TAUP 2007, September 13, 2007, Sendai

Extremely High Energy Particles and Neutrinos

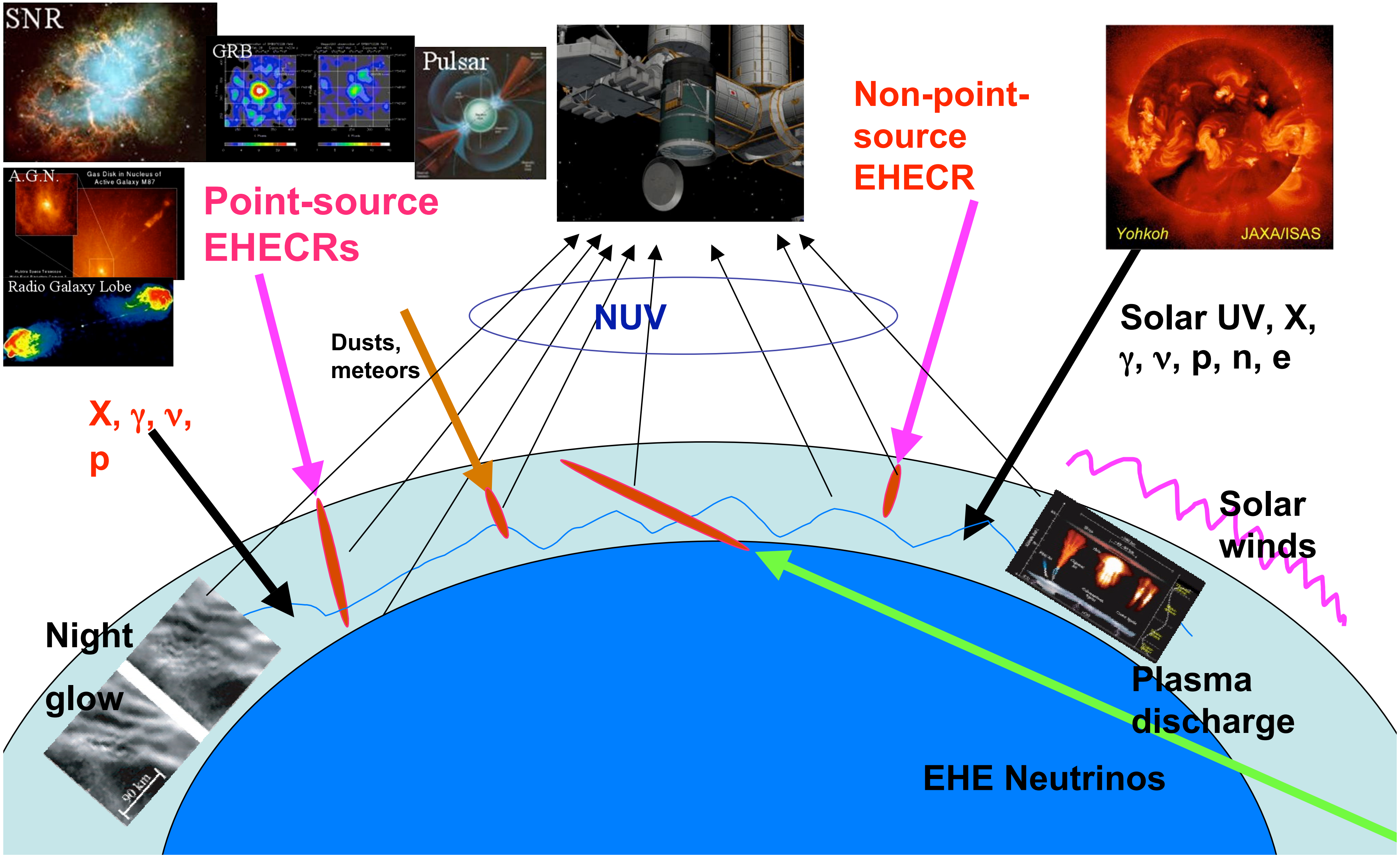
JEM EUSO mission on International Space Station

Yoshiyuki Takahashi

RIKEN, Japan

and The University of Alabama in Huntsville, USA

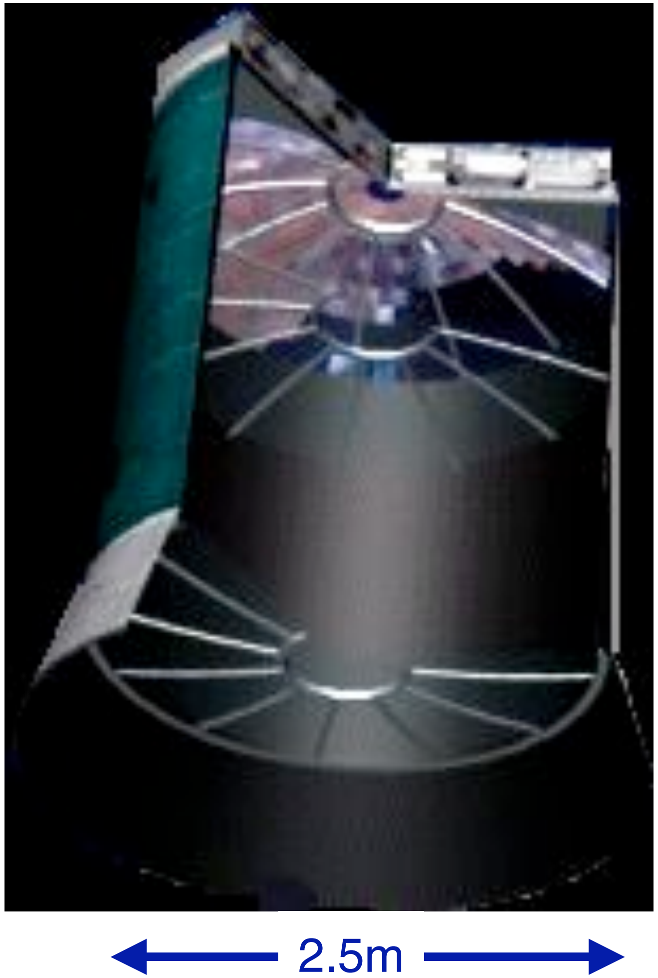
JEM-EUSO
= Astronomical Earth Observatory

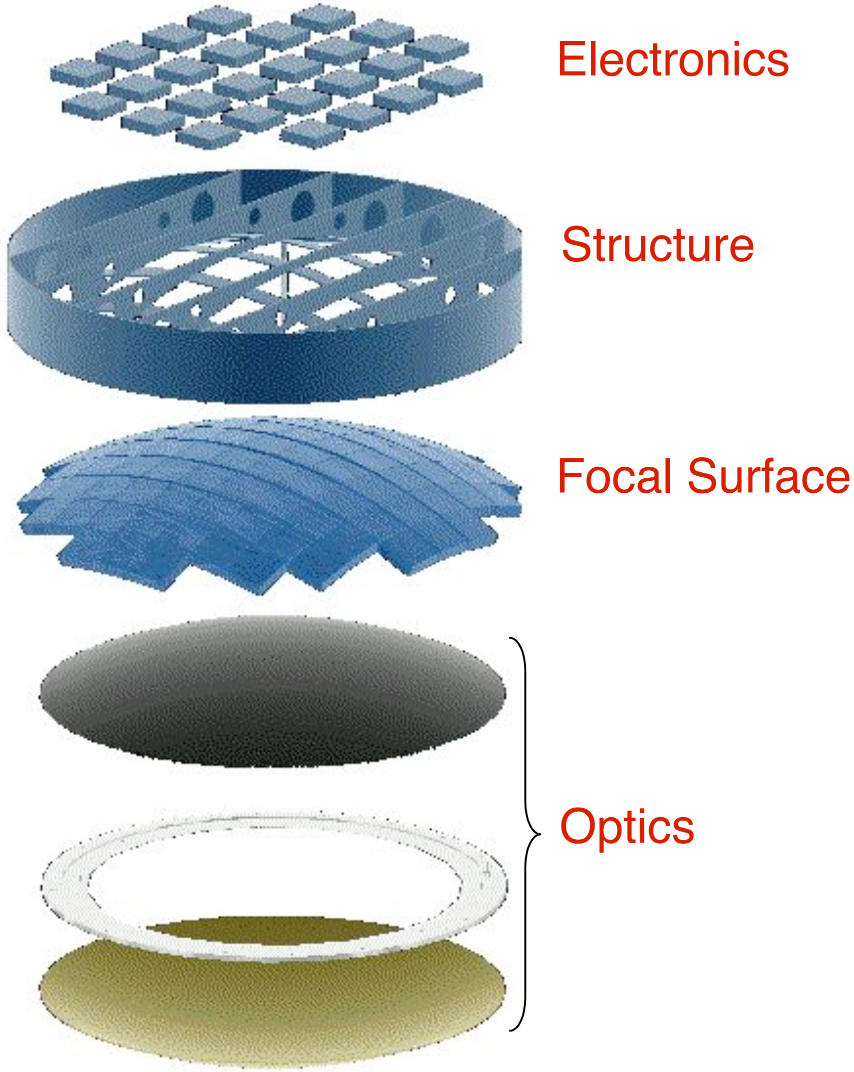


Parameters of Mission

• Time of launch:	year 2013
• Operation Period:	5 years +
• Launching Rocket :	H2B
• Transportation to ISS:	unpressurized carrier of HTV
• Site of deplyment:	JEM/ Exposure Facility #2
• Mass:	1896 kg
• Power:	998 W (in operation)
	424 W (non-operation)
• Data Transfer Rate:	297 kb/s
• Height of the Orbit:	~430km
• Inclination of the Orbit:	51.6°

JEM-EUSO Telescope Structure





Fresnel Lens

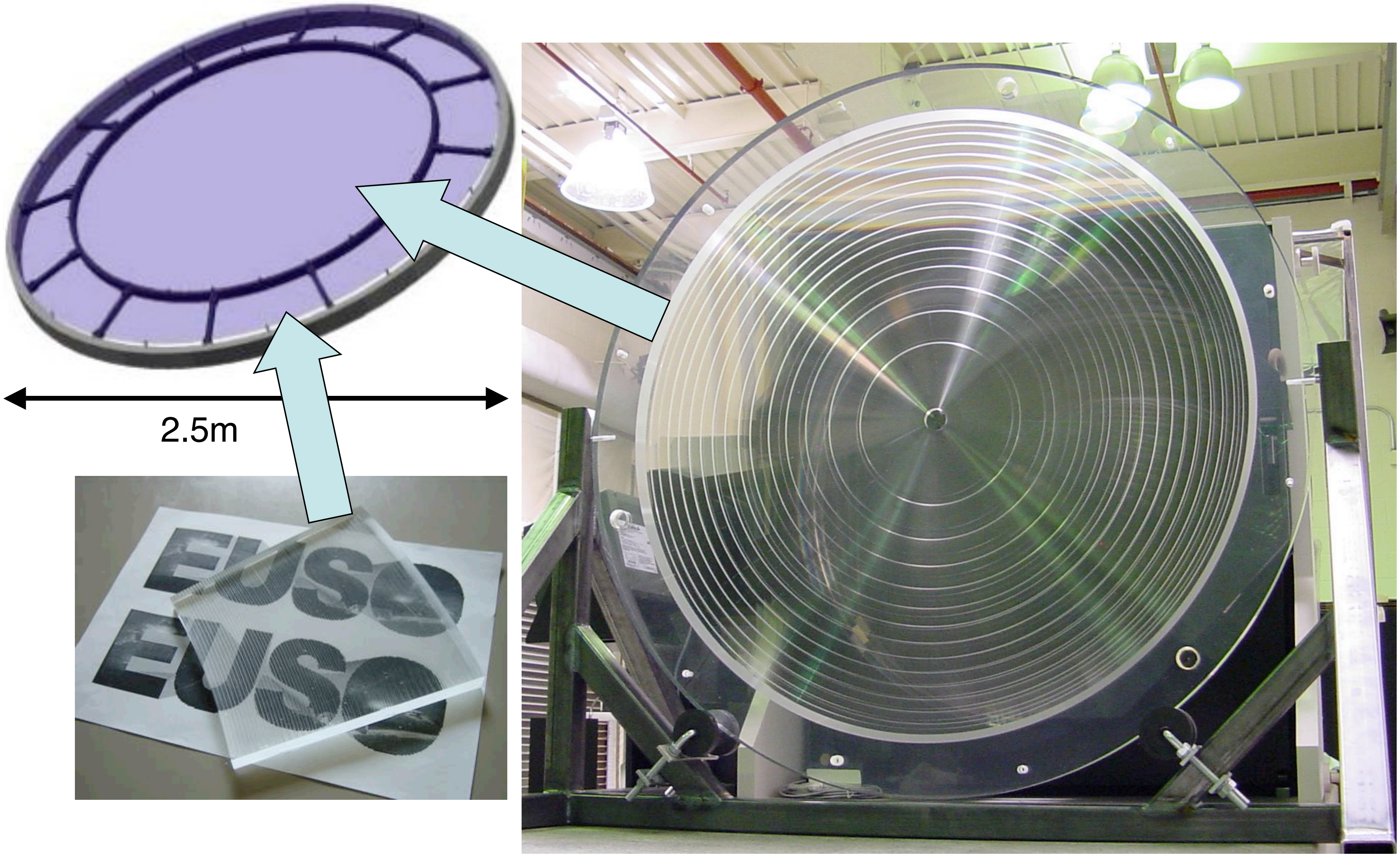


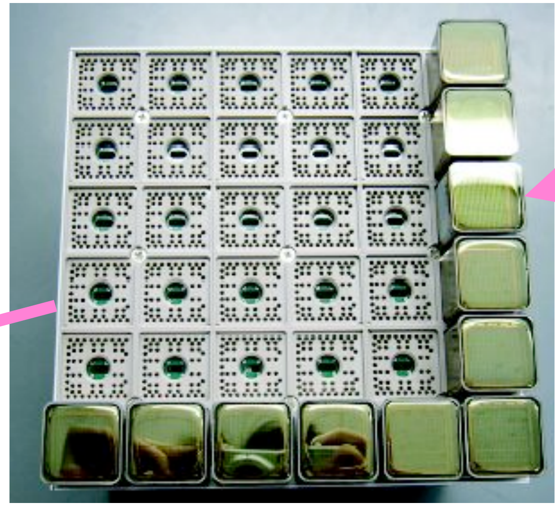
Photo Detector Module (PDM)

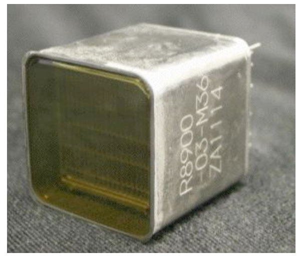
- _ Elementary Cell (EC) , _ HV module, _ HV divider

