SuperGZK NEUTRINOS $E_\nu > 1 \times 10^{20}$ eV:

TESTING PHYSICS BEYOND SM

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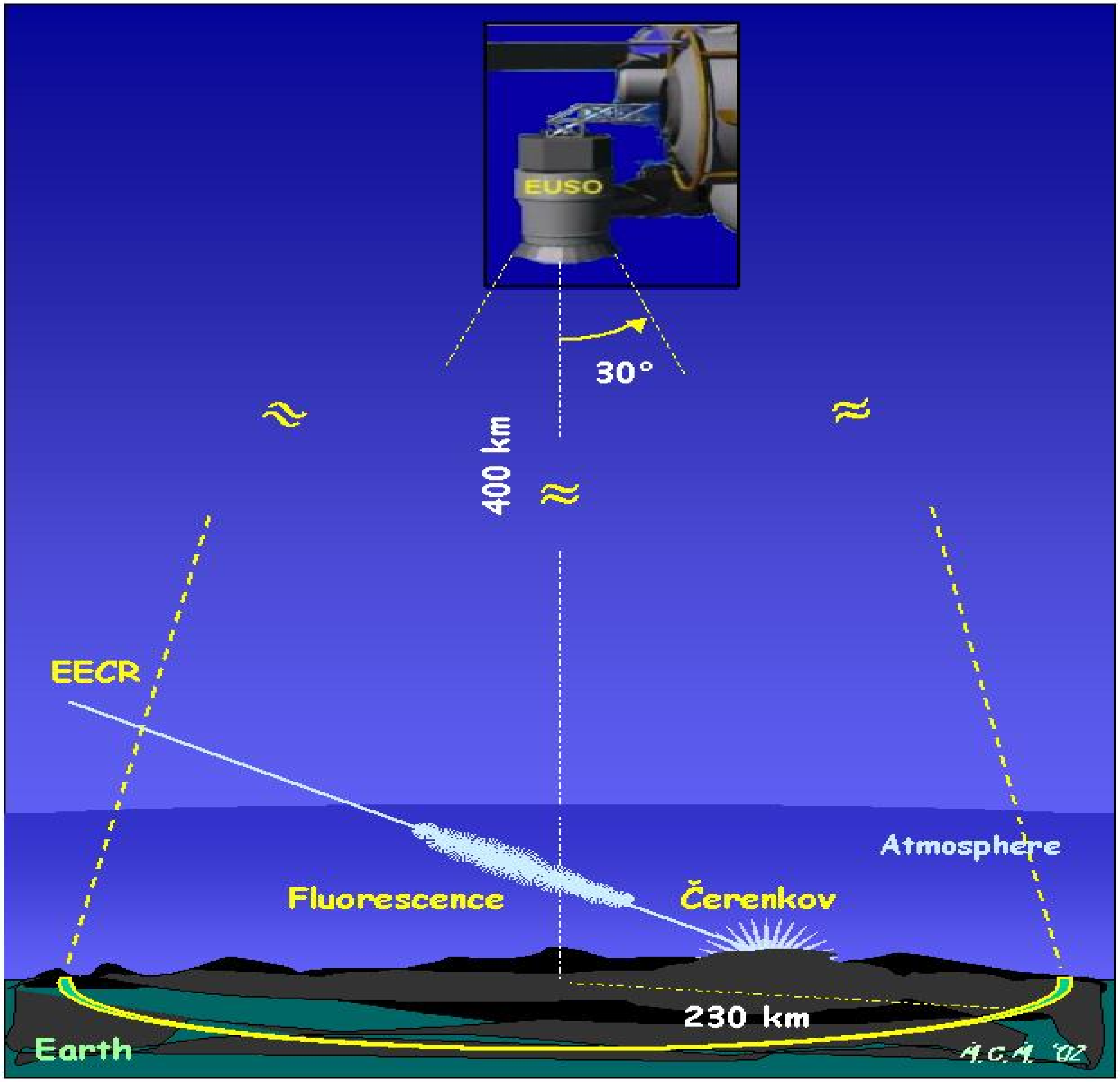
PROSPECTS for OBSERVATIONS

1. SPACE DETECTORS: EUSO and OWL



2. RADIO DETECTION

Askaryan effect (1962): coherent radio-emission by excess of electrons in a shower.

GLUE: Radio from the Moon.
RICE/ANITA: Radio from Antarctic ice.
FORTE: satellite observation of the Greenland ice.

