$$

$$\gamma + \gamma_{CMB} \rightarrow \mu^{+} + \mu^{-}$$

$$\mu \rightarrow e + \nu_{e} + \nu_{\mu}$$

$$p + \gamma_{CMB} \rightarrow e^{-} + e^{+} + p_{scattering}$$

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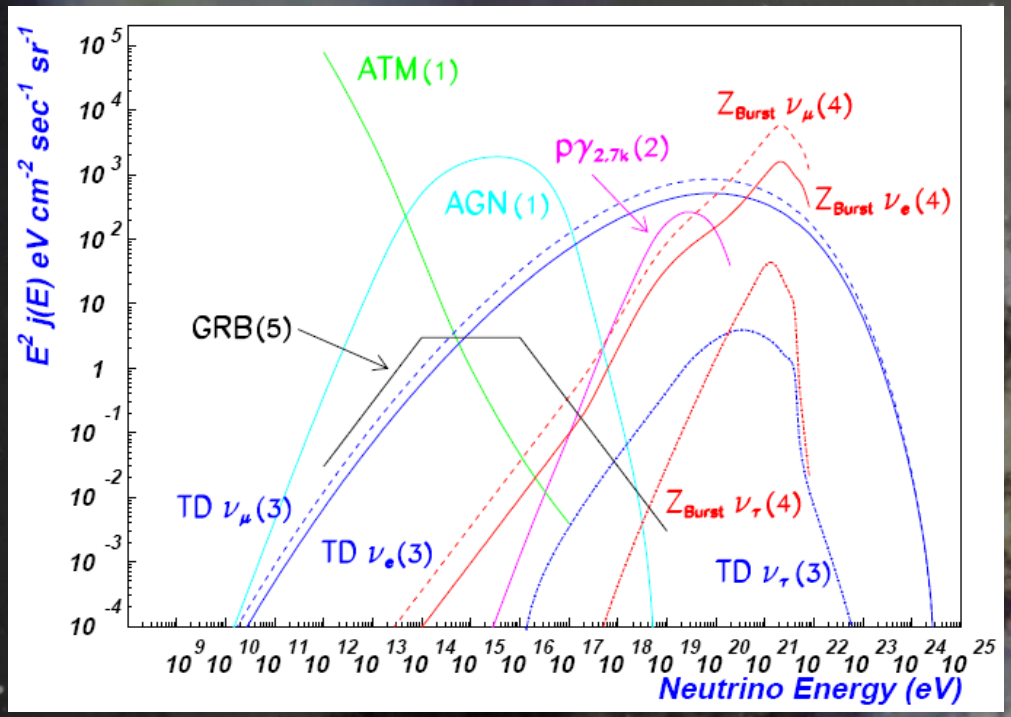
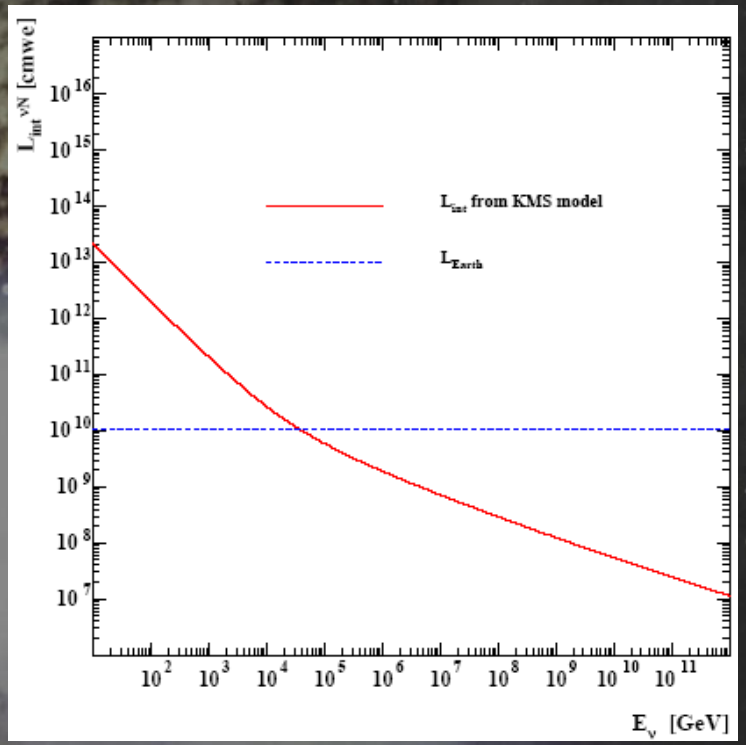
Fluxes





GZK-ν flux $E=10^{19}$ - 5 particles\км^2\year

$E \geq 10^{20}$ 1 particle\1 км^2\100 year

Huge Volumes!