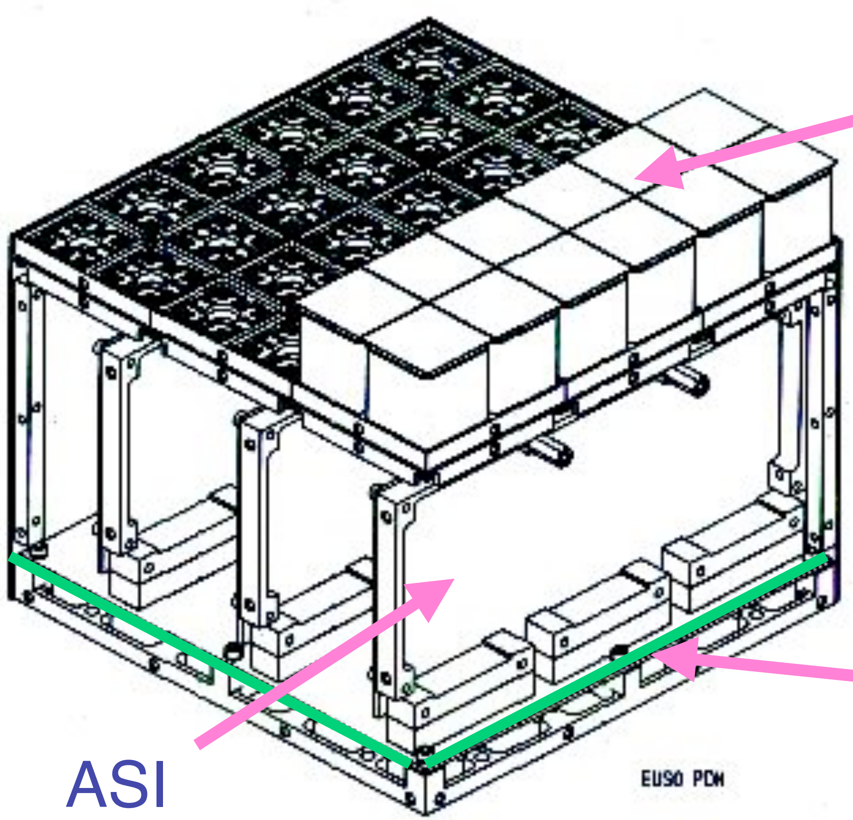
✓ Structure analysis / Vibration test

✓ Radiation test

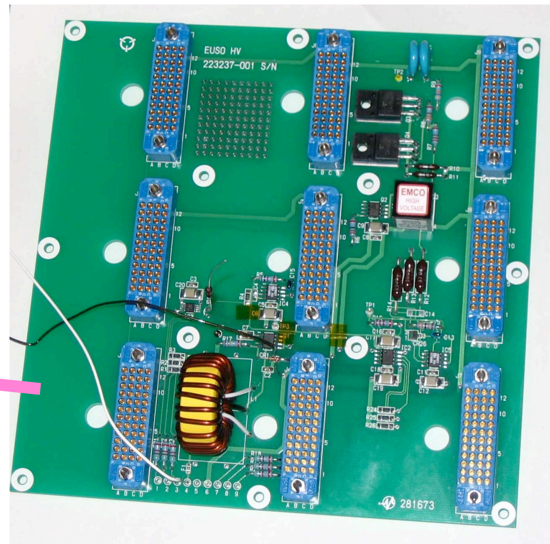
✓ Light protection circuit





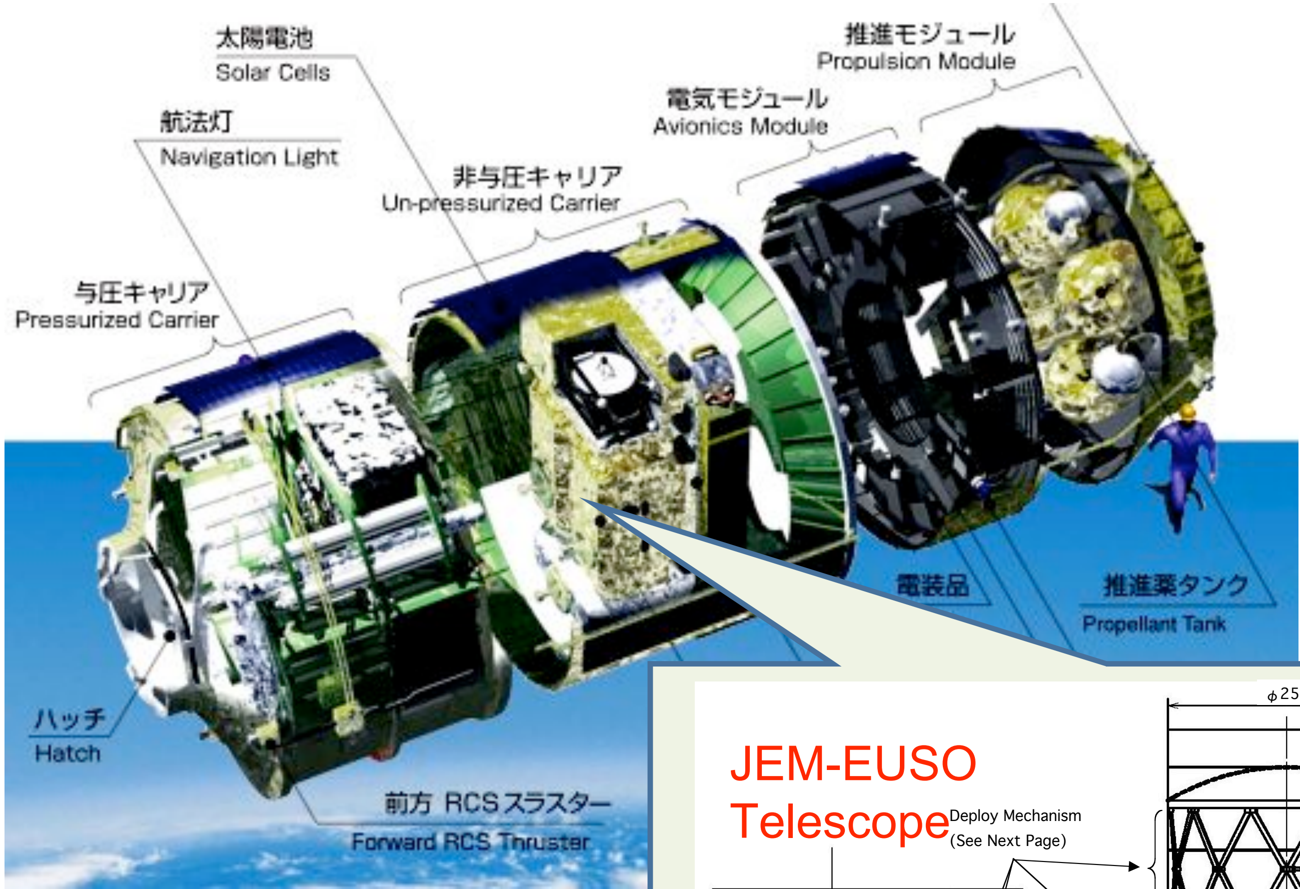


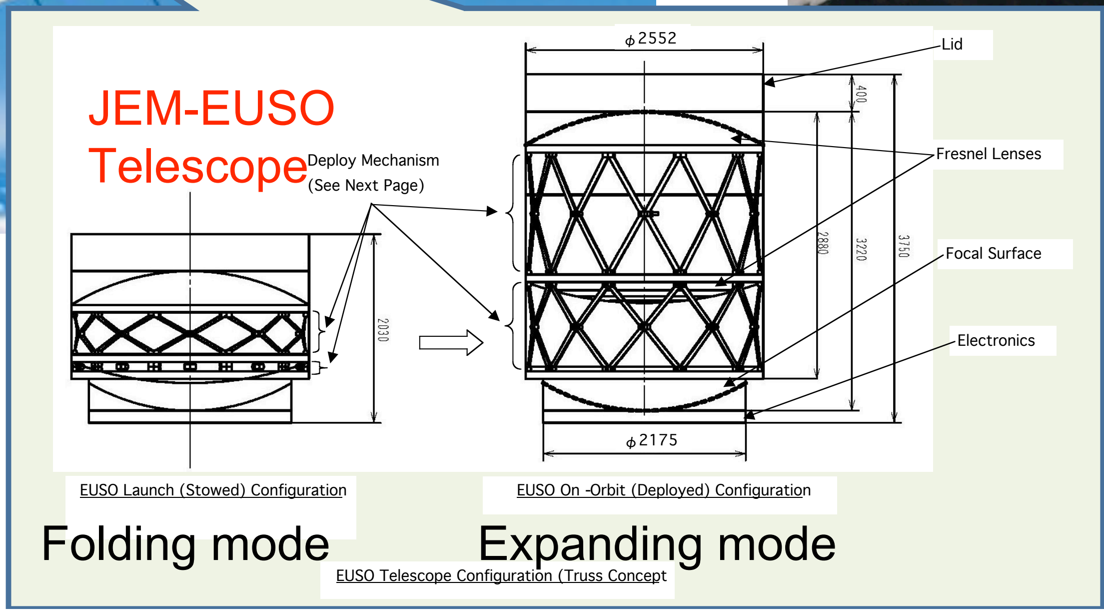
ASI



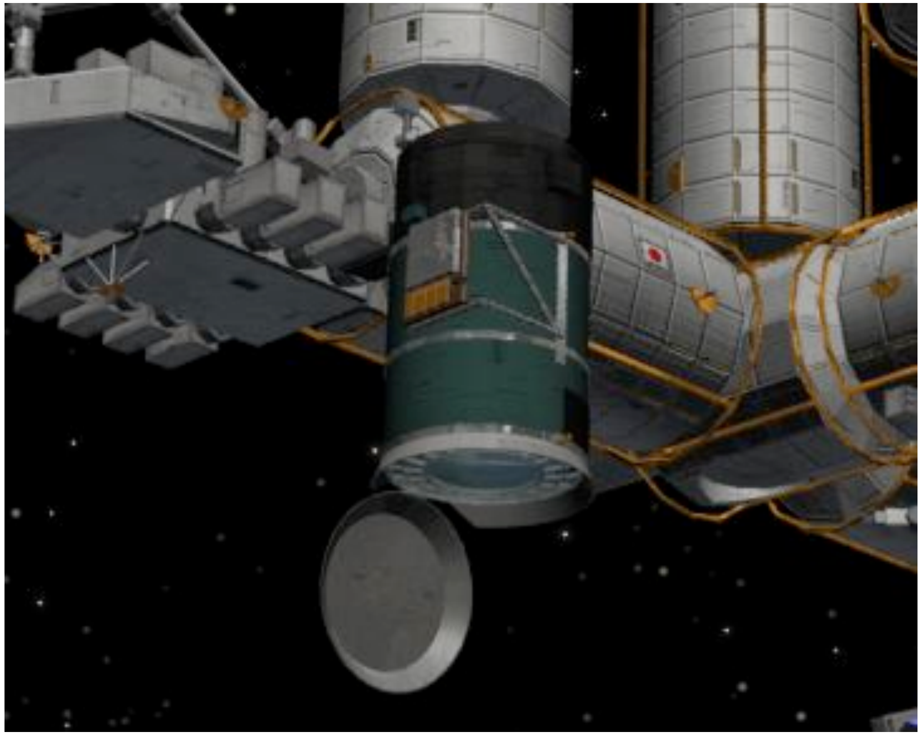
HV board

H-IIB Transfer Vehicle (HTV)

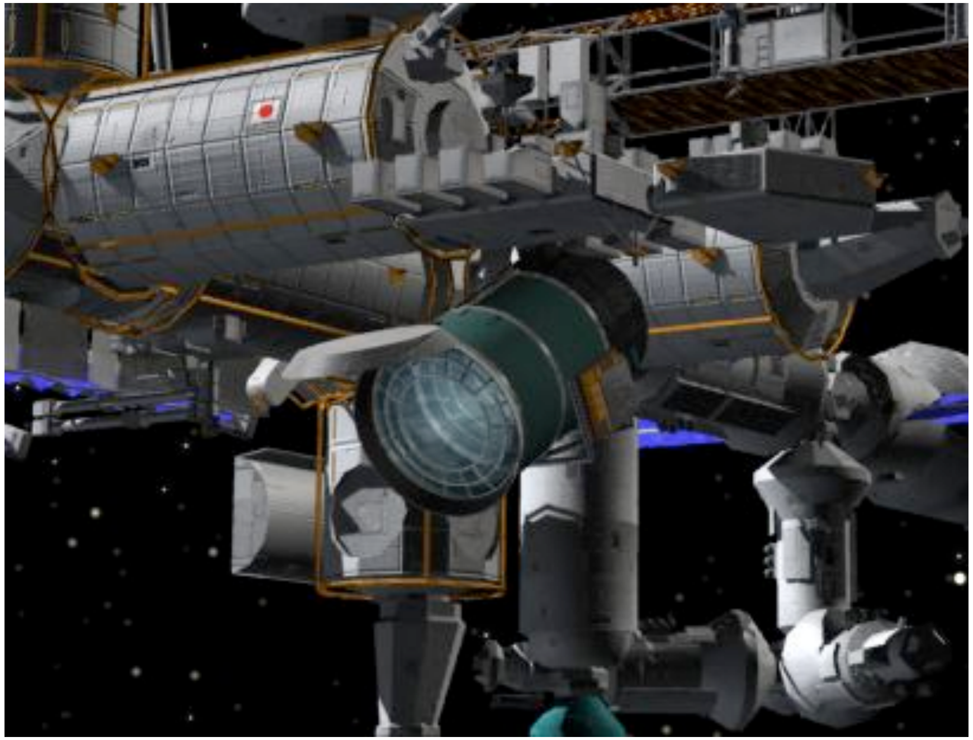




Observational modes of JEM-EUSO



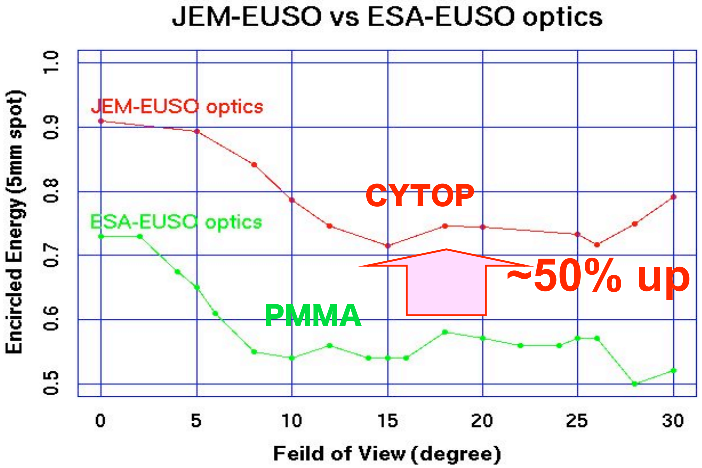
Nadir Mode



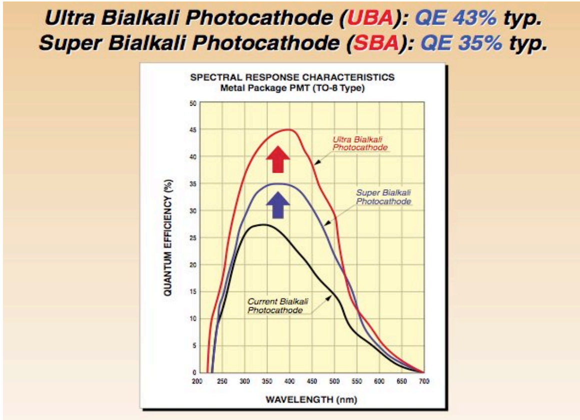
Tilted Mode

EUSO → JEM-EUSO

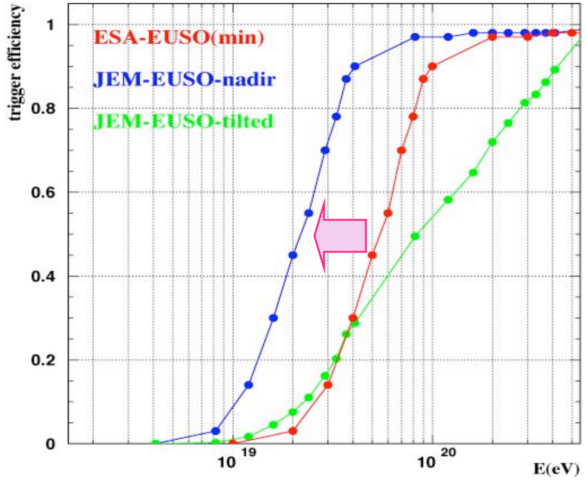
Lens Material



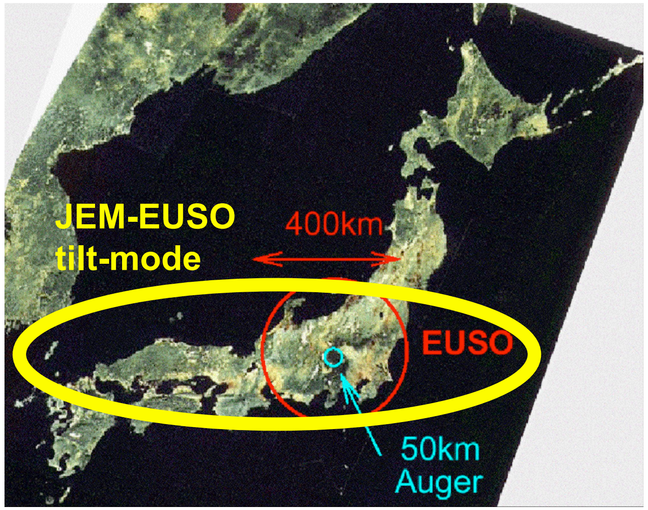
High Quantum Efficiency



Trigger Algorithm



Tilted Mode



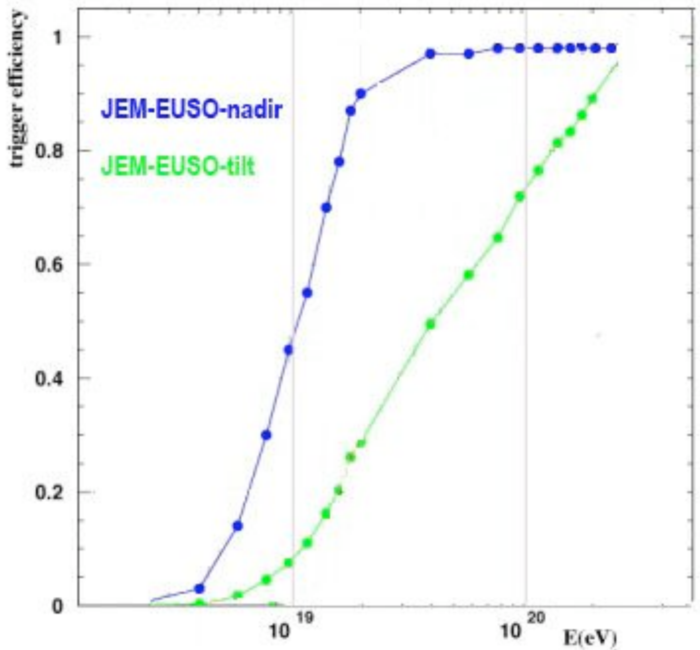
Cloud Monitor

Autonomous, but Laser and Infra-red Camera will be added

to improve evaluation accuracy of exposure
to improve reliability of detection of near-threshold airshowers