COMMON FEATURES:

- High energy detection threshold $E > (1 - 100) \times 10^{20}$ eV.
- Low-flux detection (very large effective mass).

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MOTIVATION: A crazy theory (theorist) will always be available!

GENERATION of superGZK NEUTRINOS

- COSMOGENIC ($p\gamma$) NEUTRINOS $E_\nu \sim (1-10)\times 10^{20}$ eV
- PHYSICS BEYOND STANDARD MODEL: $E_\nu > 1\times 10^{21}$ eV.

Acceleration to $E_p \gtrsim 1\times 10^{22}$ eV is a challenge for astrophysics.
TDs and SHDM provide naturally these energies:

- Decay of superheavy particles (DM and TD) : $E_\nu \lesssim 0.1 m_X$, m_X up to $M_{\rm GUT}$.
- Annihilation of monopoles connected by strings, e.g. necklaces.

$$M + \bar{M} \to A_\mu, H \to \text{pions} \to \text{neutrinos}$$

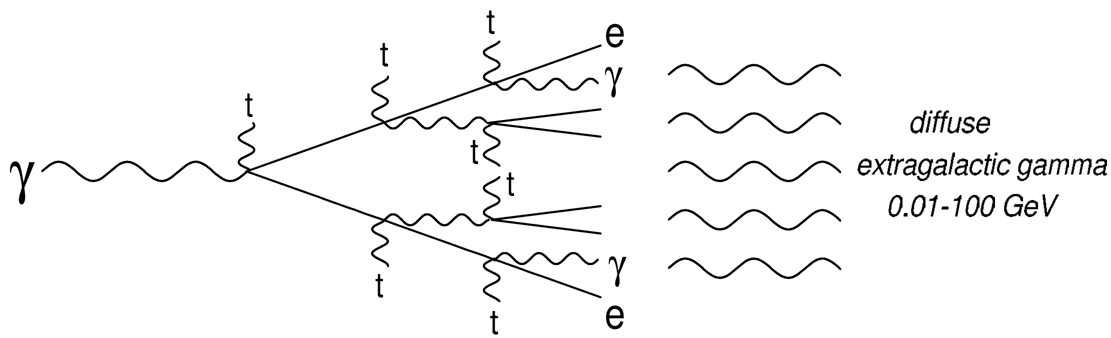
- Radiation by monopoles in network
  Emission of gauge bosons by accelerated monopoles.
  $E_\nu \sim \Gamma a$, can reach $M_{P\ell}$
- Cusps in superconducting strings

CASCADE UPPER LIMIT

V.B. and A.Smirnov 1975

e-m cascade on target photons:

$$\gamma + \gamma_{\rm tar} \to e^+ + e^-$$
$$e + \gamma_{\rm tar} \to e' + \gamma'$$



EGRET: $\omega_\gamma^{\rm obs} \sim (2-3) \times 10^{-6} {\rm eV/cm}^3$.

$$\omega_{\rm cas} > \frac{4\pi}{c}\int_E^\infty E J_\nu(E) dE > \frac{4\pi}{c} E \int_E^\infty J_\nu(E) dE \equiv \frac{4\pi}{c} E J_\nu(>E)$$

$$E^2 I_\nu(E) < \frac{c}{4\pi}\omega_{\rm cas.}$$

COSMOGENIC NEUTRINOS

$$p+\gamma_{CMB}\rightarrow\pi^{\pm}\rightarrow neutrinos$$

COSMIC RAYS AT ULTRA HIGH ENERGIES (NEUTRINO?)

V. S. BERESINSKY and G. T. ZATSEPIN
Academy of Sciences of the USSR. Physical Institute. Moscow

Received 8 November 1968

The neutrino spectrum produced by protons on microwave photons is calculated. A spectrum of extensive air shower primaries can have no cut-off at an energy $E > 3\times10^{19}$ eV. if the neutrino-nucleon total cross-section rises up to the geometrical one of a nucleon.

Greisen [1] and then Zatsepin and Kusmin [2] have predicted a rapid cut-off in the energy spectrum of cosmic ray protons near $E{\sim}3\times10^{19}$ eV because of pion production on 2.7° black body radiation. Detailed calculations of the spectrum were made by Hillas [3]. Recently there were observed [4] three extremely energetic extensive air showers with an energy of primary particles exceeding 5×10^{19} eV. The flux of these particles turned out ot be 10 times greater than according to Hillas' calculations.