Methods

Different neutrino registration methods

Optical Cherenkov emission

- Water: Baikal; ANTARES, NEMO, NESTOR (KM3Net)
- Ice: IceCube

Acoustic Cherenkov emission

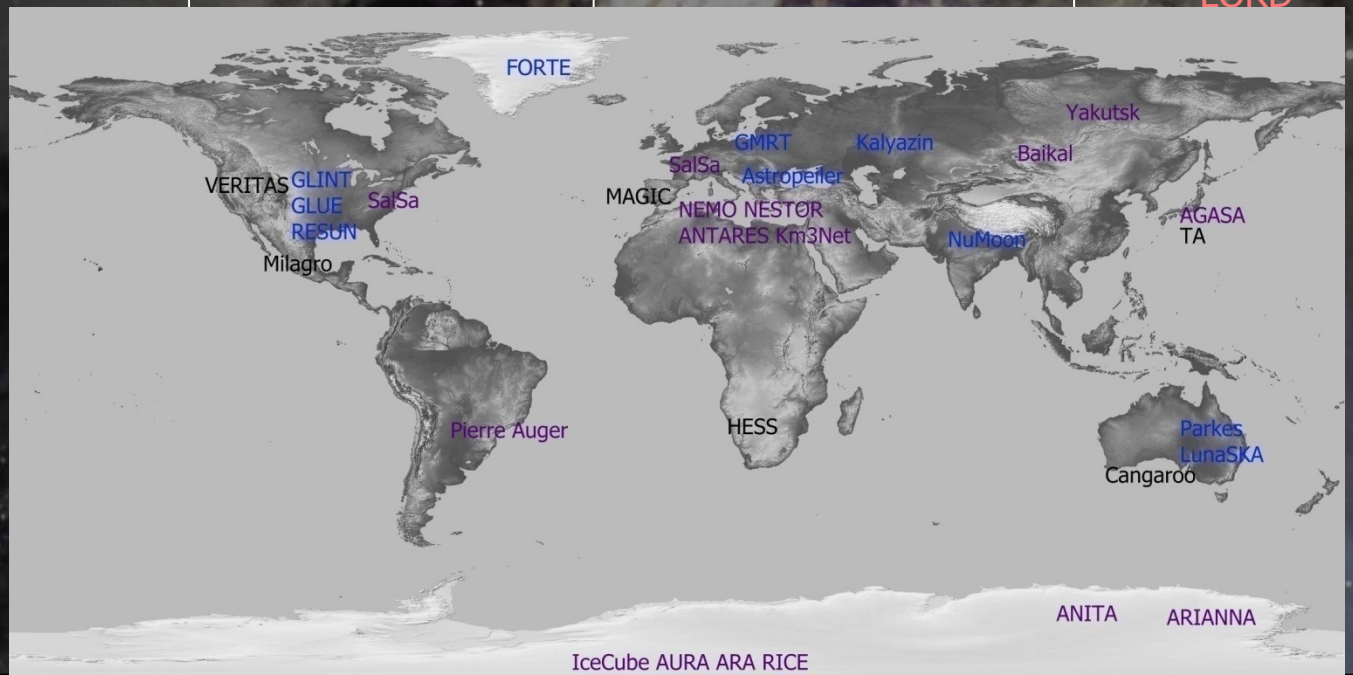
ANTARES, IceCube

Extensive Air Showers

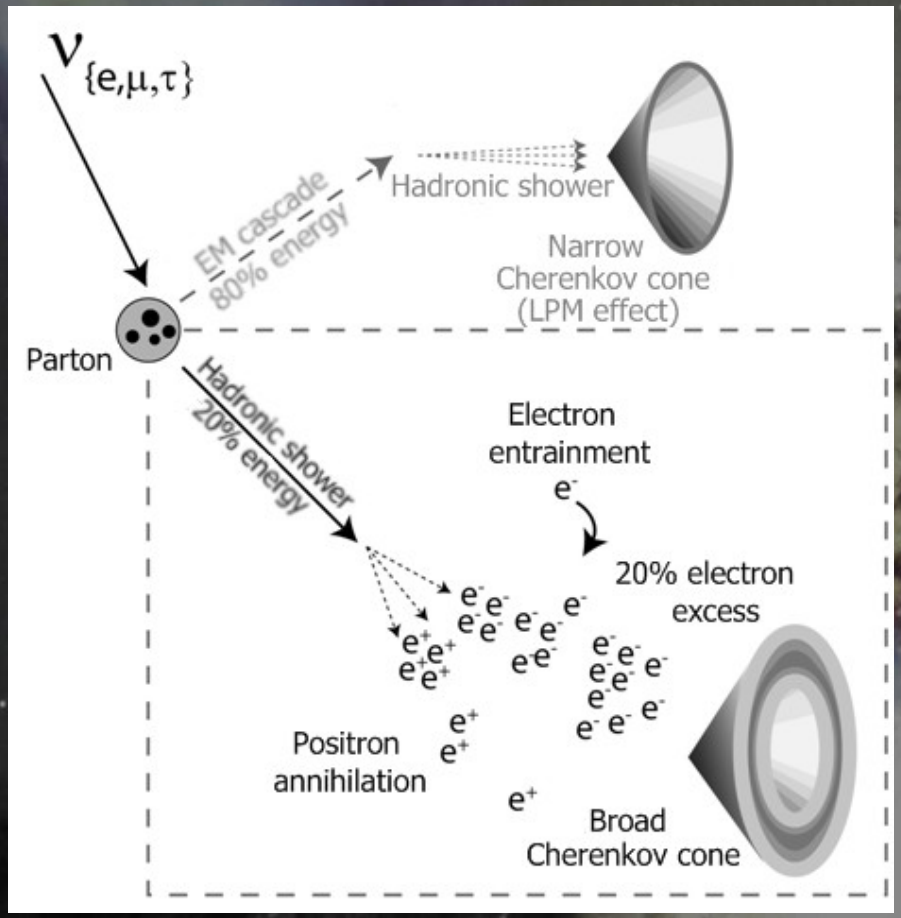
- Space: EUSO, OWL
- Earth-based: PAO

Radio Cherenkov emission

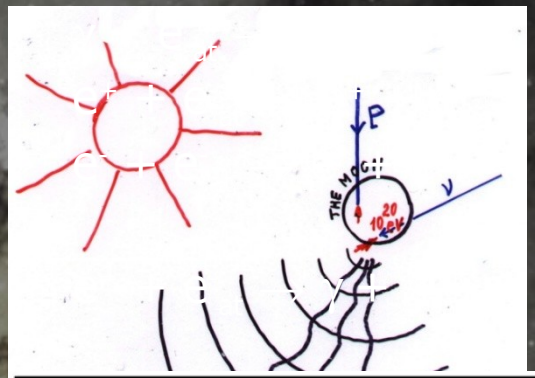
- Space: ANITA, LORD
- Earth-based: RESUN, GLINT, Astropeiler, NuMoon, GMRT, RICE, SalSa, ARIANNA, ARA, LunaSKA, LOFAR

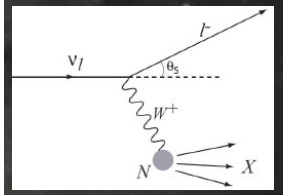


Askaryan Effect



Was predicted at 1965 by
Gurgen Askaryan
Was confirmed in 2000

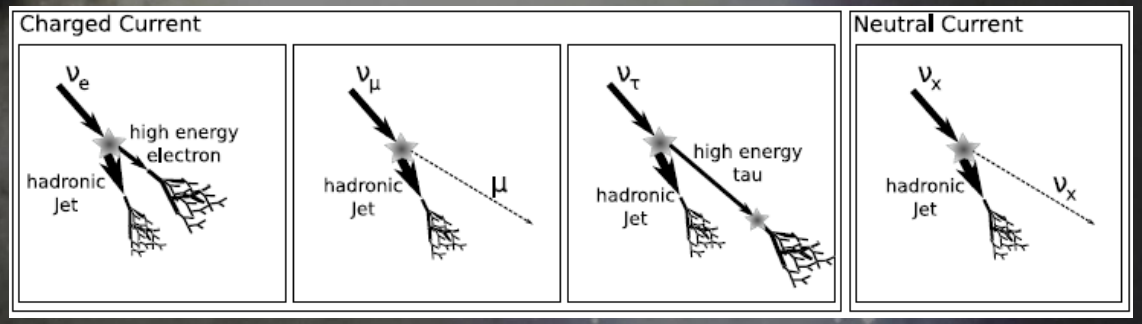




Reaction	Type	ν flavor
$\nu + N \rightarrow l^{\pm} X$	Charged	$\bar{\nu}_e\ \nu_e$
$\nu + N \rightarrow l^{\pm} X$	Charged	$\bar{\nu}_\mu \nu_\mu\ \bar{\nu}_\tau \nu_\tau$
$\nu + N \rightarrow l^{\pm} X$	Charged	$\bar{\nu}_\tau \nu_\tau$
$\nu + N \rightarrow \nu X$	Neutral	all $\nu\bar{\nu}$'s
$\nu + e \rightarrow \bar{q} q$	Resonant	$\bar{\nu}_e$
$W^- \rightarrow e\bar{\nu}_e$	Resonant	$\bar{\nu}_e$
$W^- \rightarrow \tau\bar{\nu}_\tau$	Resonant	$\bar{\nu}_e$