x 3-5 exposure at E >10^{20} eV

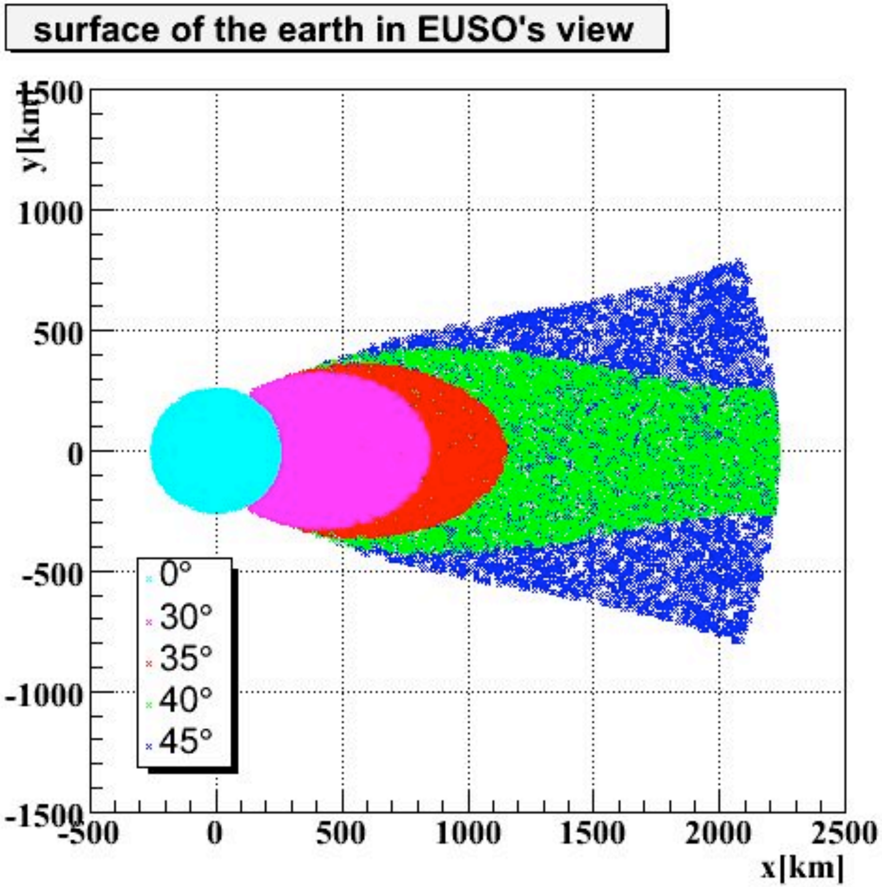
Threshold Energy for Nadir and Tilted Modes



- New optical material (CYTOP) and Advanced Design: ×1/2 reduction in E_{th}
- Higher QE devices: ×1/1.5
- Advanced Trigger algorithm: ×1/2
- Tilt mode : ×5 exposure at $E \geq 3 \times 10^{20}$ eV

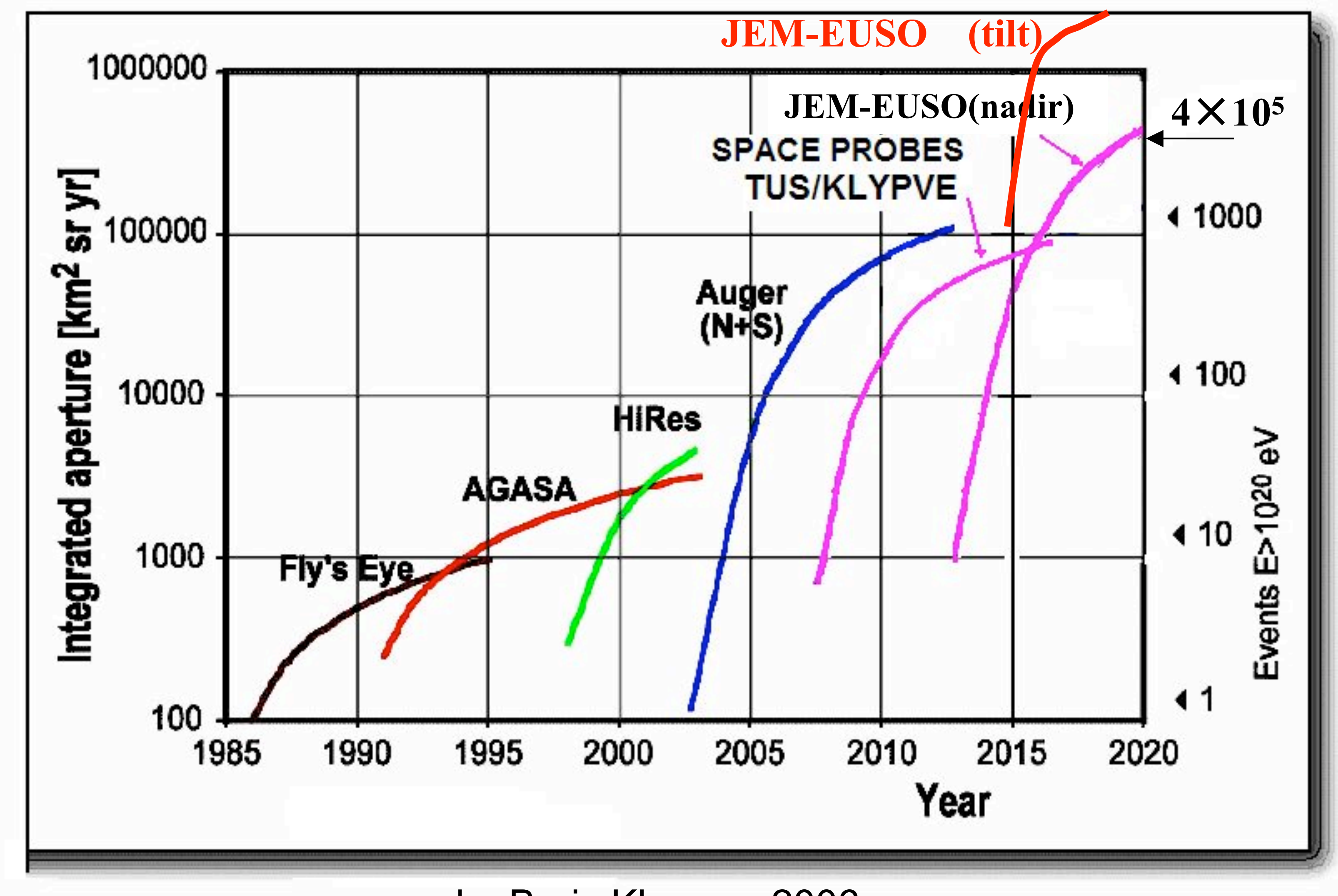
Large Nadir aperture > 10^6 km^2 yr (0.2 million km^2 sr /yr x 5 yrs)

Larger tilted aperture > **10^6 km^2 /yr** above a few times 10^{20} eV



Higashide, Wada et al., Saitama University, 2007

Progress of the study of EECR expected in the near future:



by Boris Khrenov 2006

JEM-EUSO Mission Objectives

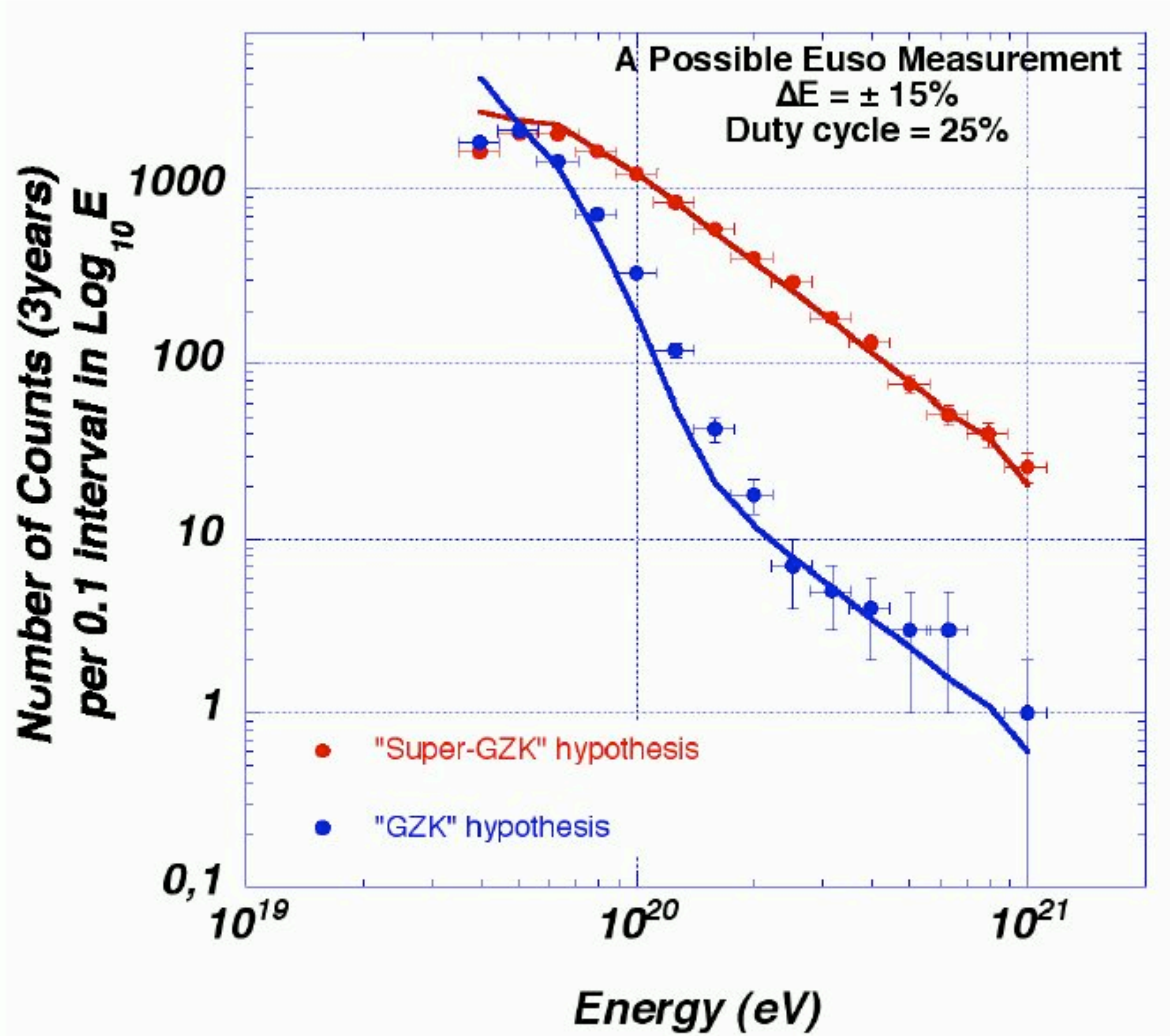
- **Primary Objective** : ***Astronomy, EHE universe > E_{GZK}***
  - Arrival directionality: ID of source & acceleration spectrum
  - Spectral analysis: useTrans-GZK and absolute calibration
  - Separation of gamma-rays, neutrinos from hadronic primaries

- **Exploratory test objectives:**
  - **Probing neutrinos and testing extra-dimensional models for neutrino cross-section**
  - **Study of Super-LHC physics**
    - Cosmological testing of local Lorentz Invariance ($\gamma_P \geq 10^{11}$, $\gamma_\nu \geq 10^{21}$)
    - Monitoring the effect of Quantum Gravity vacuum with GRBs
  - **Plasma discharges in atmosphere**
    - Blue-jets (& tau upward showers), Lightning, nightglow, meteors, etc

Primary Objective

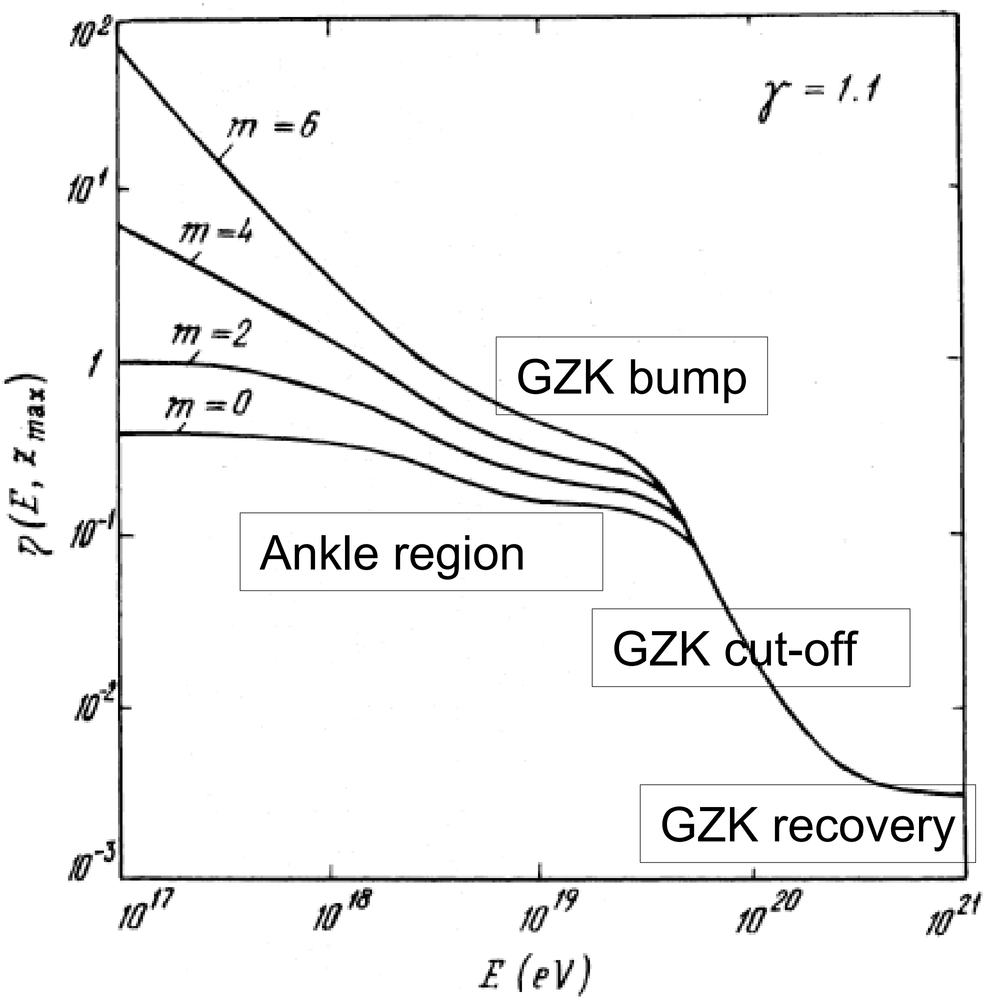
- ***Astronomy of EHE universe with*** $E > E_{GZK}$