In the light of this it seems to be of some interest to consider the possibilities of absence of rapid (or any) fall in the energy spectrum of showerproducing particles. A hypothetic possibility we shall discuss* consists of neutrinos being the showerproducing particles at $E > 3\times10^{19}$ eV due to which the energy spectrum of shower producing particles cannot only have any fall but even some flattening.

The neutrinos under consideration are originated in decays of pions, which are generated in collisions of cosmic ray protons with microwave

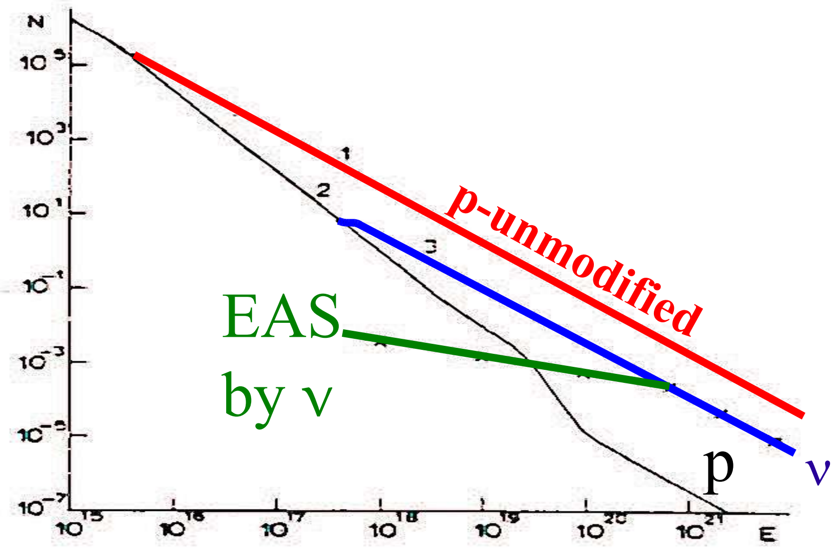


Fig. 1.

$$J_{\nu}(E)=\frac{2}{3}3\left(\frac{E_{\nu}}{E_{p}}\right)^{\gamma_g-1}\frac{1}{1-\alpha^{\gamma_g-1}}\quad J_p^{unm}(E)$$