Attenuation length at 1GHz in
Moon regolith is 18 m
Ice is 1 km

Shower length ~ 1.5 m
Lateral size of cascade ~ 10 cm
Coherent up to ~3GHz
The duration of the shower ~ 2-6 ns



"Coherent Radio Emission from Cosmic Showers in Air and in Dense Media", Askar'yan, G. A., Soviet Physics JETP, Vol. 21, p.658, 1965

MOON

Radio Cherenkov Emission

GLUE 2004

Kalyazin 2005

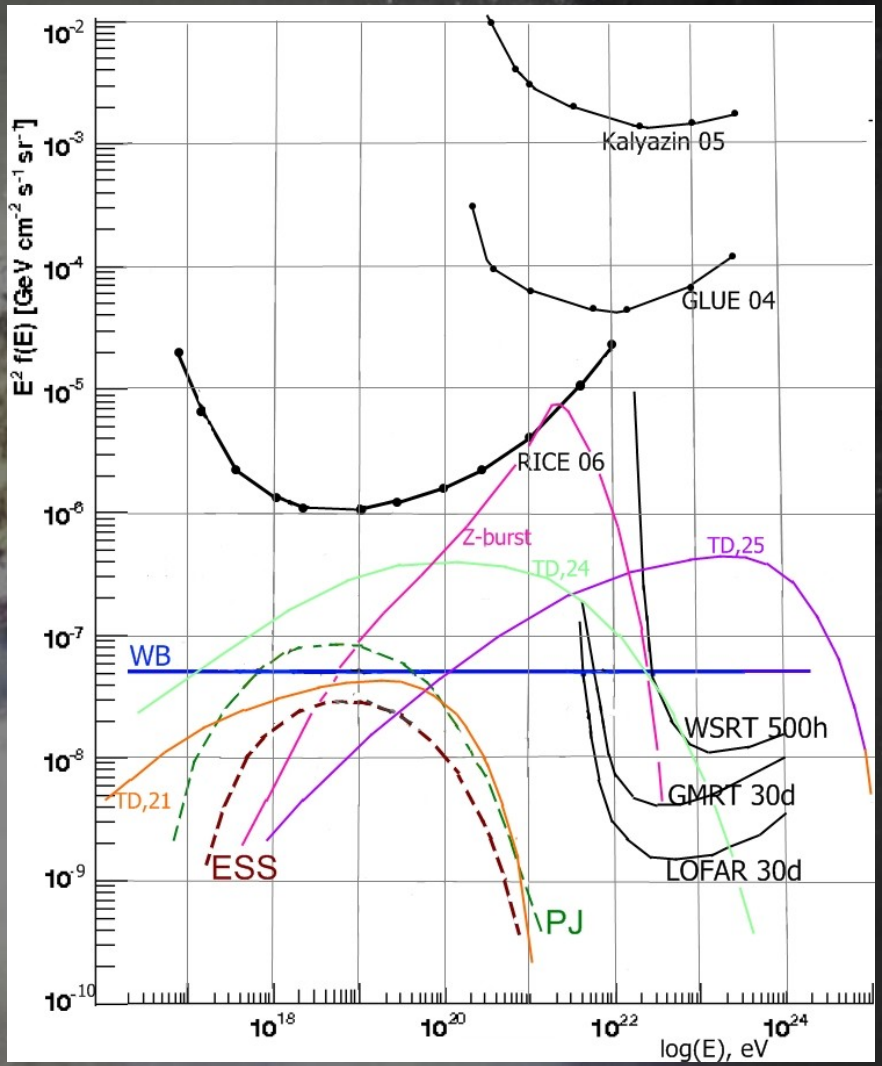
Parkes 2007

NuMoon

GMRT

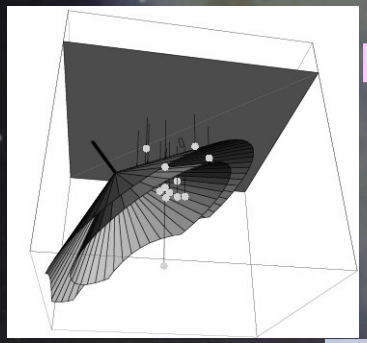
RESUN

GLINT



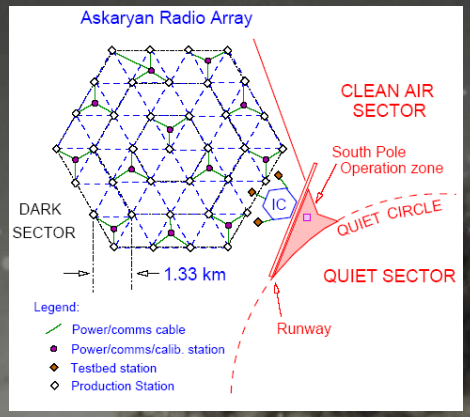
LOFAR LunaSKA (ATCA) SKA

Radio Cherenkov emission

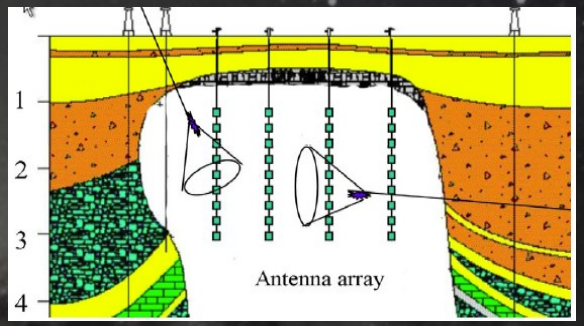


RICE

ARA



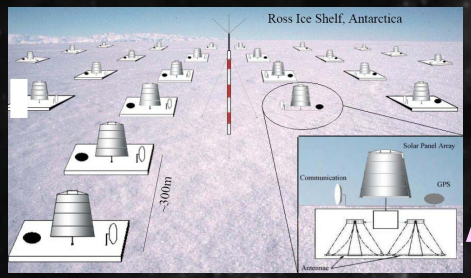
SalSa



AURA

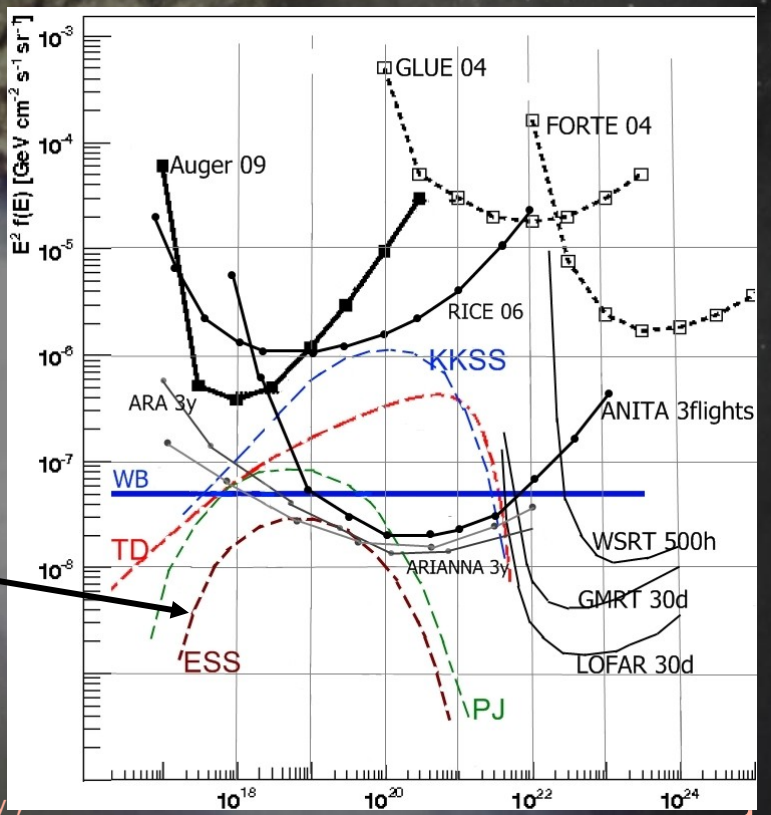
ANITA

Auger (1y)	3*10³ км²	1
IceCube (3y)	1 км³	1.5
ANITA (45d)	10⁶ км³	<5
SalSa (3y)	3*10³ км³	<70



ARIANNA

Cosmic rays are protons



"Radio Detection of GZK Neutrinos - AURA status and plans", H. Landsman etc, Proceedings of the 30th International Cosmic Ray Conference, Vol. 4, p827–830

"Simulation of the Event Reconstruction of Ultra High Energy Cosmic Neutrinos with Askaryan Radio Array", Shang-Yu Sun, Pisin Chen and Melin Huang, 2010, arXiv:1002.0023