Expected observable events

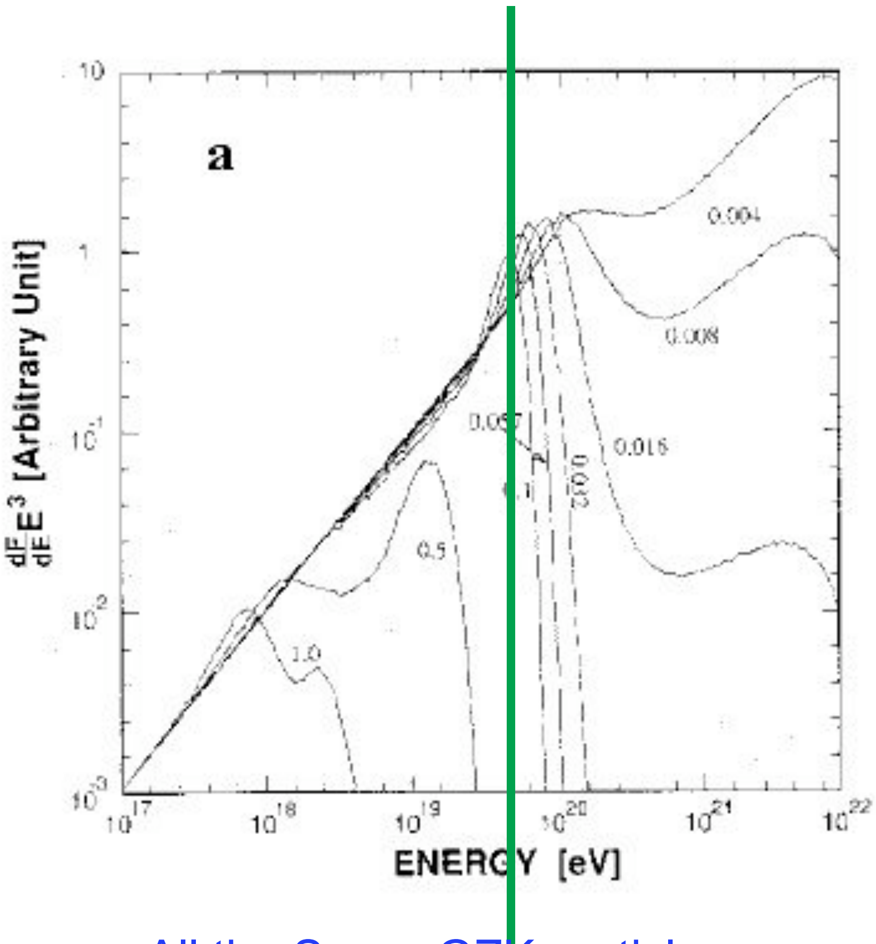


Point Sources

Propagation limit: Trans-GZK Complex:



Berezinsky&Grigorieva 1988



All the Super-GZK particles from sources within ~ 200 Mpc can be seen above 5 x 10^{19} eV, If linearly traceable

Full sky map of deflection angles in extragalactic space

By K.Dolag, D.Grasso, V.Springel, and I.Tkachev

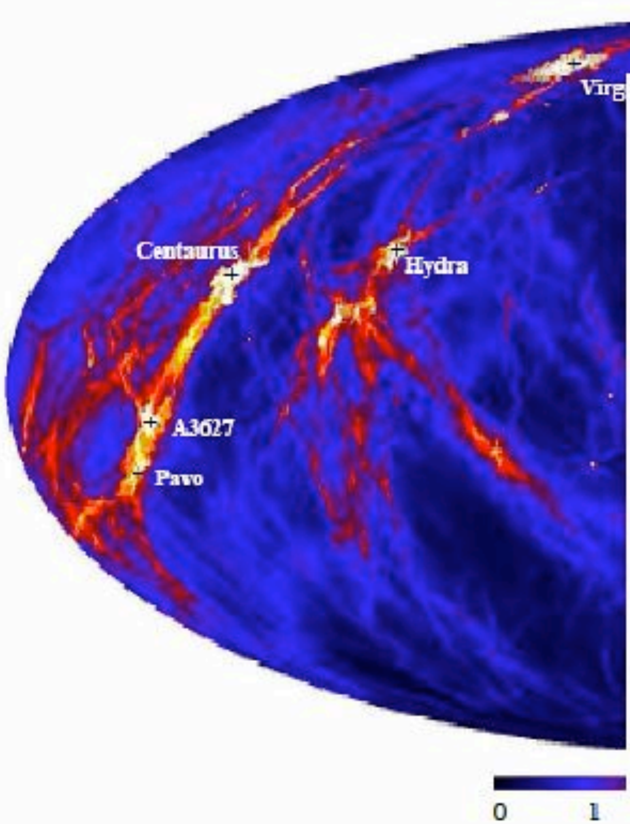


FIG. 1: Full sky map (area preserving projection) of c
scale. All structure within a radius of 107 Mpc aroun
with the galactic anti-center in the middle of the ma
corresponding halos in the simulation.

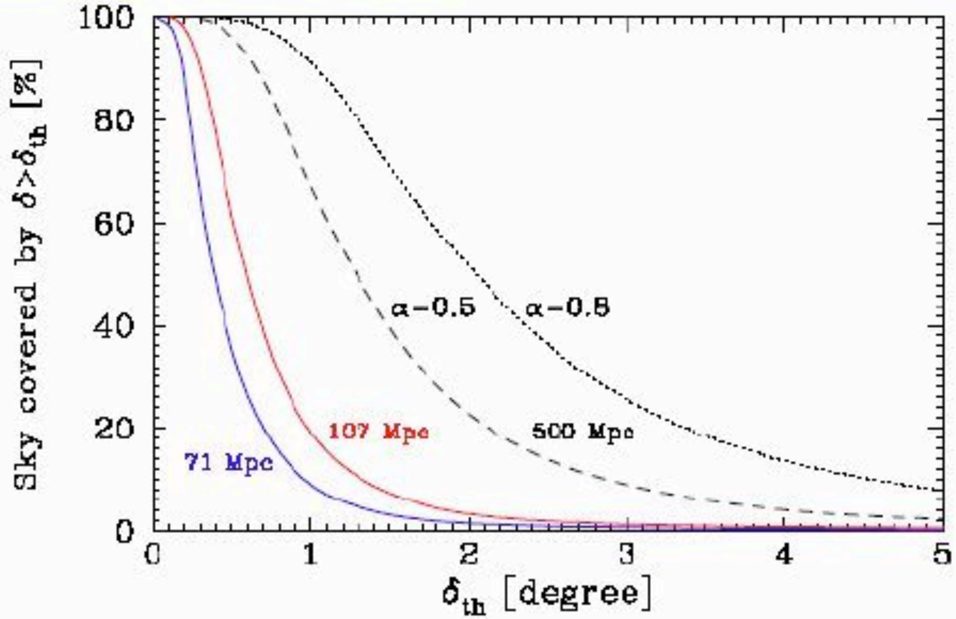
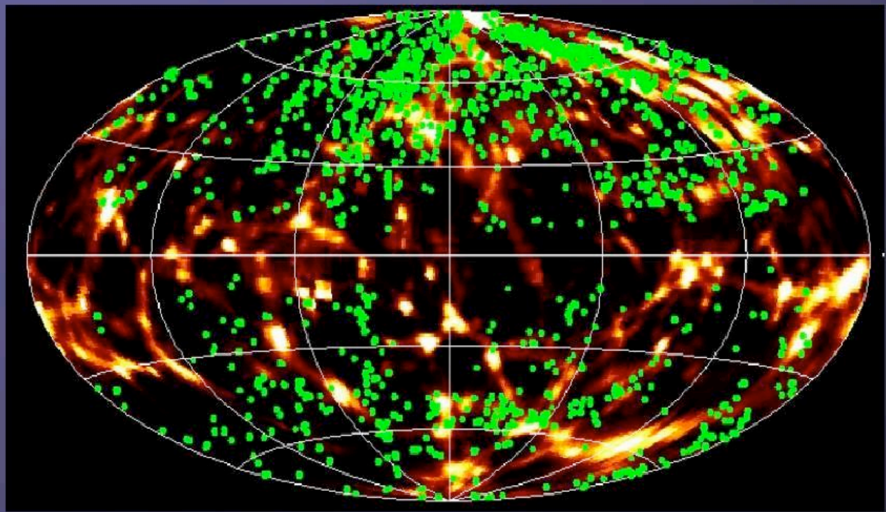


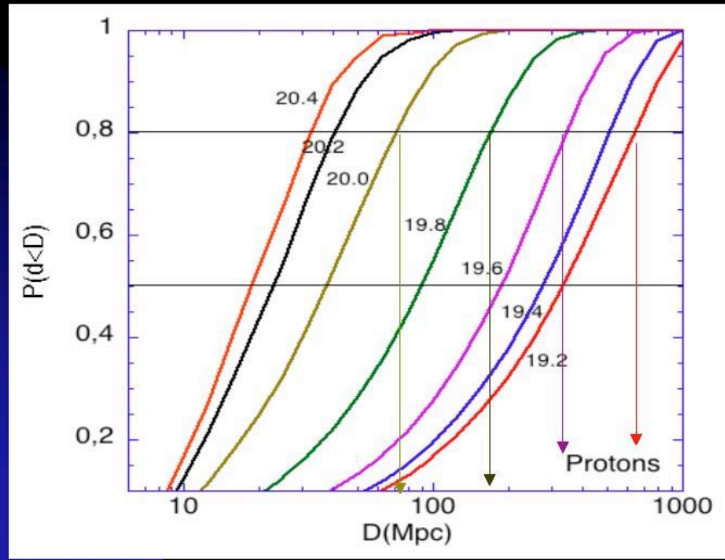
FIG. 2: Cumulative fraction of the sky with deflection angle larger than δ_{th}, for several values of propagation distance (solid lines). We also include an extrapolation to 500 Mpc, assuming self similarity with $\alpha = 0.5$ (dashed line) or $\alpha = 0.8$ (dotted line). The assumed UHECR energy for all lines is 4.0×10^{19} eV.

Matter (90Mpc) and Galaxies(45Mpc)

By A.Kravtsov

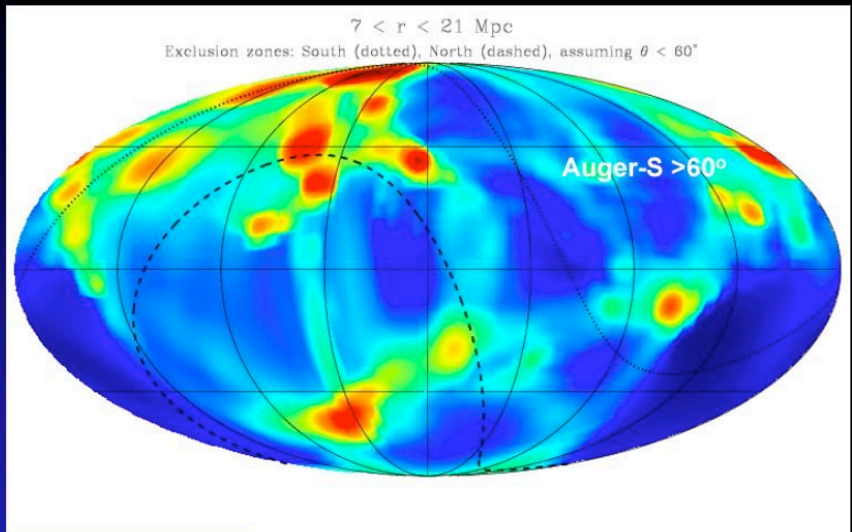


Proton Horizon



Allard

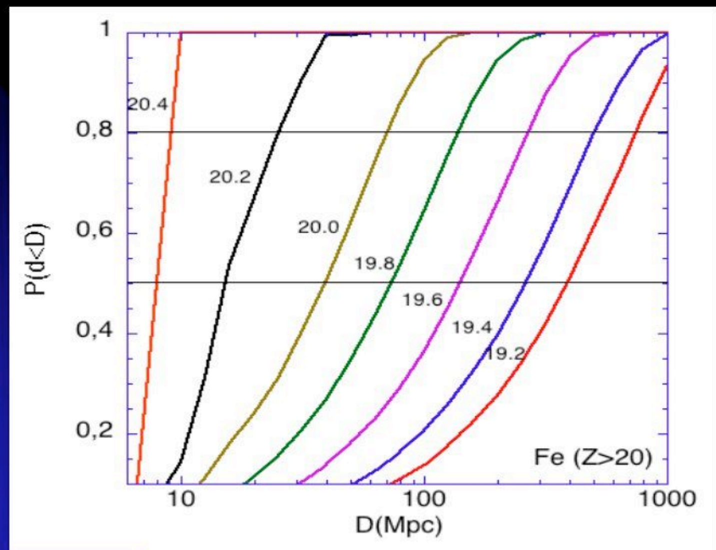
Dark Matter within 20 Mpc



Galactic Center in the Center!!!