$$\frac{E_{\nu}}{E_{p}}\approx\frac{0.2}{4}=0.05$$

RECENT WORKS

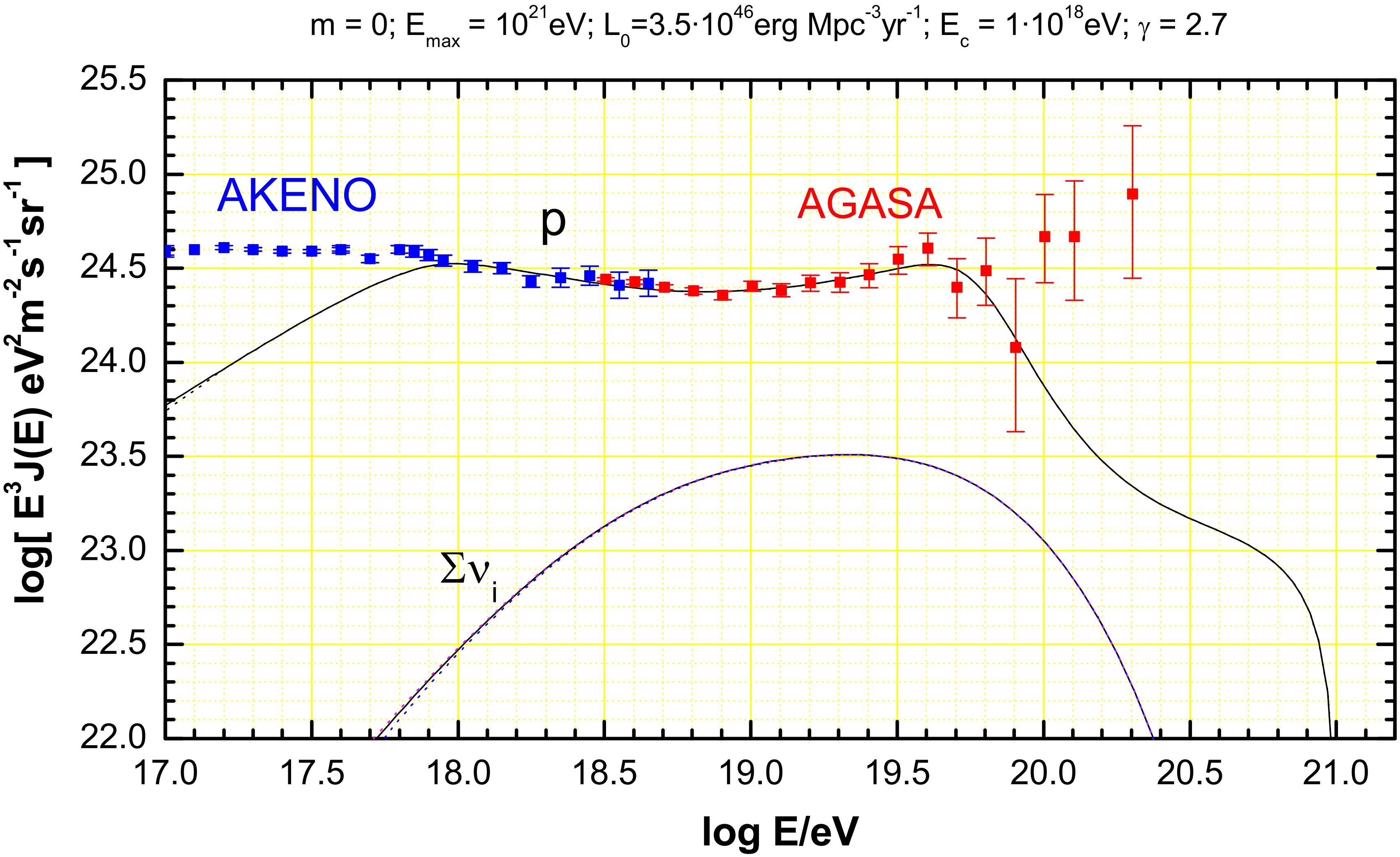
- Engel, Seckel, Stanev 2001
- Kalashev, Kuzmin, Semikoz, Sigl 2002
- Fodor, Katz, Ringwald , Tu 2003
- VB, Gazizov, Grigorieva 2003

APPROACH and RESULTS:

- Normalization to the observed UHECR flux
- Neutrino flux is SMALL in non-evolutionary models with $E_{\rm max} \leq 10^{21}$ eV
- Neutrino flux is LARGE in evolutionary models with $E_{\rm max} \geq 10^{22}$ eV