Future Experiments

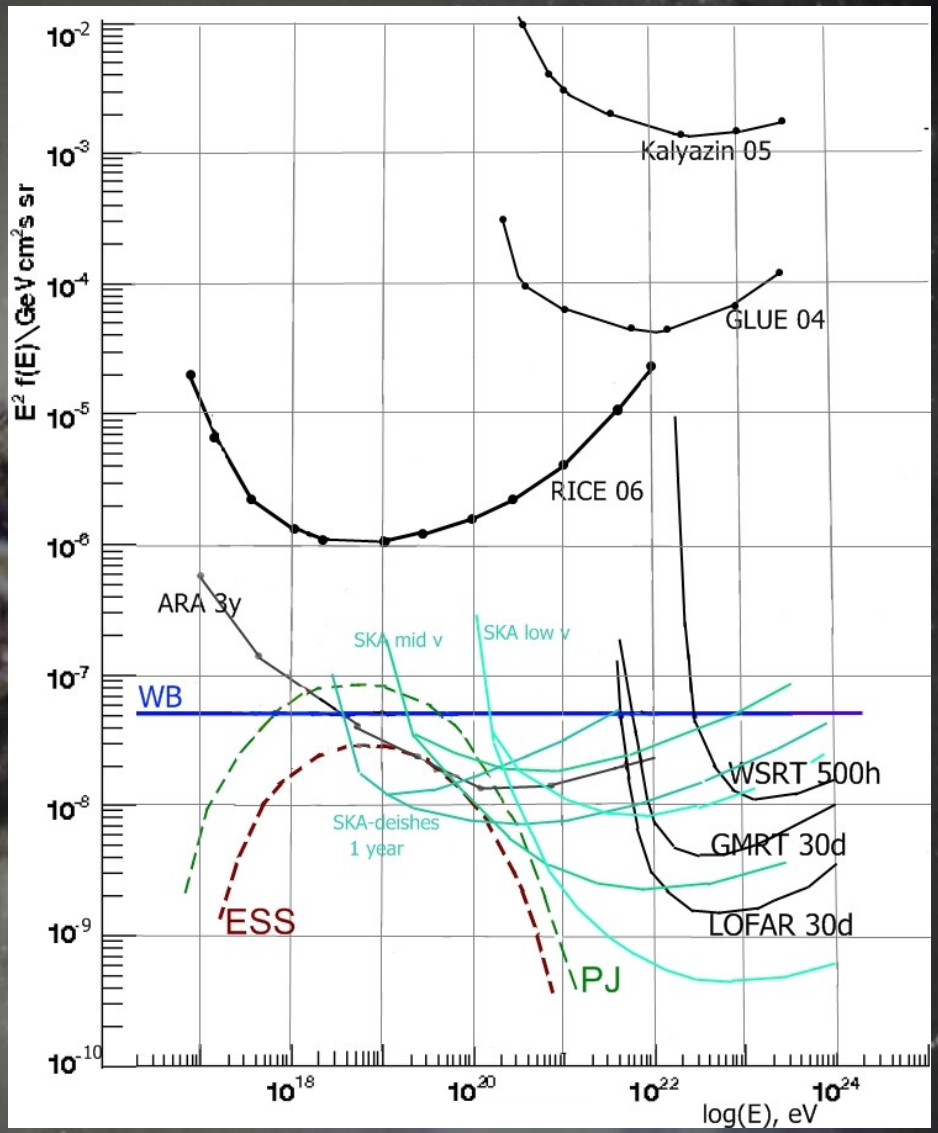
ANITA / RICE

LORD — Constructed – 2012, Results – 2014

ARIANNA
ARA
AURA
SalSa — Constructed – 2014, Results – 2017

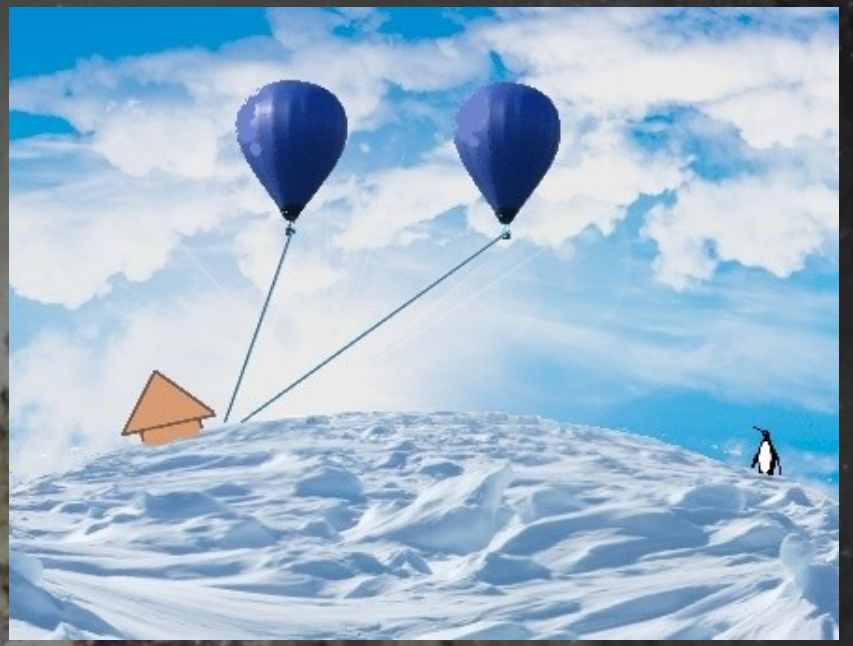
SKA — Constructed > 2021, Results > 2023

SKA	>$2000
LOFAR (Dutch)	€52
ANITA (3 flights)	$32
ARIANNA	>$200
KM3Net	€300
IceCube	$271
Auger	€85
SalSa	$125
KM3Net	<€200
ARA	$8