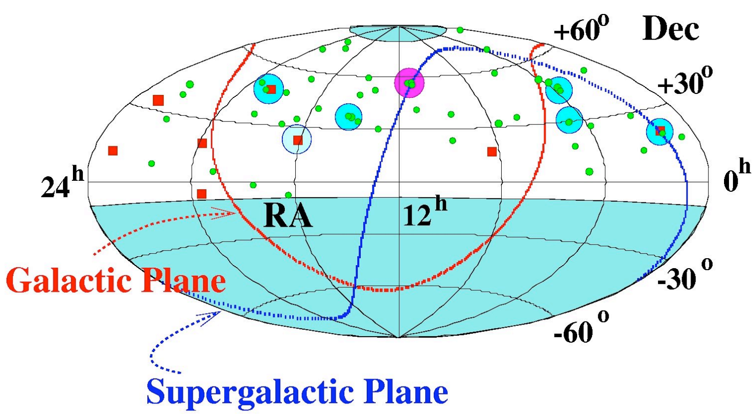
Kravtsov, Armengaud

Fe Horizon

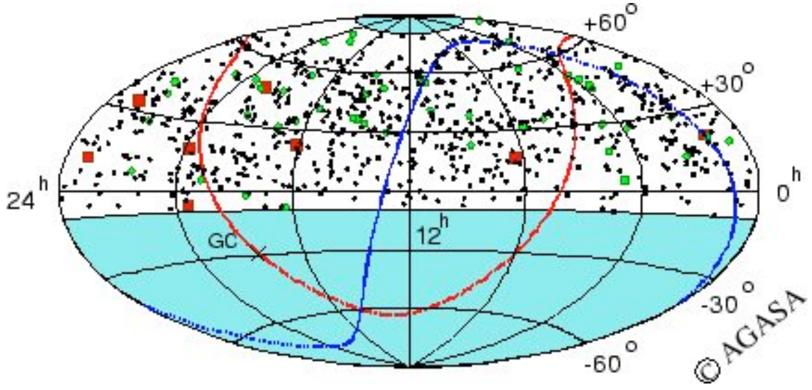


Allard

Arrival Direction Distribution - Compact sources



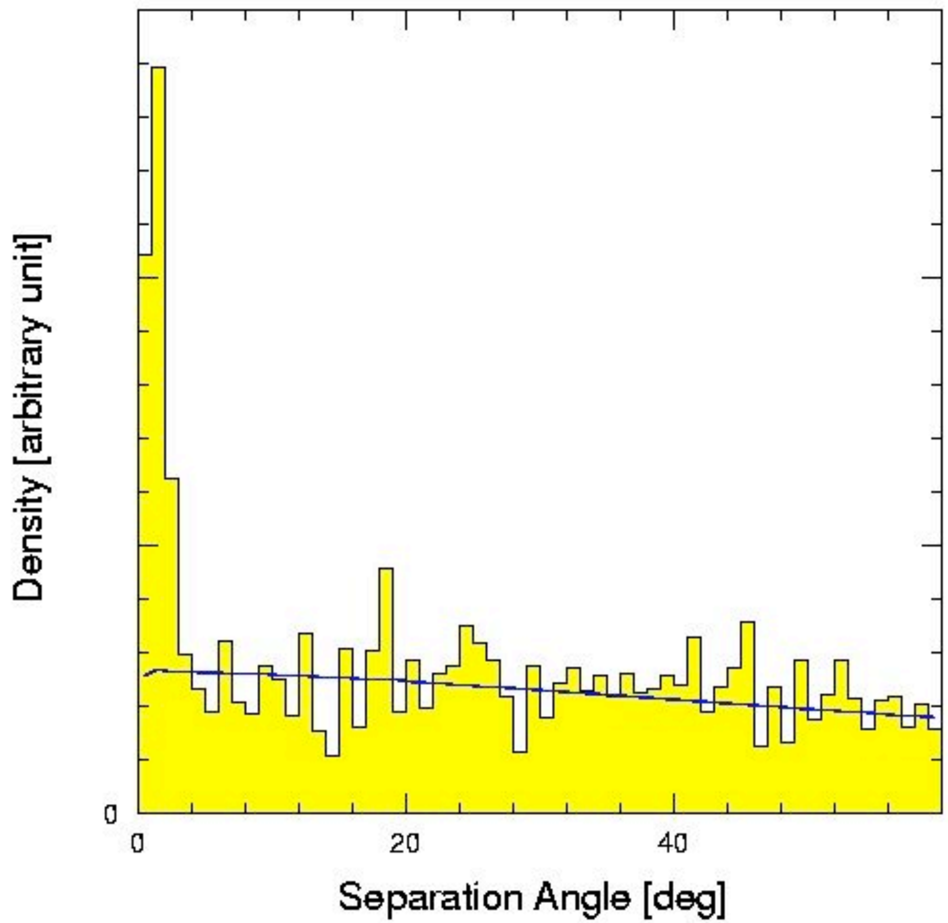
AGASA



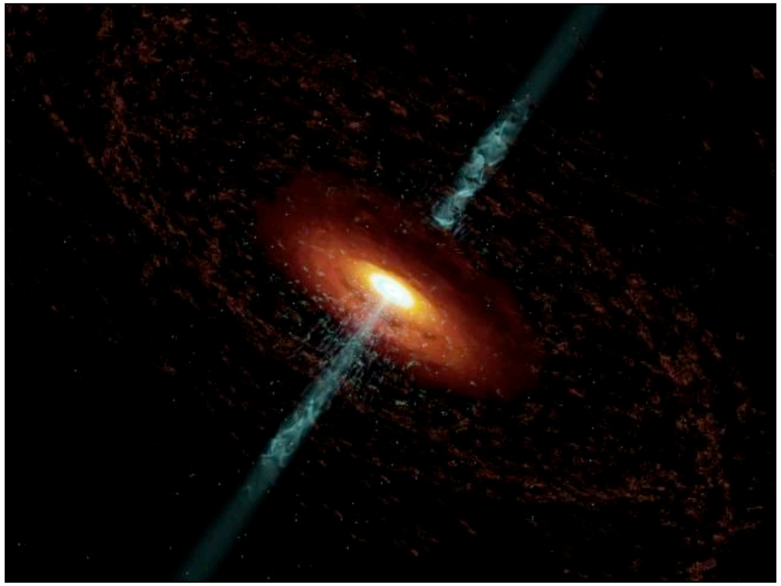
> 1000 Galaxies within 200 Mpc

AGASA

~5 sigma effect

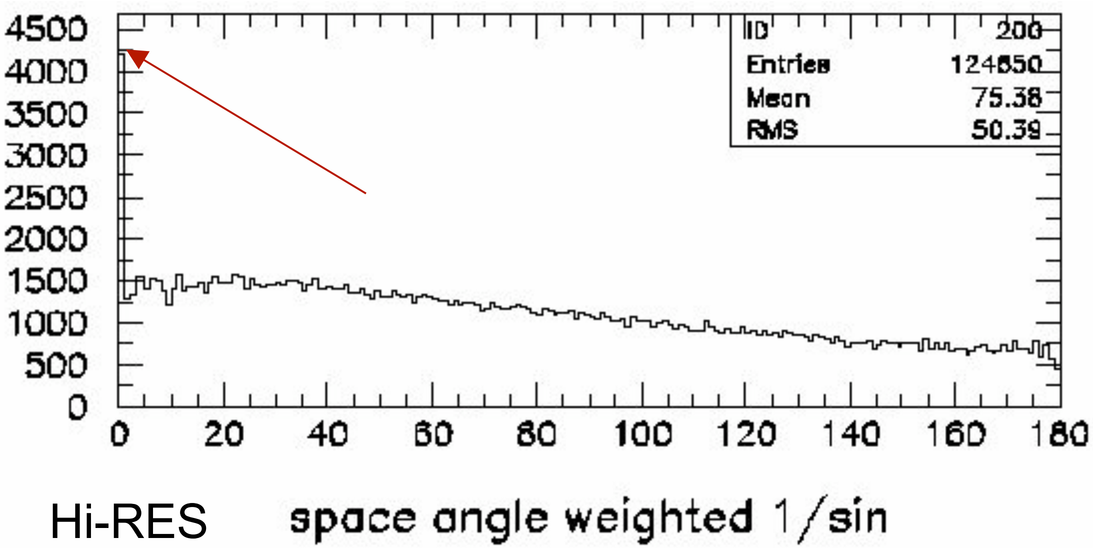


Correlation with BL Lac (Jui as of 2006)

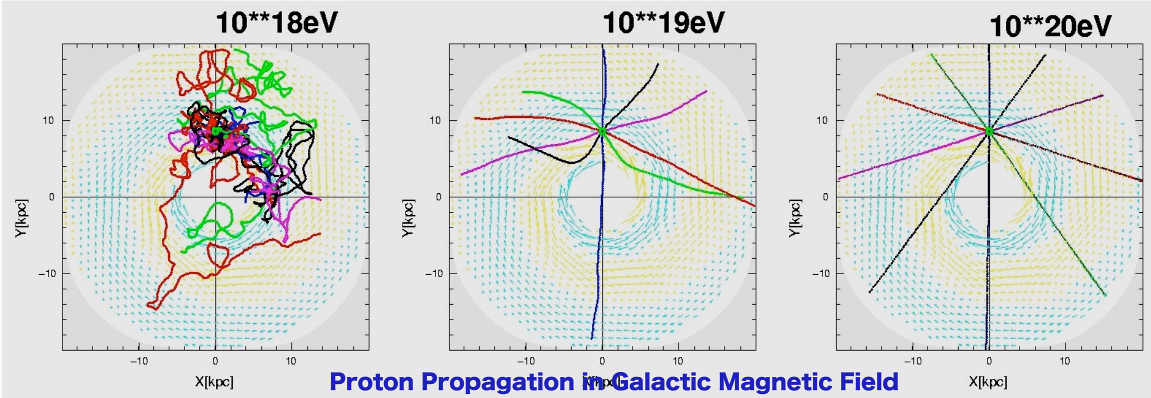


- BL Lac Object - special type of blazar, active galaxy with jet axis aligned with our line of sight.
- Blazars are established sources of TeV γ-rays
- Candidates for accelerating cosmic rays to EeV energies

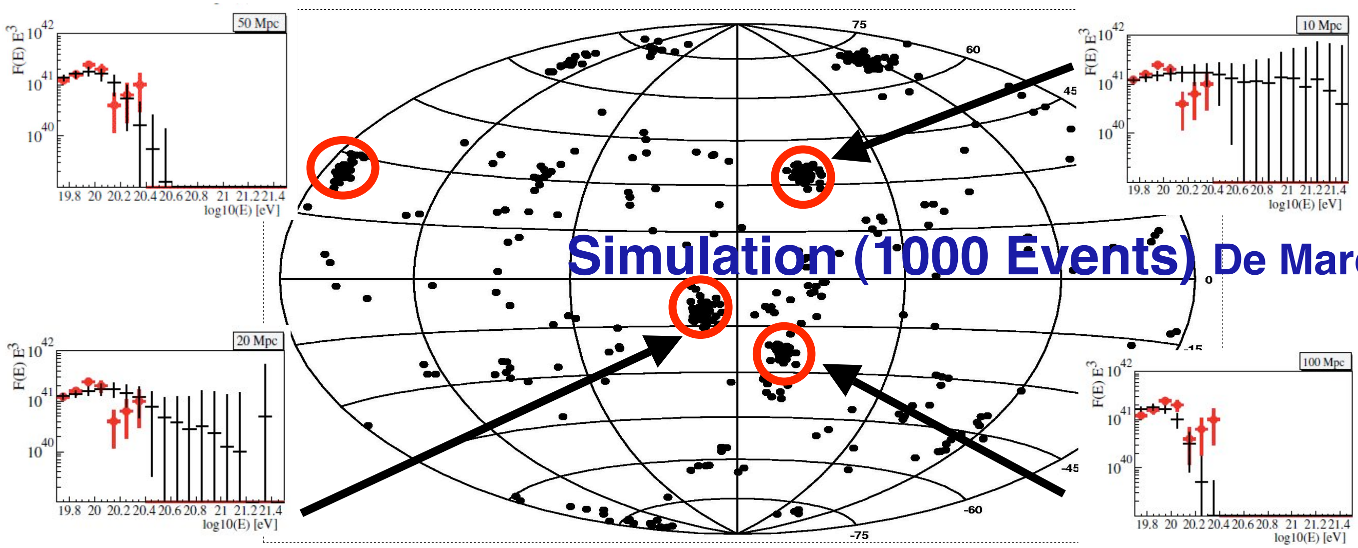
Tinyakov and Tkachev, JETP 74 (2001) 445.
Tinyakov and Tkachev, Astropart. Phys. 18 (2002) 165.
Gorbunov et al., ApJ 577 (2002) L93.
Evans, Ferrar, and Sarkar, Phys.Rev. D67 (2003) 103005.
Torres et al., Astrophys.J. 595 (2003) L13.
Gorbunov et al., JETP Lett. 80 (2004) 145.
Stern and Poutanen, ApJ 623 (2005) L33.



10^{20}eV proton can be traced back to a point source



All-sky Freedom*
from GM
above 10^{20} eV



De Marco/Blasi 2003

1000 events with E > 7 x 10^{19} eV in the whole sky,

Tens of cluster can be seen and their source spectra can be measured as a function of distance

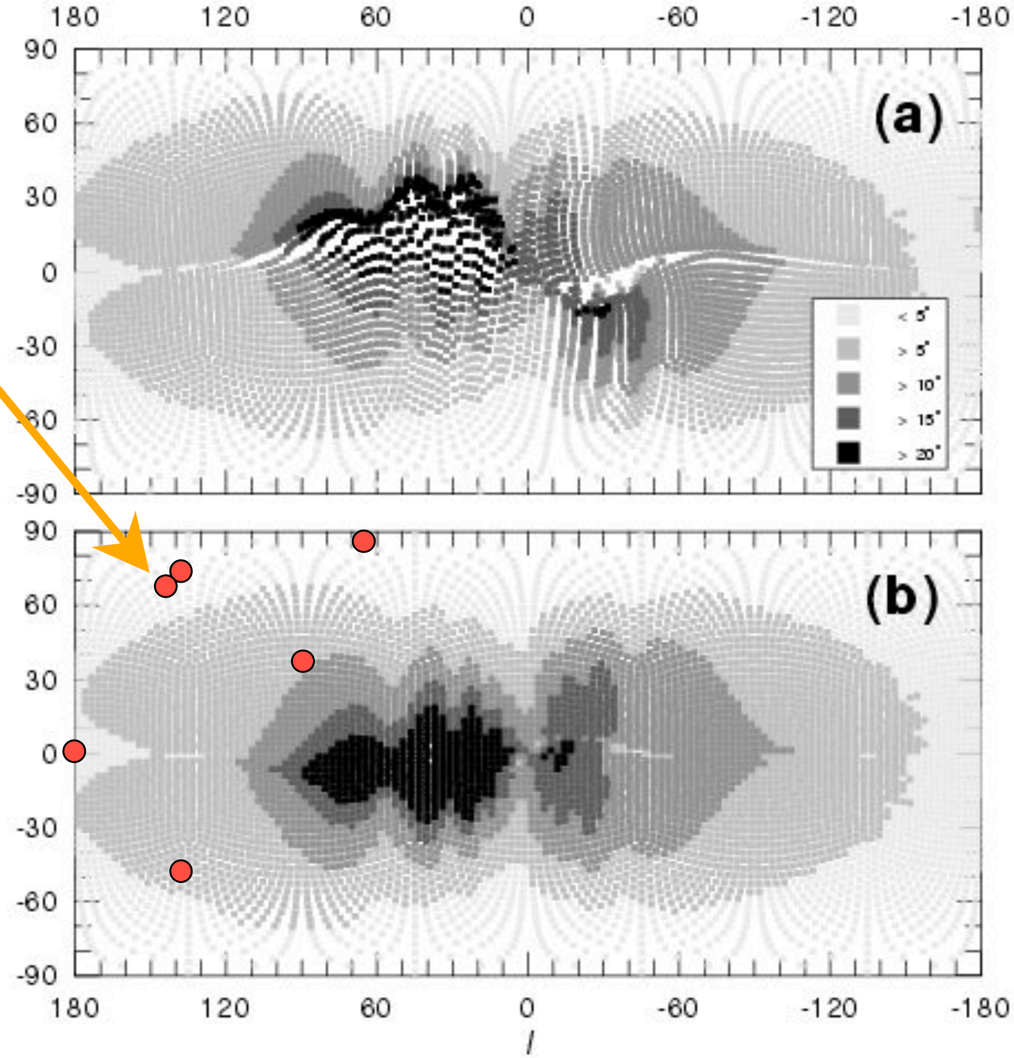
→ **Particle Astronomy is with > 10^{20} eV**

But be aware of the deflecting Galactic Magnetic Field, too

Galactic Magnetic Field is still so high that a part of the southern sky is difficult for Particle Astronomy for E < 10^{20} eV

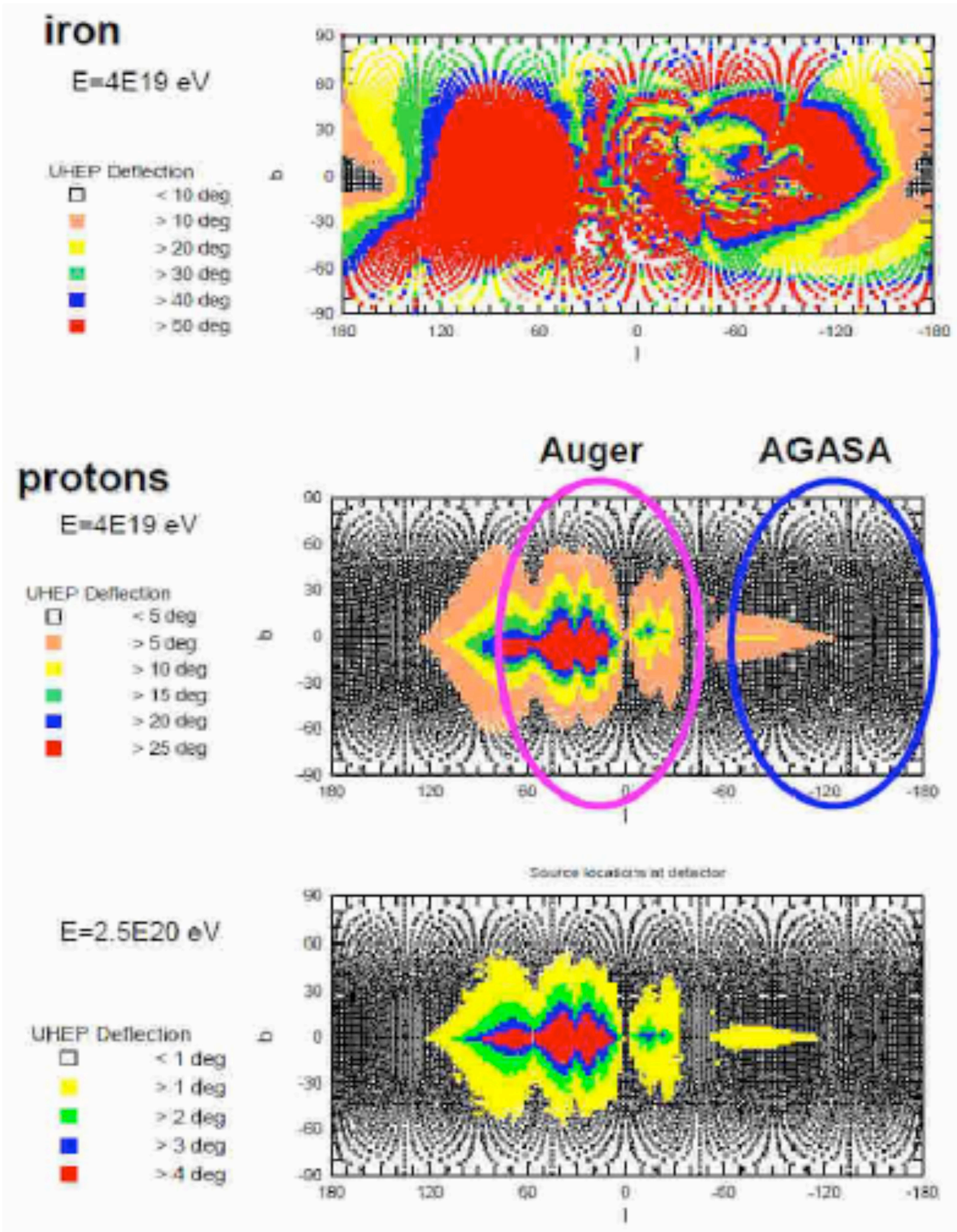
Note that most AGASA clusters are outside the 5° region (low B field)