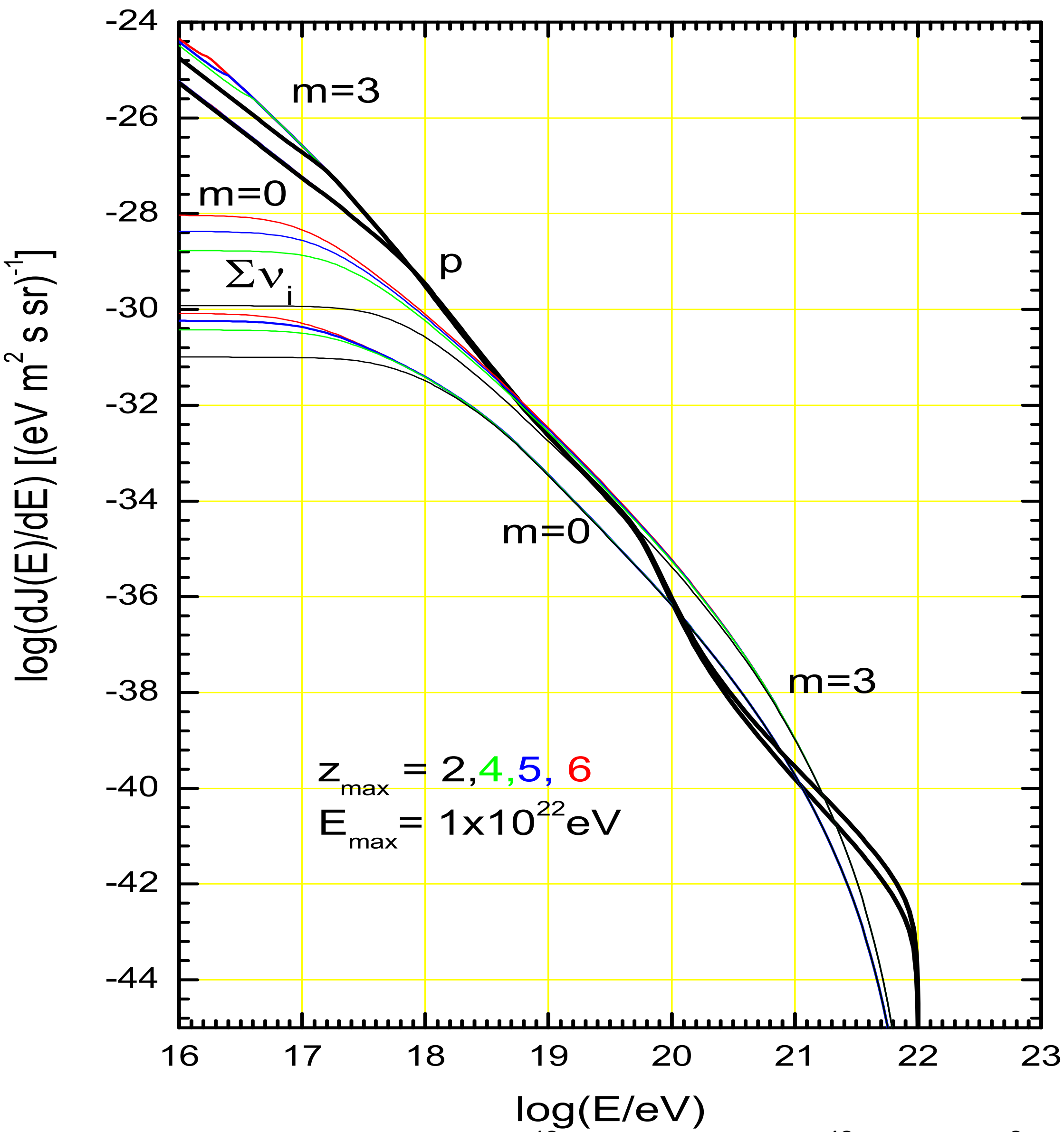
The BGG model for UHECR

LOW ENERGY LIMIT FOR COSMOGENIC NEUTRINOS



The observed UHECR flux does not guarantee the detectable UHE neutrino flux

COSMOGENIC NEUTRINOS IN BGG MODELS



m=0: γ=2.7; E_c=1x10^{18}eV; L_0= 3.5x10^{46}erg Mpc^{-3}yr^{-1}

m=3: γ=2.5; E_c=3x10^{17}eV; L_0= 2.5x10^{46}erg Mpc^{-3}yr^{-1}

UHE NEUTRINOS FROM SUPERHEAVY DARK MATTER

- **PRODUCTION: many efficient mechanisms at post-inflationary epochs, most attractive one is production in time-varying gravitational field. Creation occurs when $H(t) \sim m_X$. Since $H(t) \leq m_\phi \sim 10^{13}$ GeV:**