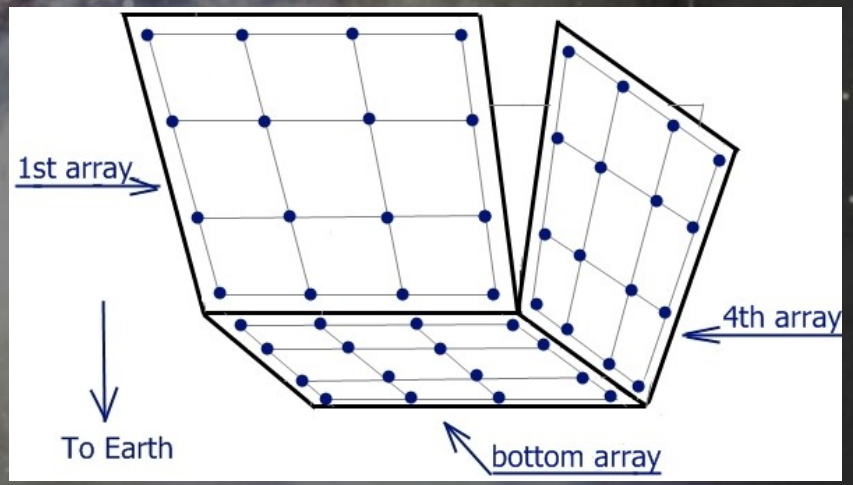


RITA

Radio Ice Tethered
Antenna in Antarctica

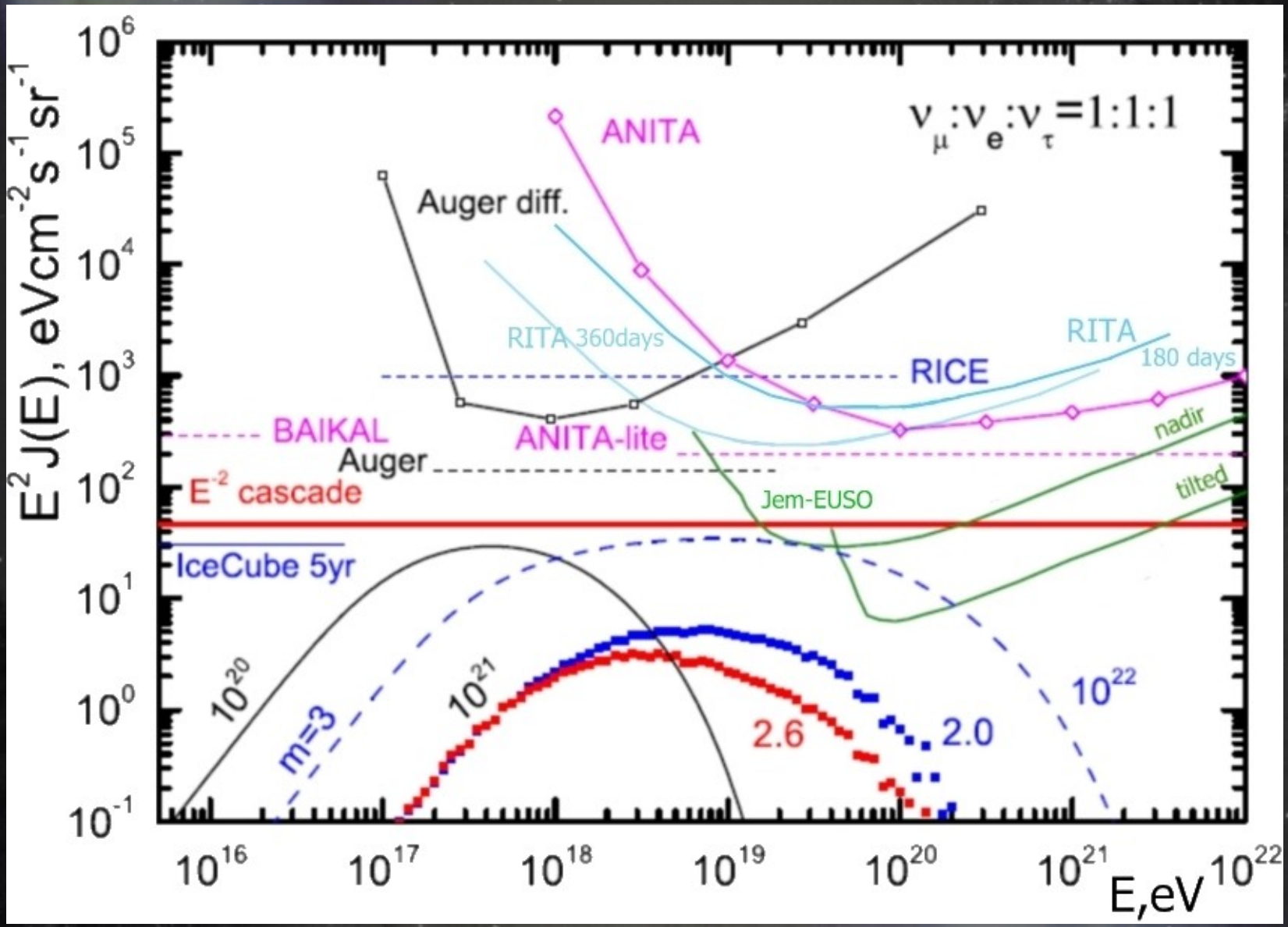


4-5 arrays
16 dipoles in each
760 MHz bandwidth 120MHz
Sensivity: 1.5 MJy or 0.13 μV/m/MHz
Height: 1-3 km over ice near the Vostok Station
Ice depth: to 3.5 km
Effective Target Volume: ~50 km^3 (10^{19} eV)
Planned time exposure: 180 days
Number of balloons: ~ 5