- Null results by AUGER may not be inconsistent with AGASA clustering or AGN point-source analyses of AGASA and Hi-Res data
- Southern sky may still be unkind to source astronomy below E < 10^{20}eV
- Pairs and AGN correlations, if any, should reasonably be feasible at E > 10^{20} eV



G. A. Medina Tanco et al. astro-ph/9707041

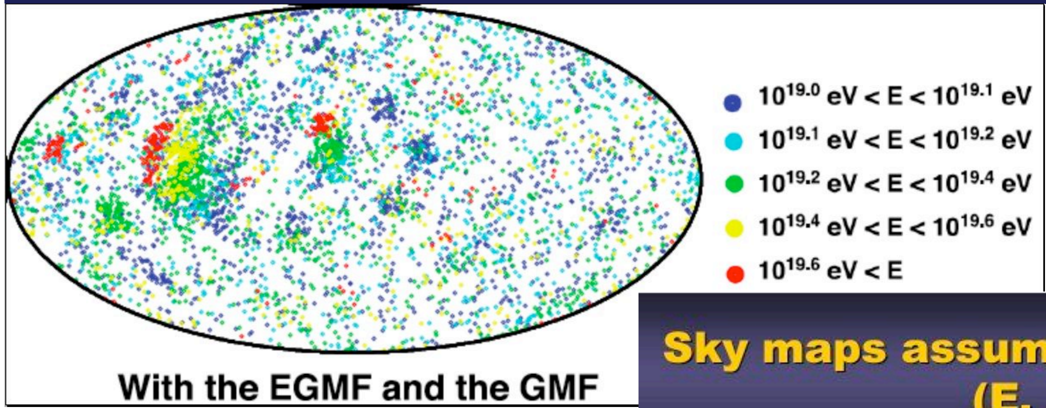
Astro-ph/0607543v1 2006

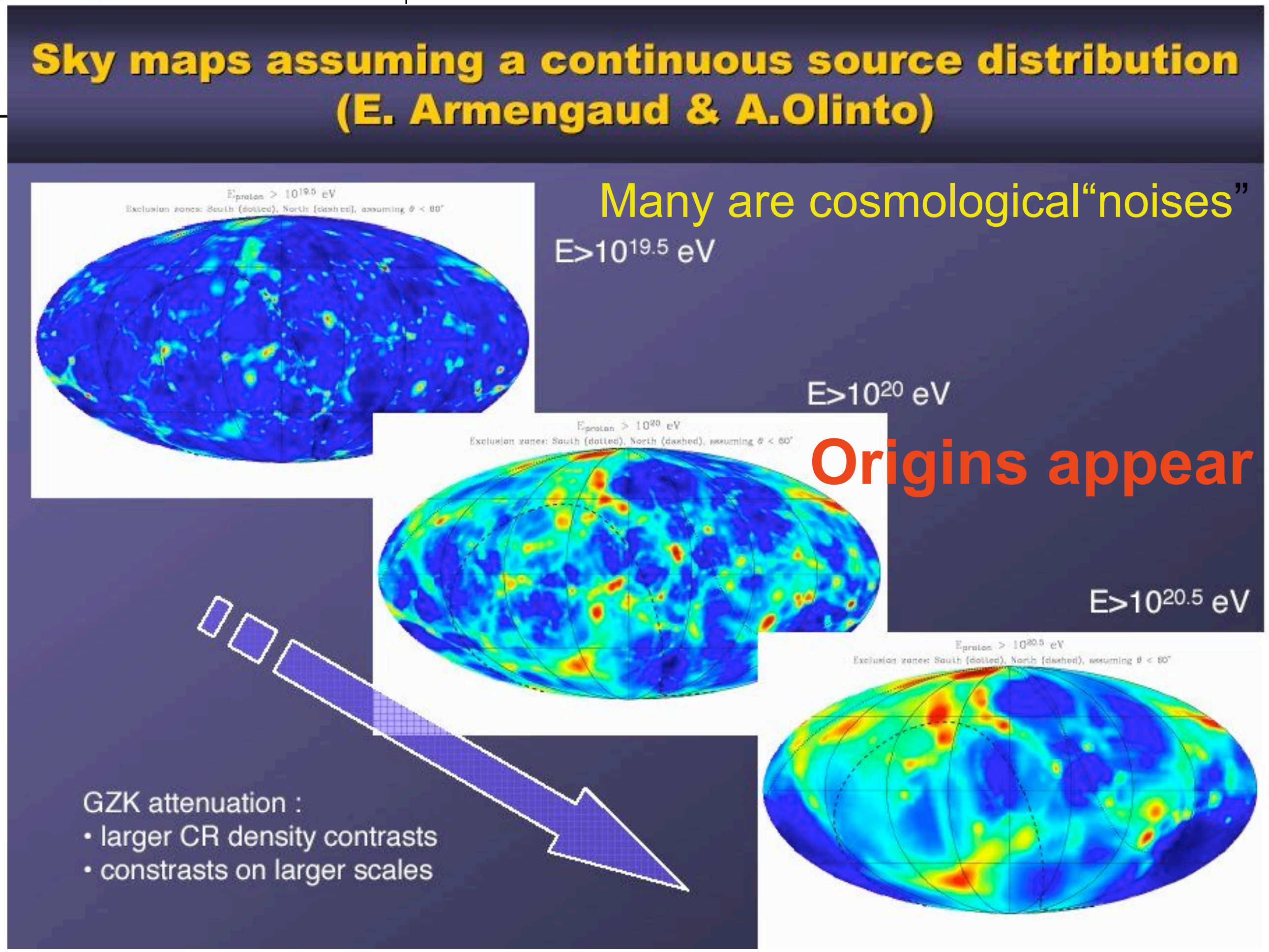


Survey for Medium & Large Scale Annisotropy

if EHECRs trail
the Matter, Bright Galaxies,
Clusters, and Dark Matter
populations

Bright Galaxies (Takami - Sato 2006; Olinto 2007)