$$m_X \sim 10^{13}\ \mathrm{GeV}.$$

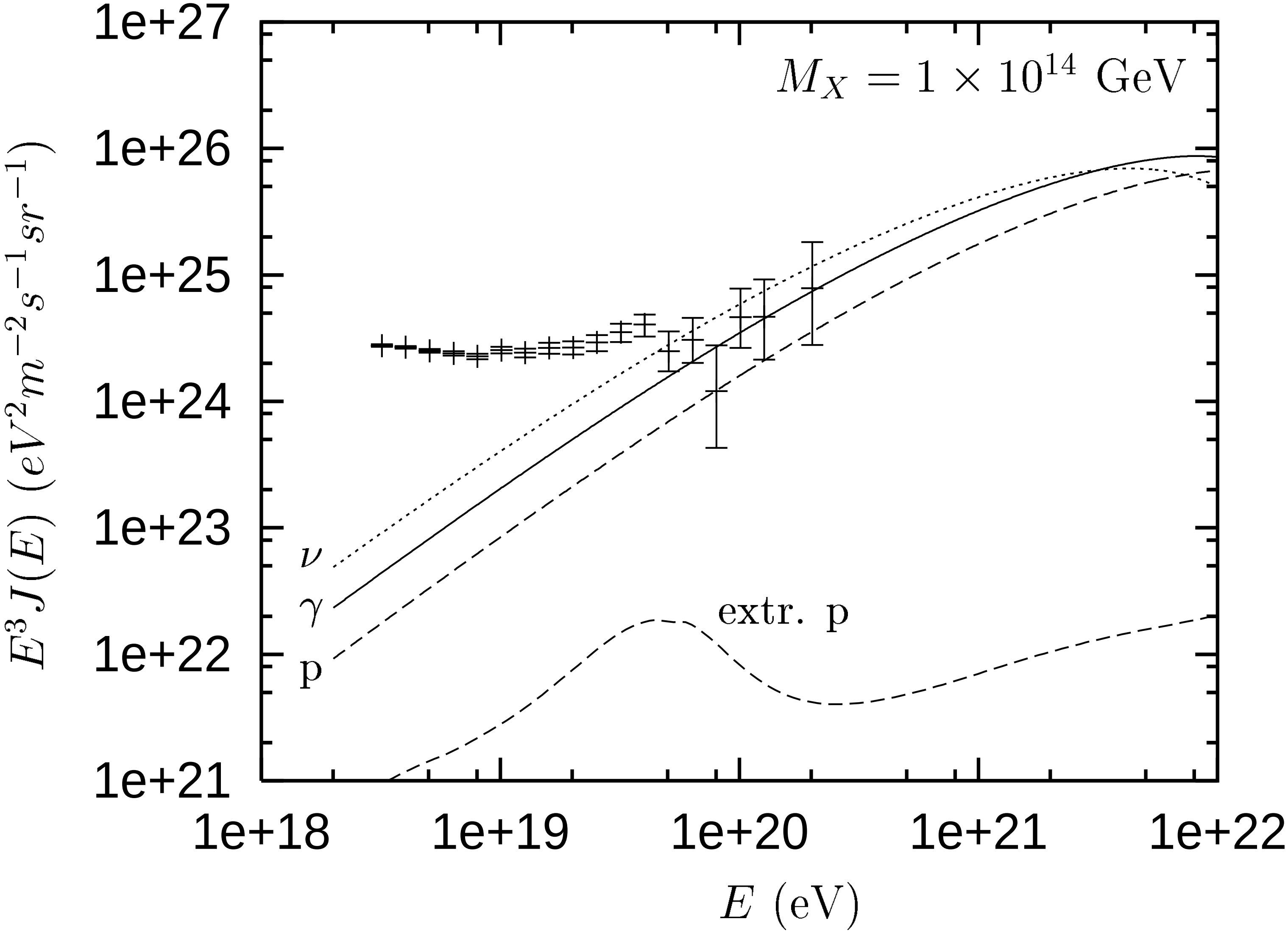
  e.g. $m_X \sim 3 \times 10^{13}$ GeV results in $\Omega_X h^2 \sim 0.1$.

- **LONGEVITY OF SHDM PARTICLES.**
  Discrete gauge symmetry protection, like R-parity for neutralino. Decay is provided by superweak effects: wormhole, high dimension operators etc.

- **ACCUMULATION IN THE GALACTIC HALO.**
  Like for any DM, overdensity=2.1$\times 10^5$.

- **X-PARTICLE DECAY.**
  Ratio of fluxes $\nu : \gamma : p \approx 4 : 2 : 1$,
  Energy spectrum: $J_{\mathrm{SHDM}}(E) \propto E^{-\gamma_g}$, with $\gamma_g \approx 1.94$.

UHE NEUTRINOS FROM SHDM



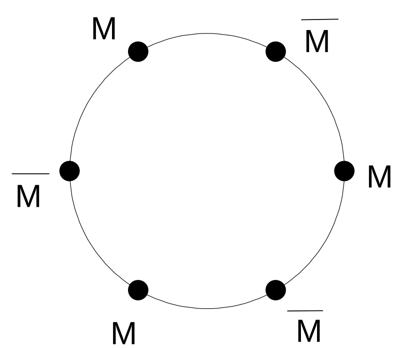
UHE NEUTRINOS FROM TOPOLOGICAL DEFECTS

Symmetry breaking in early universe results in phase transitions, which are accompanied by Topological Defects.

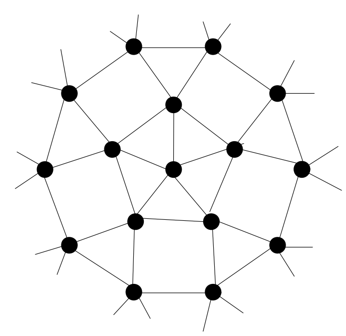
TDs OF INTEREST FOR UHE NEUTRINOS.