Maximum neutrino flux at ~10^{19} eV



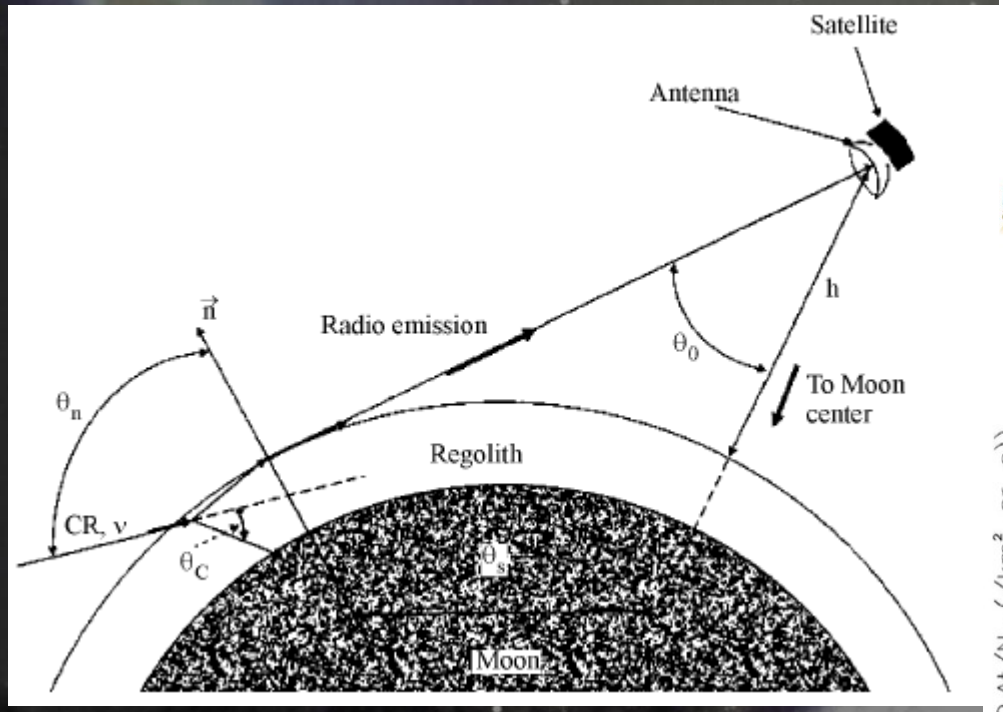
RITA

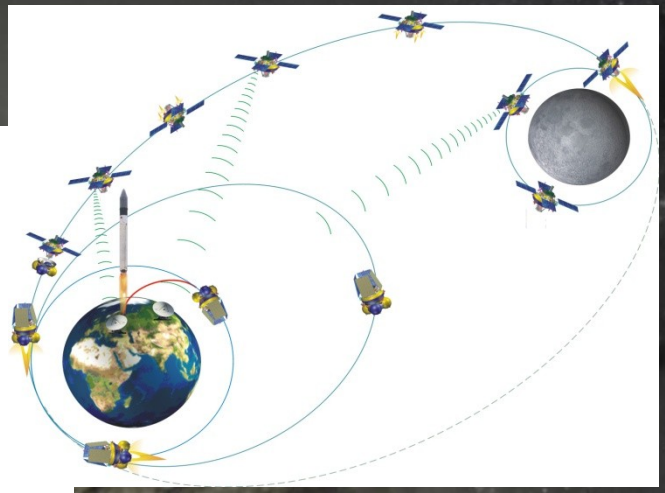
760 MHz Sensivity: 0.9 Mjy Height: 3 km over
Time exposure: 180 days Number of balloon: 1

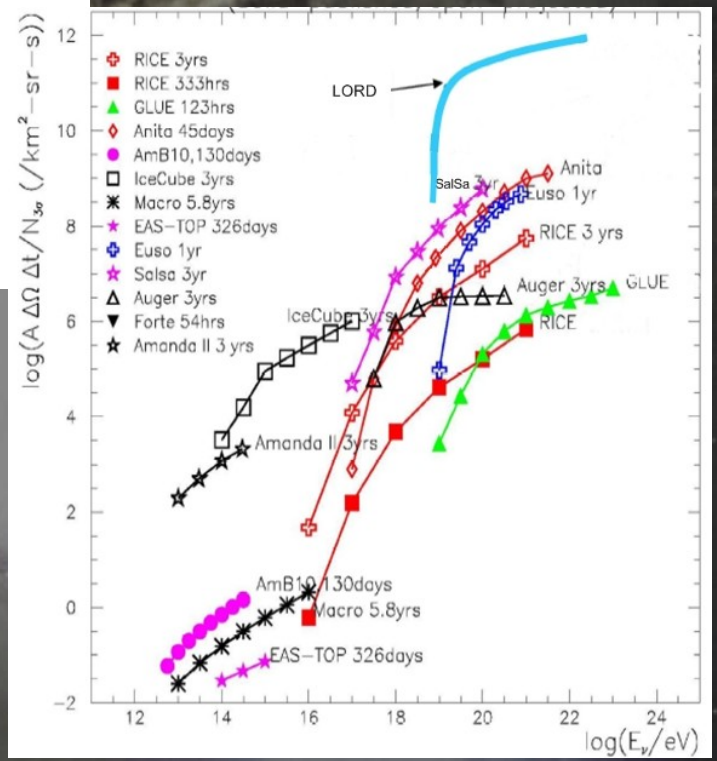


"Fermi-LAT restrictions on UHECRs and cosmogenic neutrinos", V. Berezinsky, A. Gazizov et al., arXiv:1003.1496