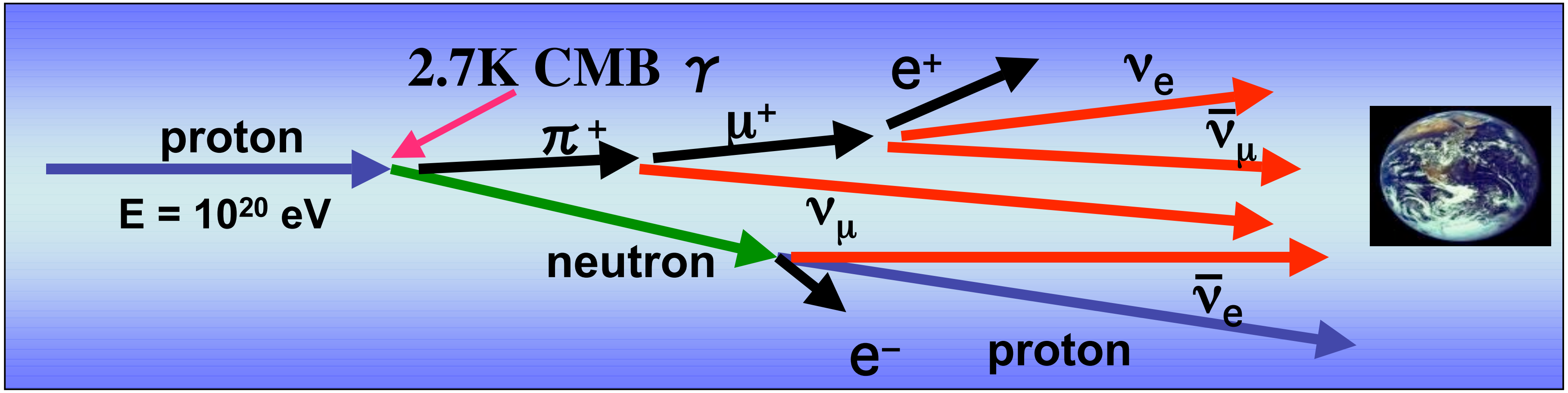




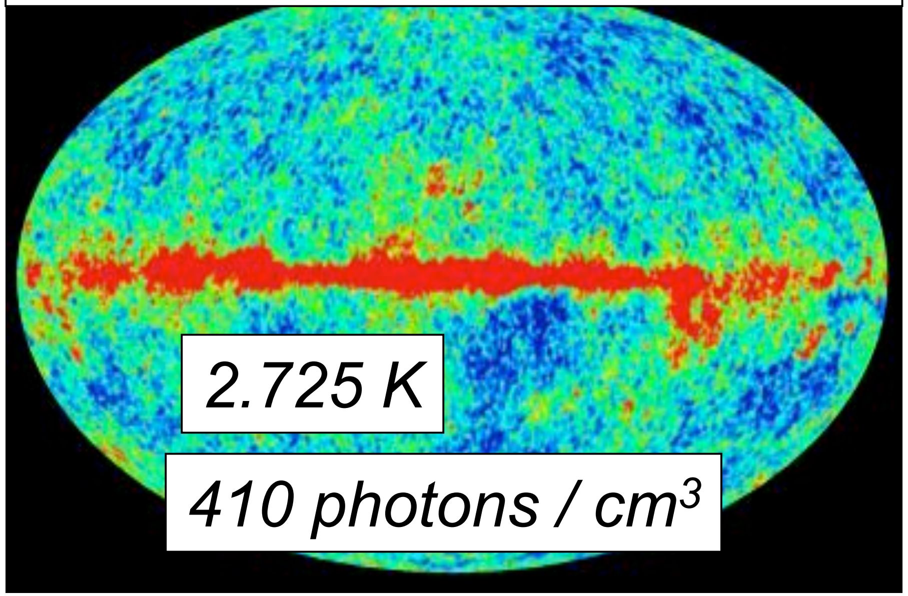
Exploratory Sciences

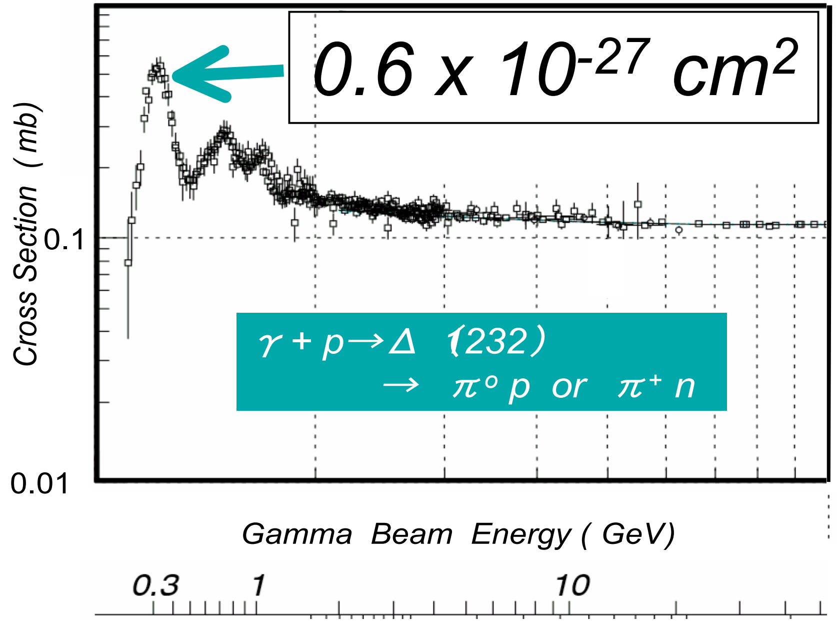
EXPLORATION 1a: GZK Neutrinos

(1) GZK Neutrinos should exist so long as L.I. holds



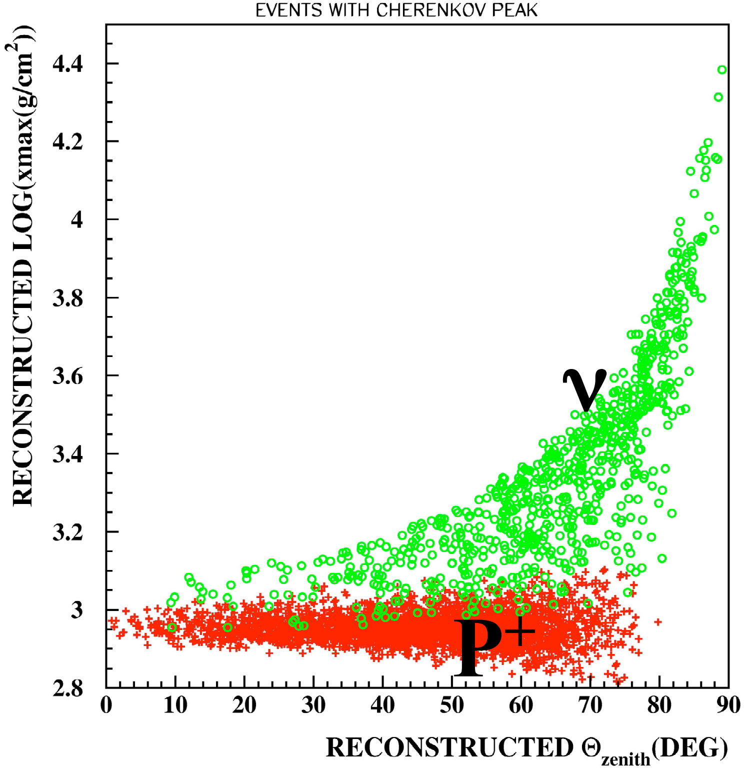
Cosmic Microwave Background



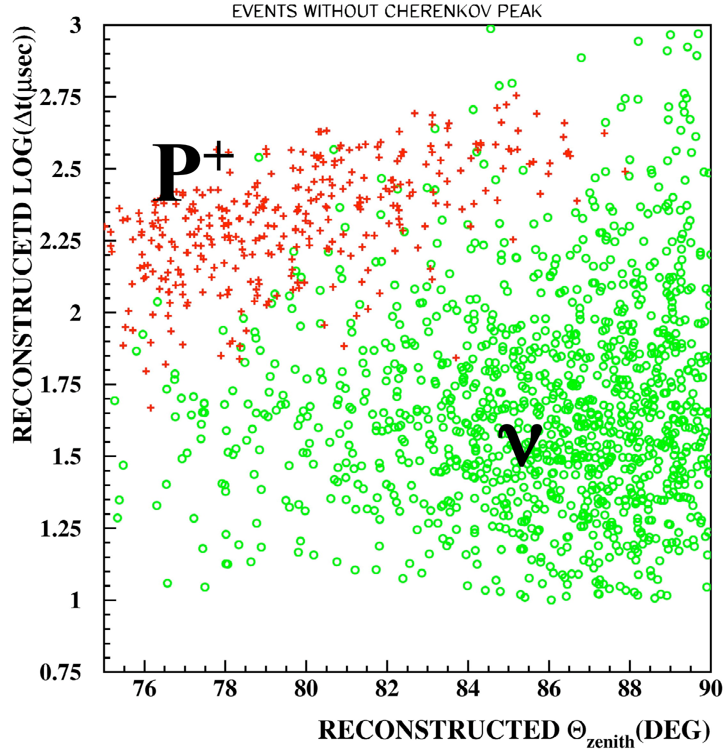


FLUORESCENT EVENTS : PROTON - NEUTRINO SEPARATION

golden **Xmax Select.**



Fluorescence only **Shape Select.**

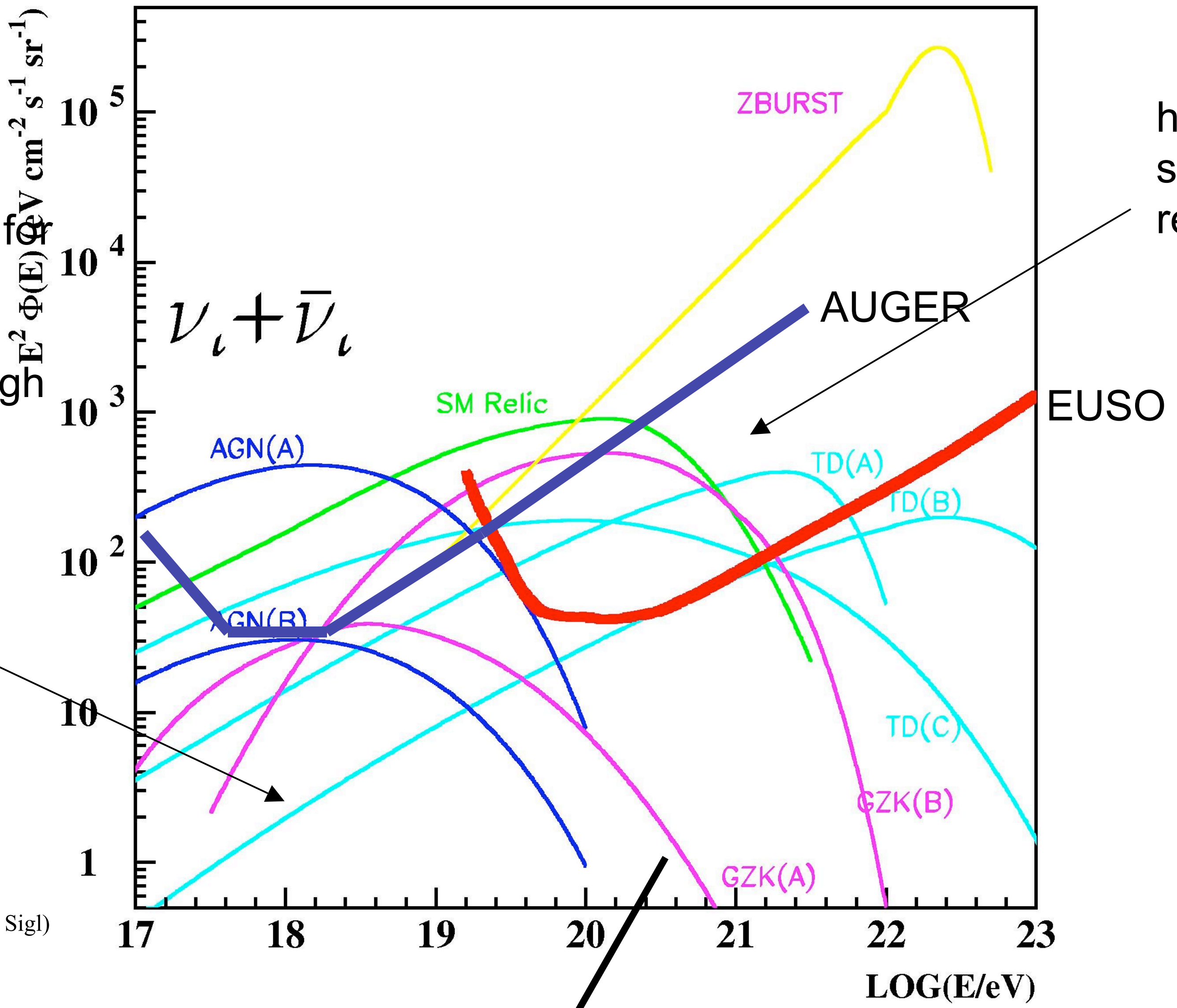


Rejection > 10^{-4}

(but for Ethr=10^{18}eV rejection>10^{-6} are needed)

EUSO redbook

10^{18} eV: region for 'safe' neutrino astronomy but requires very high rejection rate of protons and their 2ries



highly speculative region

(Kalashek, Kuzmin, Semokov, Sigl)

Phys. Rev. D66 2002

GZK (A) is the only one "guaranteed" flux of neutrinos …. ~0.3 events/year in EUSO

EXPLORATION 1c: Extra-dimension

Neutrino cross section gets very high if higher dimension → *O(1)*μb at 10^{20} eV

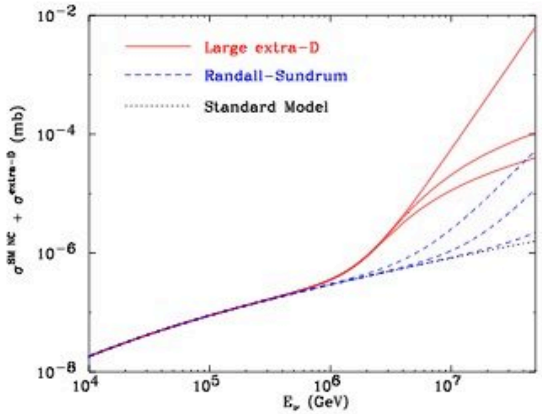
⋆ High-Energy Cosmic Neutrinos:

- HE νN scattering well-understood in the SM *

$$\sigma(\nu_L N) = \int dx \sum_f \tilde{\sigma}(\nu_L f)\ x f(x, Q^2)$$

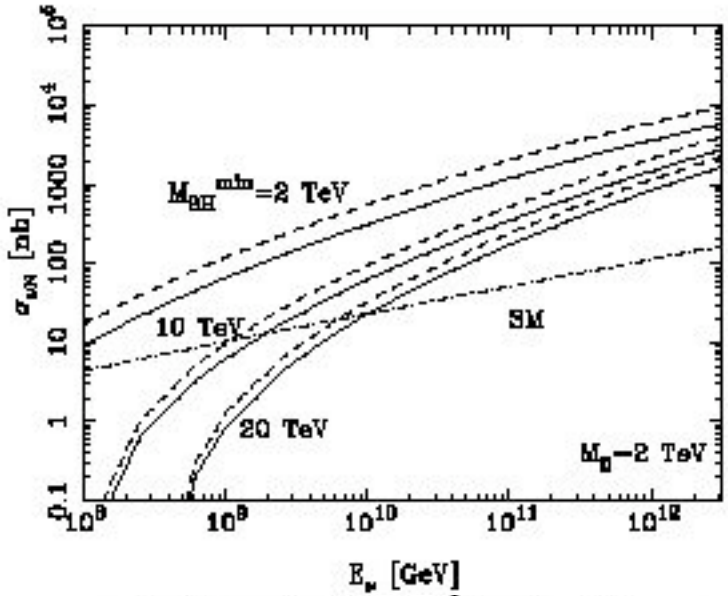
can be made use of to study physics beyond the SM:

$$Int.\ Length \sim \frac{1}{n_V \sigma_\nu}.$$



*R. Gandhi, C. Quigg, M.H. Reno, I. Sarcevic (1996, 1998); M.H. Reno, I. Sarcevic, G. Sterman, M. Stratmann, W. Vogelsang (2001).

Mary Hall 2005



In these mini-black hole calculations, one takes the neutrino-parton cross section to be

$$\hat{\sigma}(\nu j \to BH) = \pi R_s^2 \,|_{M_{BH}=\sqrt{\hat{s}}}\ \theta(\sqrt{\hat{s}} - M_{BH}^{\min}) \quad (11)$$

where the Schwarzschild radius R_S is given by

$$R_S = \frac{1}{M_D}\left[\frac{M_{BH}}{M_D}\left(\frac{2^n \pi^{\frac{n-3}{2}} \Gamma(\frac{3+n}{2})}{2+n}\right)\right]^{\frac{1}{1+n}} . \quad (12)$$

Anchordoqui, Feng, Goldberg, Shapere Phys Rev D65, 124027 (2002)

L A Anchordoqui *et al* JCAP06(2005)013; Randall-Sundrum scheme

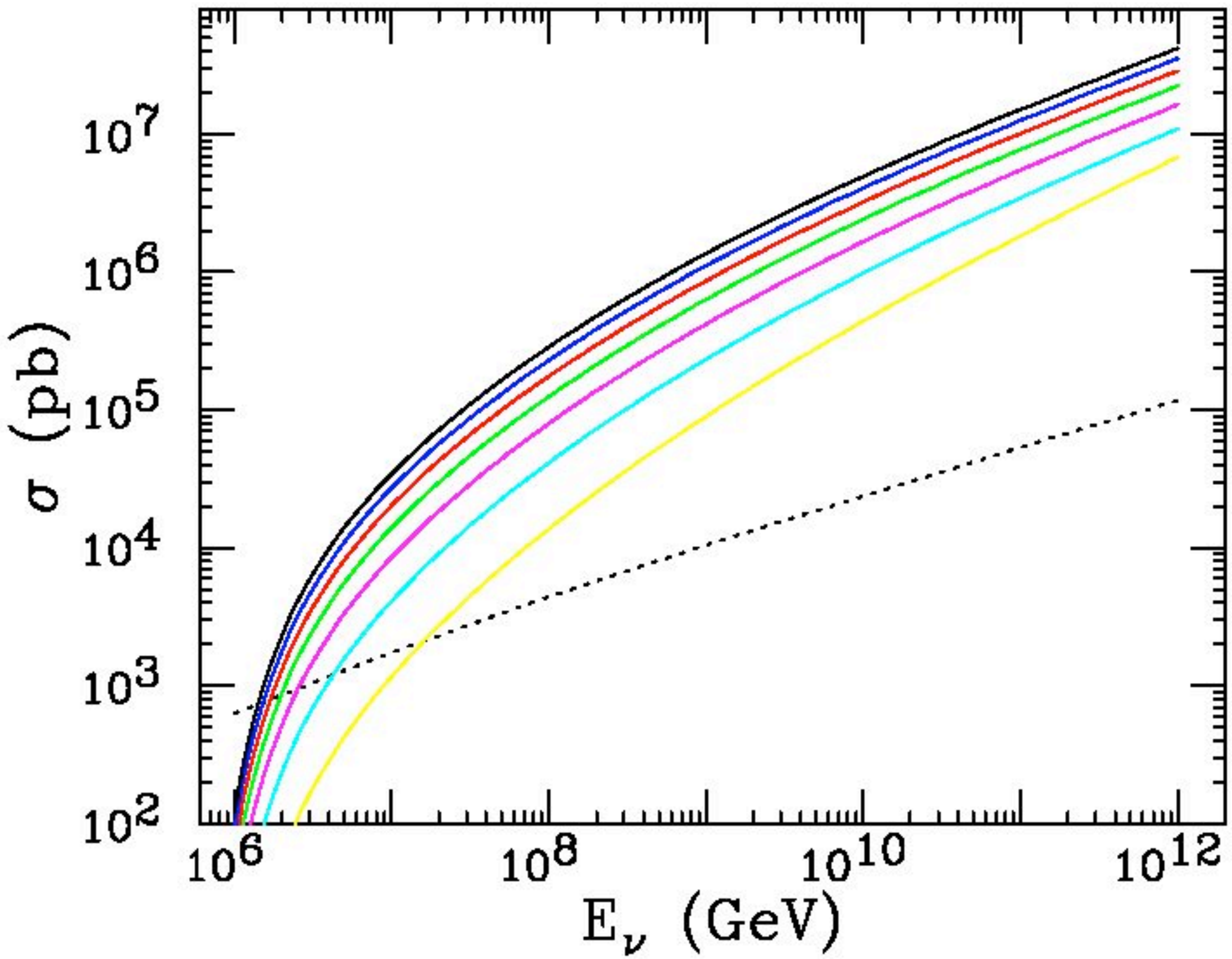
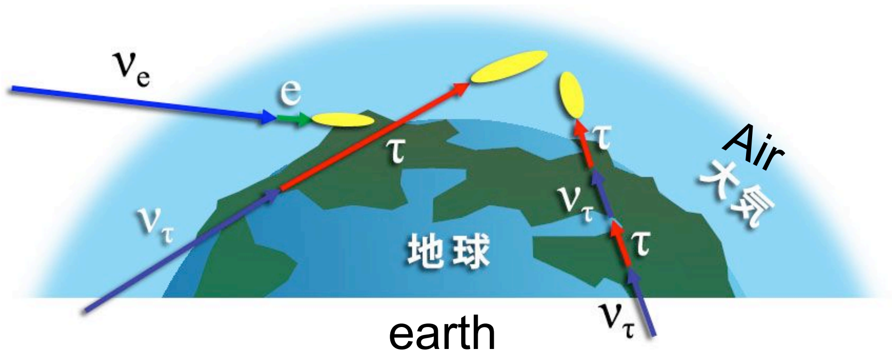
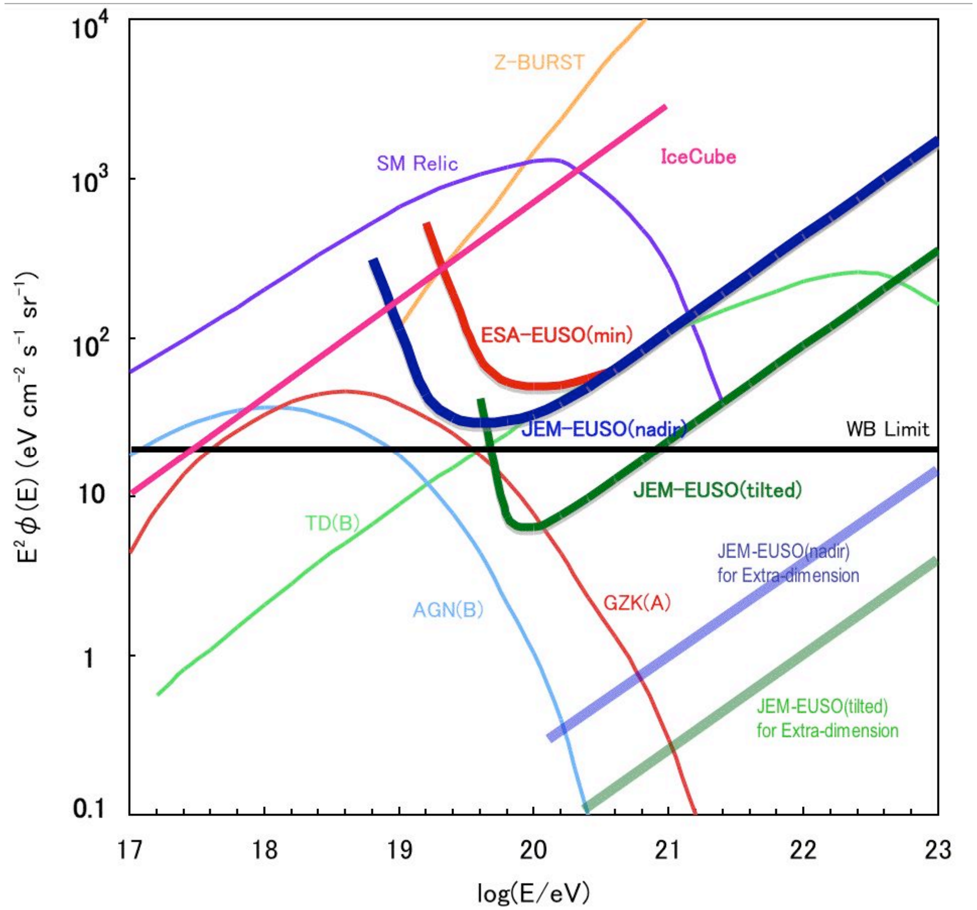


FIG. 28: Cross sections $\sigma_{\nu N \to BH}$ for $n = 1, \ldots, 7$ (bottom to top) for $M_D = 1$ TeV, $x_{min} = 1$. The SM cross section [124] is indicated with a dotted line. Published in Ref. [253].