- **Monopoles:** $G \to H \times U(1)$
- **Ordinary strings:** $U(1)$ **breaking**
- **Superconducting strings:** $U(1)$ **breaking**
- **Monopoles connected by strings:** $G \to H \times U(1) \to H \times Z_n$
  e.g. necklaces $Z_n = Z_2$.

NECKLACE



MS NETWORK



NECKLACES

V.B., A.Vilenkin, PRL 79, 5202, 1997

$$G \underset{\eta_m}{\rightarrow} H \times U(1) \underset{\eta_s}{\rightarrow} H \times Z_2$$

mass of monopole: $m = 4\pi\eta_m/e$, tension: $\mu = 2\pi\eta_s^2$

Due to gravitational radiation, strings shrink, and monopoles inevitably annihilate.

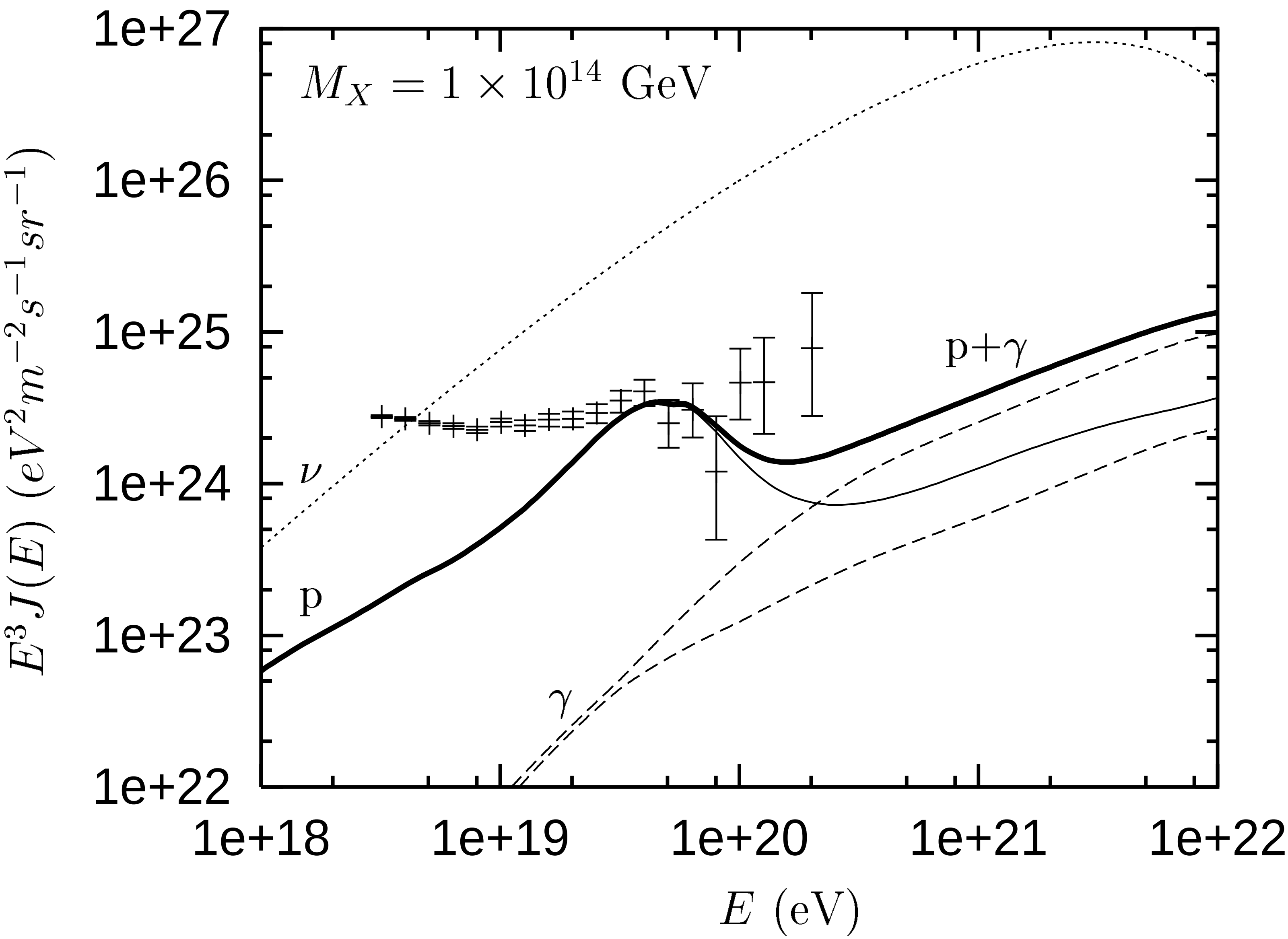
$$M + \bar{M} \rightarrow A_\mu, H \rightarrow \text{pions} \rightarrow \text{neutrinos}$$