LORD
Lunar Orbital Radio Detector



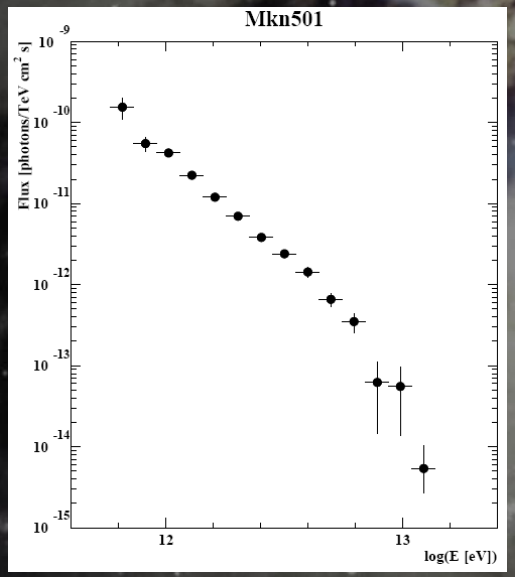


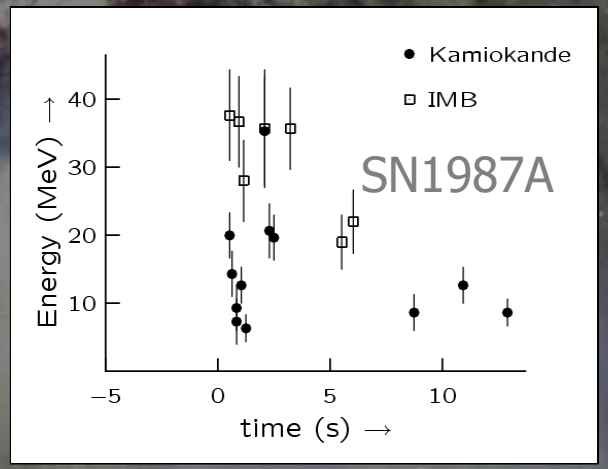


"Detection of Ultrahigh-Energy Cosmic Rays and Neutrinos by Radio Method Using Artificial Lunar Satellites", G. A. Gusev, Cosmic Research, 2006, Vol. 44, No. 1, pp. 19–38

For what?

Neutrino Cross section
Elementary particle physics on PeV-EeV scale
Heavy dark matter content in the Universe
Active galaxies' phase
Particle acceleration mechanism in astrophysical sources
- AGN & GRB & SN & BH