Caution:
Hawking radiation hypothesis of BH is not firm and could be wrong,
→no observable increase of σ

JEM-EUSO maximum sensitivity for Neutrinos with extra* dimensions (preliminary; TBC)

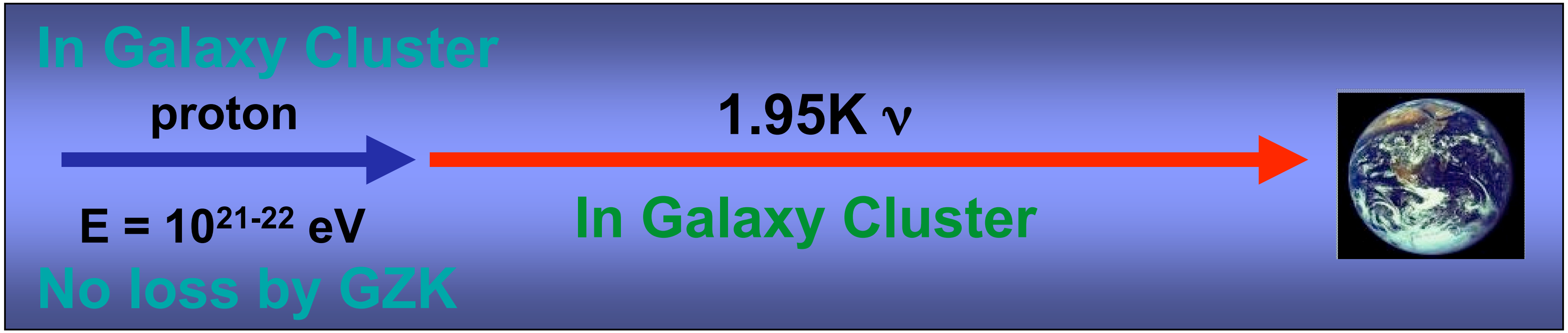




*Hundreds of neutrino events

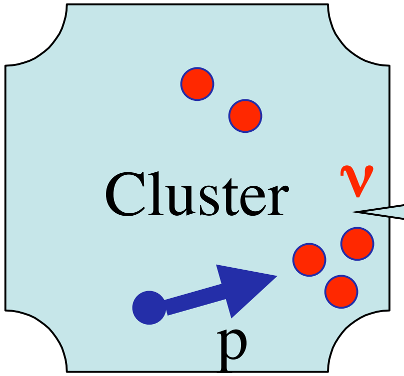
EXPLORATION 1b: BB Neutrinos

(2) BB relic neutrinos boosted to EHE by EHE protons



Cosmic Neutrino Background

$T\nu / T\gamma$
$= (4/11)^{1/3}$
$= 1.945\ K$



$n_{\nu 0} = (3/22) < n_{\gamma 0} > \xi$
$\approx 56 \times \xi$ neutrinos / cm^3

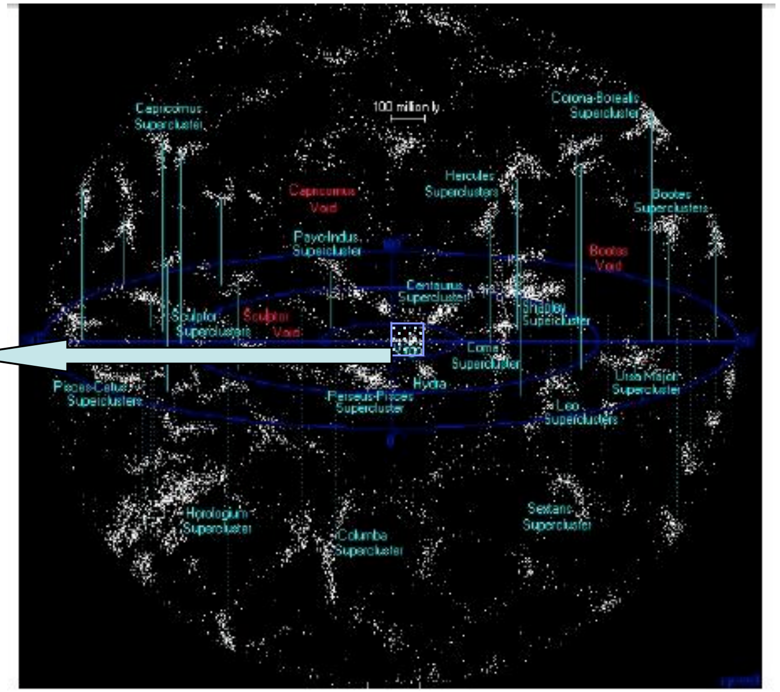


Figure 12: Various massive galaxy superclusters[66] in our "vicinity". The Milky Way is at the center of the coordinate system.

Big-bang Relic neutrinos

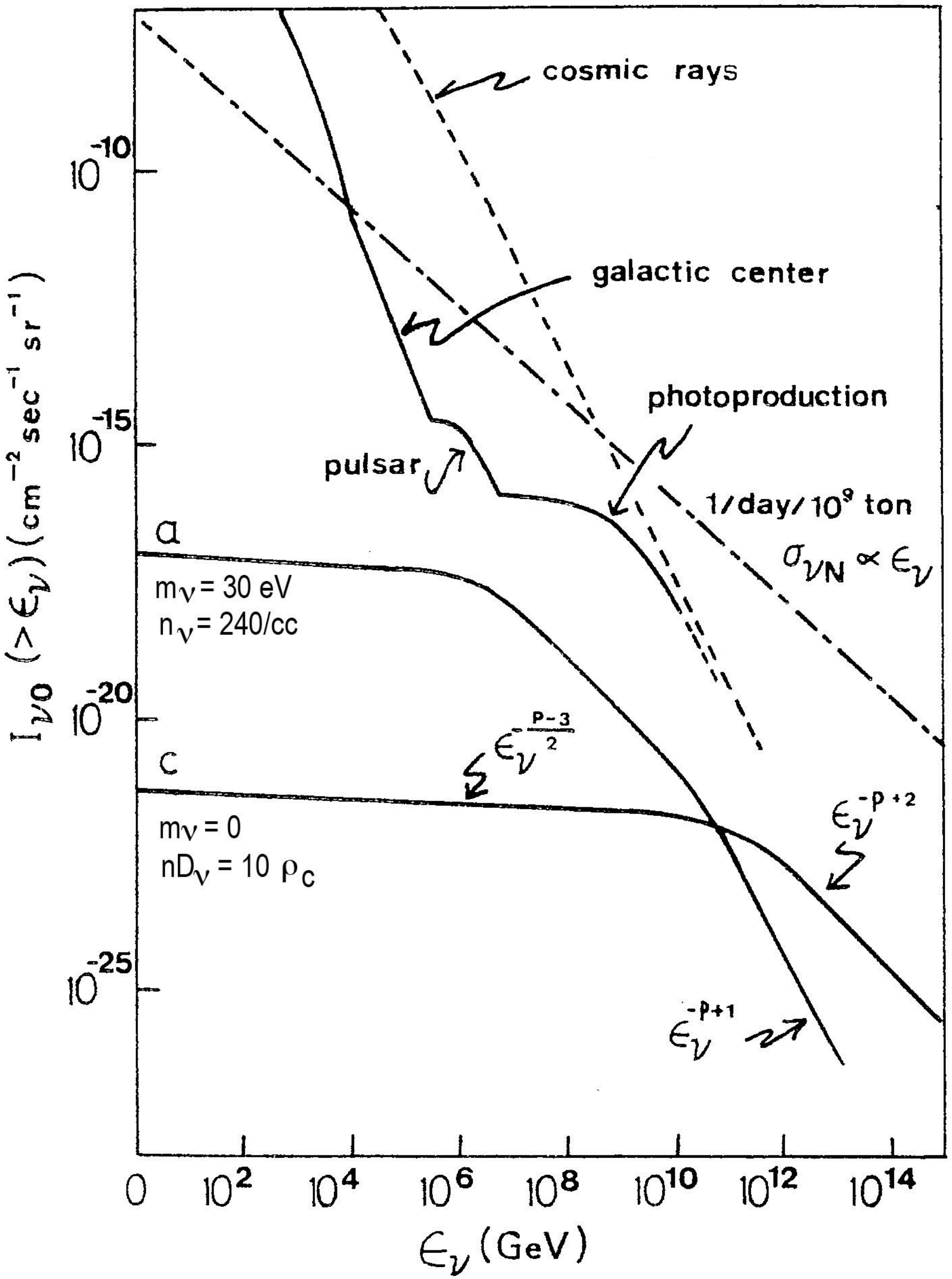
- Undiscovered "final holy grail" for BB model
  = Cosmic Relic ν's (1.95 K),

  should be kicked upward to EHE
  by pν elastic / inelastic back scattering

$$P_{EHE} + \nu_{1.95K} \rightarrow \nu_{EHE} + P$$

  in ν-rich (x10^2) and EHE-rich (x10^2) source region clusters

- It should become observable if 5 -11 dimension scenario is correct. Need testing

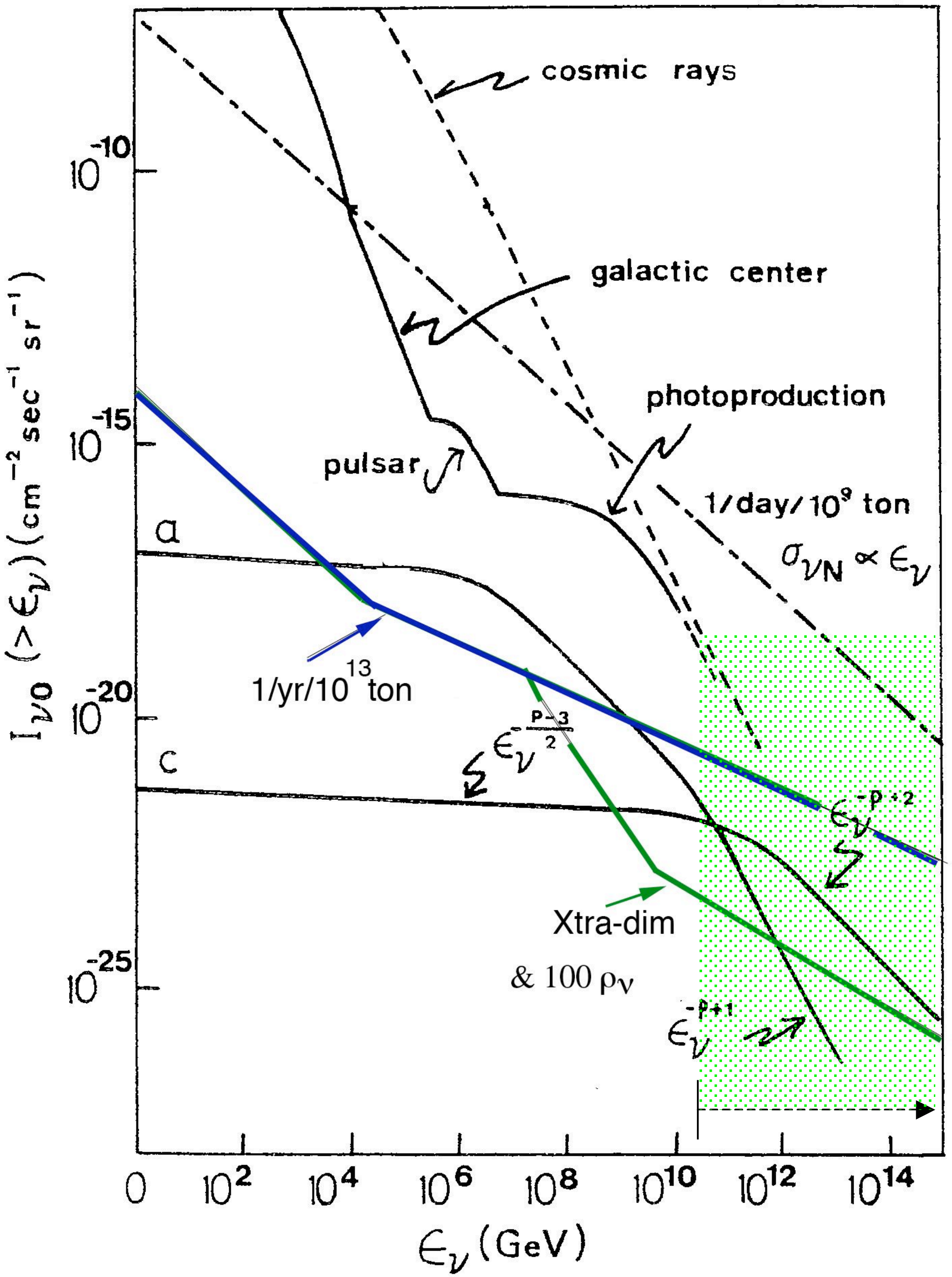


T. Hara and H. Sato

Prog. Theor. Phys. 64, 1089 (1980)

$$\frac{[Q(\epsilon_1)]_{\text{massive}}}{[Q(\epsilon_1)]_{\text{massless}}} = \frac{p+5}{2^{(p+5)/2}} \frac{(m_\nu c^2)^{(p+1)/2} n_0}{\int \epsilon^{(p+1)/2} n(\epsilon) d\epsilon}.$$

These spectra are correct for $\epsilon_1 < (m_p c^2)^2/\epsilon$. For higher energy, the spectral shape of $\epsilon_1^{-(p-1)/2}$ in (8) gradually changes



The comparison between the cases (A) and (C) is given for elastic scattering as

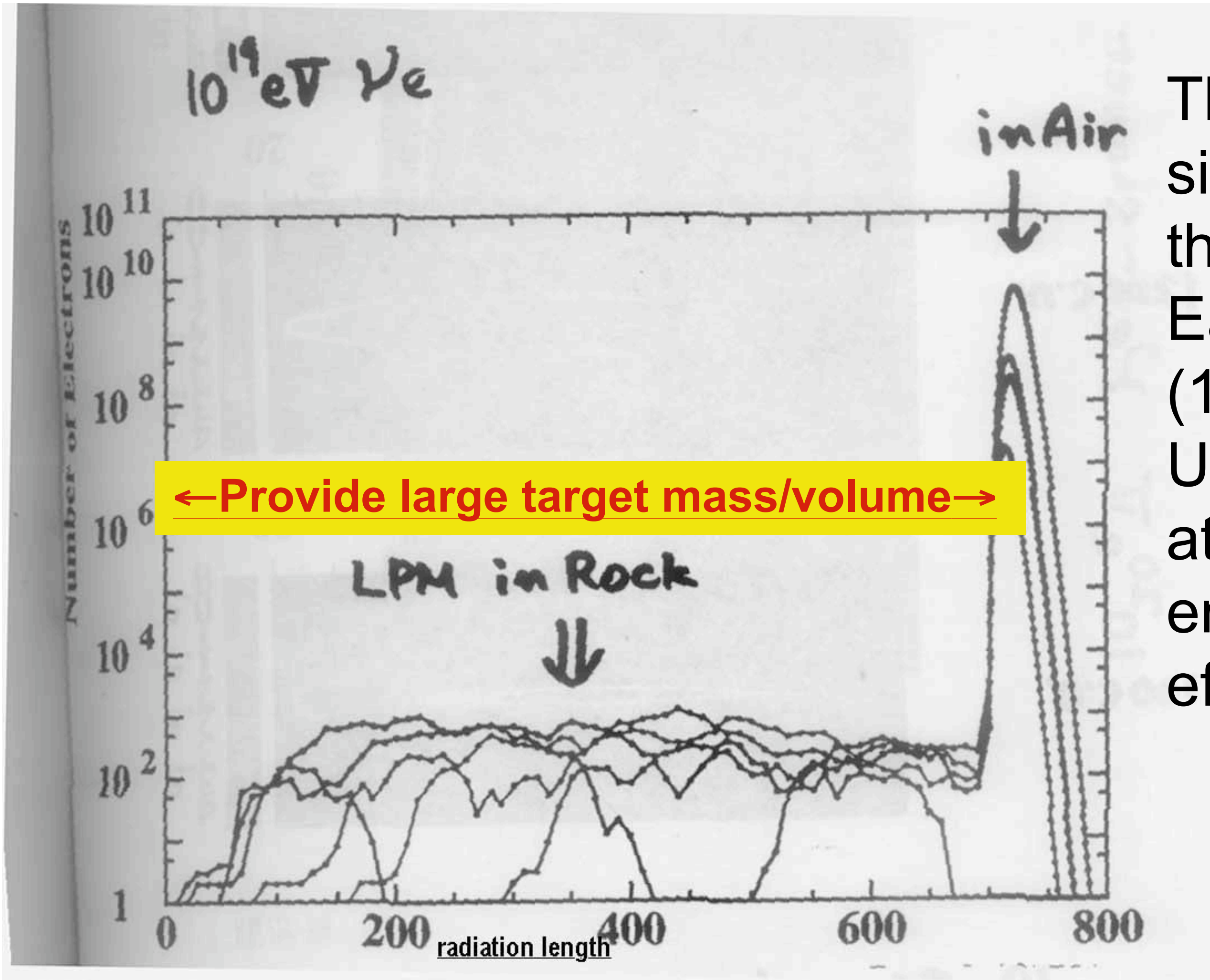
$$\frac{[I_{\nu 0}(>\epsilon_\nu)]_{\text{massive}}}{[I_{\nu 0}(>\epsilon_\nu)]_{\text{massless}}} = \frac{\rho_{m\nu}}{\rho_{D\nu}}\left(\frac{m_\nu c^2}{\epsilon_F}\right)^{(p-1)/2}.$$

Then, if $\rho_{m\nu}=\rho_{D\nu}$, the flux in the massive case is larger by $(m_\nu c^2/10^{-2}\text{eV})$ for $p=3$.

JEM-EUSO atmospheric can't see any relic ν's

But if extra-dimension is correct, JEM-EUSO'd see 10 - 30 relic ν's

Furthermore, there is a positive role of LPM for earth-skimming e-neutrinos



Kusano, Inoue (Saitama Univ., 2000)

The LPM effect would significantly increase the detectability of the Earth-skimming events (10^{19} - 10^{21} eV) and Upward neutrino events at 10^{16-19} eV by enhancement of ~ x 50 effective target.

JEM-EUSO would see more ν's.

JEM EUSO Science Summary

1. **EHE Astronomy is promising & robust**

2. **Neutrinos** and Super-LHC fundamental physics are in sight.

Techniques: Matured-tech, rapidly improving.

Ground Obs. (Auger/TA): needed and helping.

Carrying the heritage of AGASA/Hi-Res/TA/Auger into Space-era and making ISS having Frontier Astronomy / Astrophysics