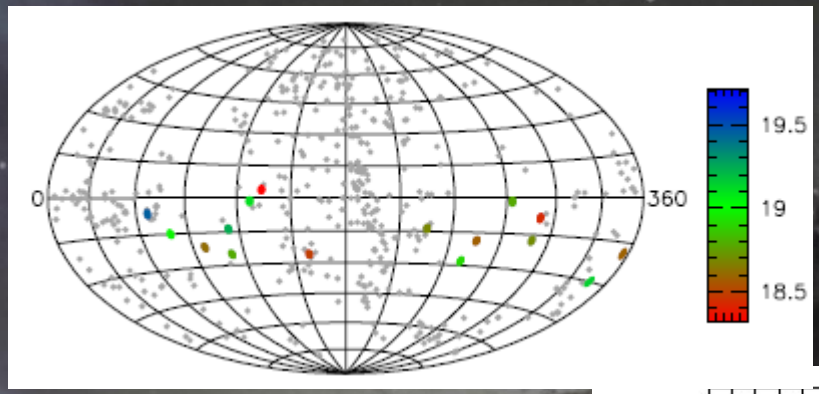


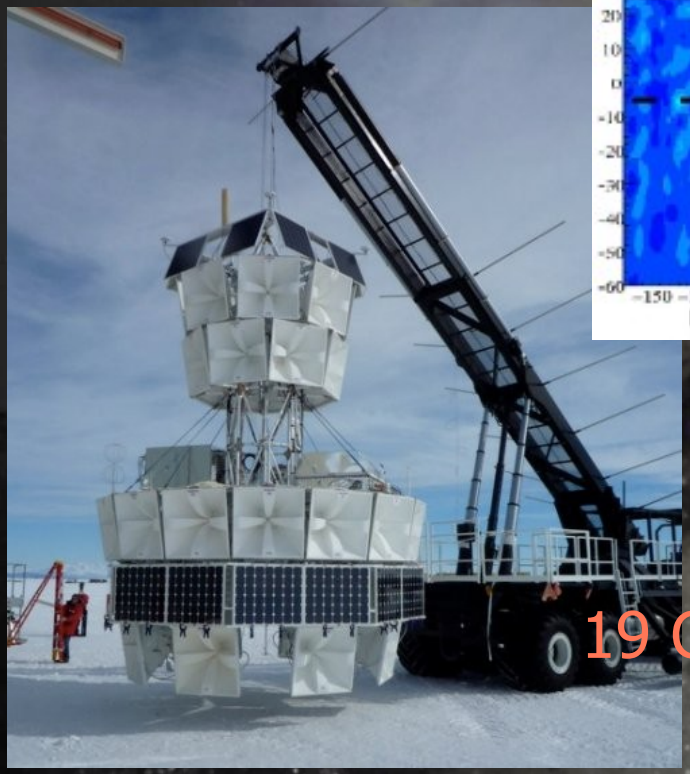
Paradox

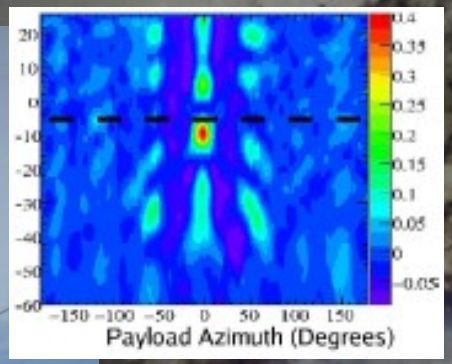
10^{13} eV γ L_{int} ~ 70 Mpc

Markarian 501
136 Mpc

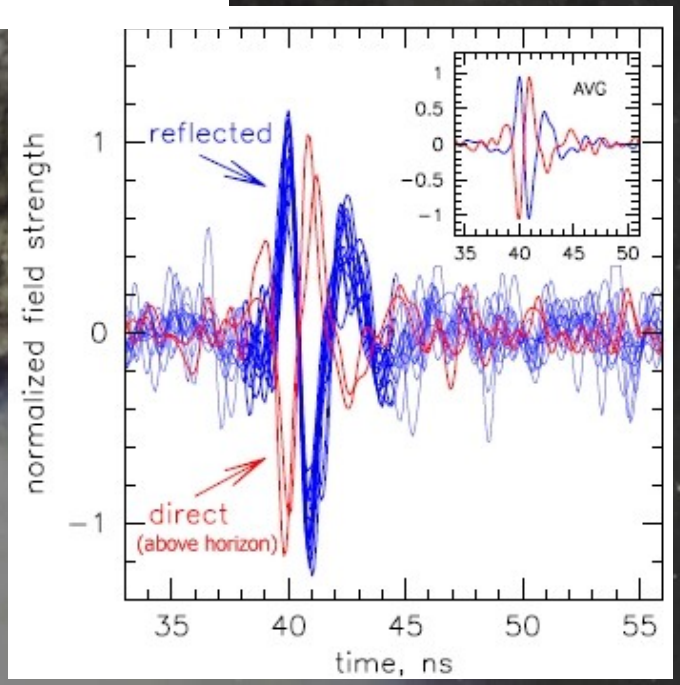
Catch!







ANITA



19 Cosmic rays:(…. & 2 may be neutrinos!

"Observation of Ultra-high-energy Cosmic Rays with the ANITA Balloon-borne Radio Interferometer", 2010, arXiv:1005.0035

"Observational Constraints on the Ultra-high Energy Cosmic Neutrino Flux from the Second Flight of the ANITA Experiment", ANITA colloboration, arXiv:1003.2961, 2010

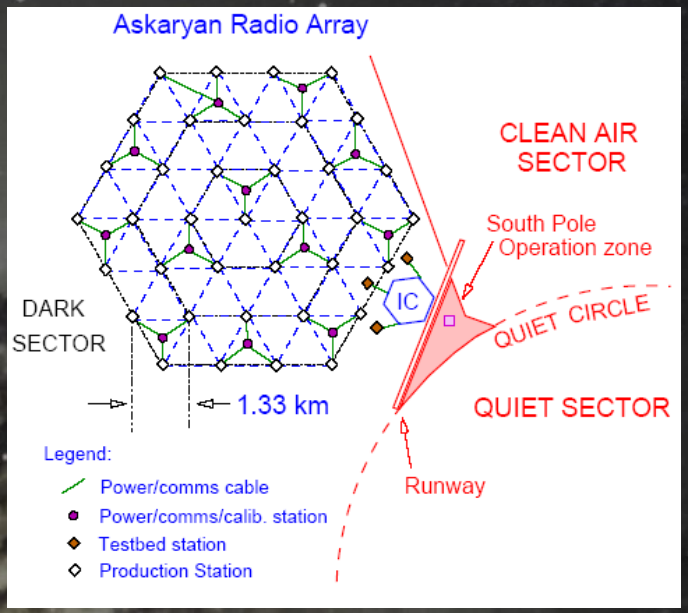

Thank Y for patience

Radio Cherenkov emission

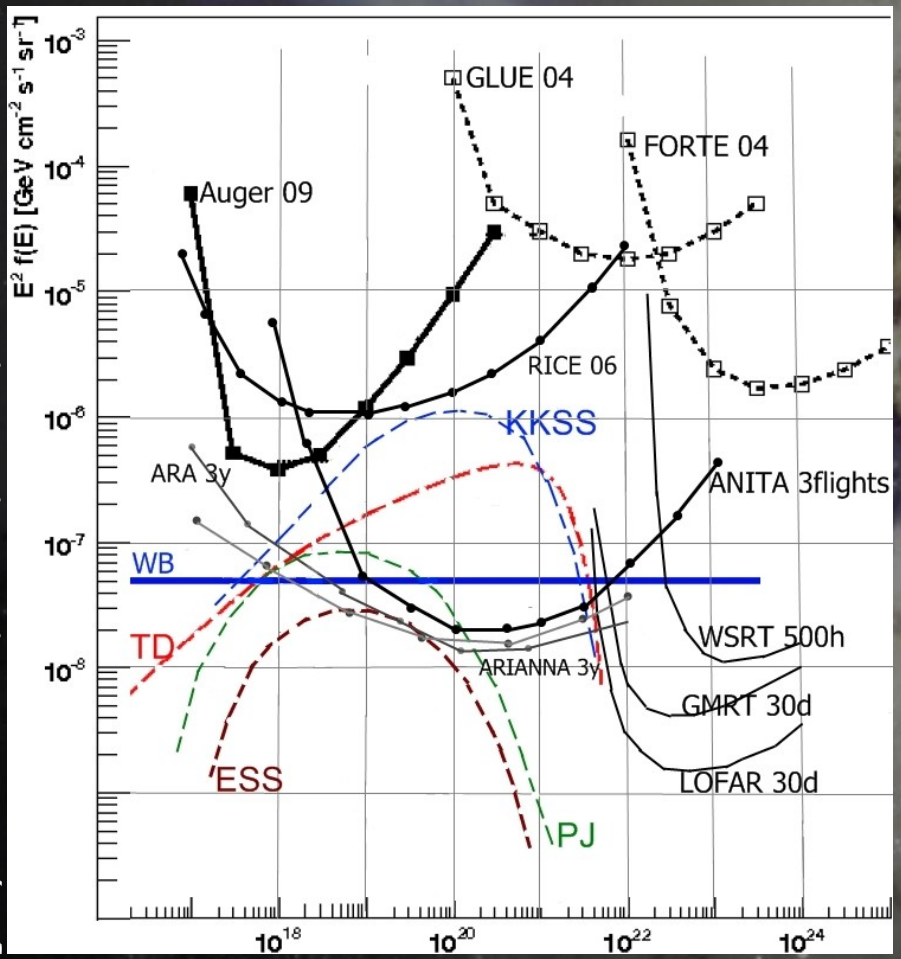
ARA

Askaryan Radio Array

~ 80 km², 37x12 antennas



"Simulation of the Event Reconstruction of Ultra High Energy Cosmic Neutrinos with Askaryan Radio Array", Shang-Yu Sun, Pisin Chen and Melin Huang, 2010, arXiv:1002.0023



AURA

Askaryan Underice Radio Array

100 – 1000km³

Antennas, Data analysis, Electronics, control and equipment from:

IceCube ANITA RICE

"Radio Detection of GZK Neutrinos - AURA status and plans", H. Landsman etc, Proceedings of the 30th International Cosmic Ray Conference, Vol. 4, p827–830