Production rate of X-particles: $\dot{n}_X \sim r^2\mu/t^3 m_X$, where $r = m/\mu d$.
Energy density $\omega \sim m_X \dot{n}_X t$ must be less 2×10^{-6} eV/cm^3 (EGRET).

$$r^2\mu \leq 8.5 \times 10^{27}\ \text{GeV}^2$$

Neutrino energy: $E_\nu^{\max} \sim 0.1 m_X \sim 10^{13}(m_X/10^{14})$ GeV

UHE NEUTRINOS FROM NECKLACES



MONOPOLES CONNECTED BY STRINGS

V.B., X.Martin, A.Vilenkin, PR D56, 2024, 1997

$$G \underset{\eta_m}{\rightarrow} H \times U(1) \underset{\eta_s}{\rightarrow} H \times Z_N$$

Due to cosmological evolution monopoles become relativistic at $t \sim t_0$: $\Gamma_0 \gg 1$.

Monopoles oscillate due to $f = \mu$ and obtain a proper acceleration $a_{\max} = \frac{2}{3\sqrt{3}}\Gamma_0^2\Omega$.

In case $a \gg m_X$ (m_X is the boson mass) accelerated monopoles can radiate the massive gauge bosons with

$$P = \frac{g^2}{16\sqrt{6}\pi^2}\Gamma_0^3\Omega^2,$$

$$E_{\max} = \Gamma_0 a_{\max} = \frac{\pi^2}{3}\Gamma_0^3\Omega$$

$E_{\max}$ REACHES THE PLANCKIAN SCALE !

UHE MIRROR NEUTRINOS

1. CONCEPT OF MIRROR MATTER

Mirror matter is based on the theoretical concept of the space reflection, as first suggested by Lee and Yang (1956) and developed by Landau (1956), Salam (1957), Kobzarev, Okun, Pomeranchuk (1966) and Glashow (1986, 1987).

Extended Lorentz group includes reflection: $\vec{\mathbf{x}} \to -\vec{\mathbf{x}}$.
In particle space it corresponds to **inversion** operation I_r.
Reflection $\vec{x} \to -\vec{x}$ and time shift $t \to t + \Delta t$ commute as coordinate transformations.
In the particle space the corresponding operators must commute, too:

$$[\mathcal{H}, I_r] = 0.$$

Hence, I_r must correspond to the conserved value.

- Lee and Yang: $I_r = P \cdot R$, where R transfers particle to mirror particle:

$$I_r \Psi_{\rm L} = \Psi'_{\rm R} \quad \text{and} \quad I_r \Psi_{\rm R} = \Psi'_{\rm L}$$

- Landau: $I_r = C \cdot P$, where C transfers particle to antiparticle.

2. OSCILLATION OF MIRROR AND ORDINARY NEUTRINOS

Kobzarev, Pomeranchuk, Okun suggested that ordinary and mirror sectors communicate only gravitationally.

COMMUNICATION TERMS include EW SU(2) singlet interaction term:

$$\mathcal{L}_{\rm comm} = \frac{1}{M_{\rm Pl}}(\bar{\psi}_L\phi)(\psi'_R\phi') \tag{1}$$

where $\bar{\psi}_L = (\bar{\nu}_L,\ \bar{\ell}_L)$ and $\phi = (\phi_0^*,\ -\phi_+^*)$.
After SSB, Eq.(1) results in mixing of ordinary and mirror neutrinos.

$$\frac{v_{\rm EW}^2}{M_{\rm Pl}}\bar{\nu}_L\nu'_R,$$

with $\mu \equiv v_{\rm EW}^2/M_{\rm Pl} = 2.5\cdot 10^{-6}$ eV.

It implies oscillations between ν and ν'.

Berezhiani, Mohapatra (1995) and Foot, Volkas (1995).

3. UHE NEUTRINOS FROM MIRROR TDs

In two-inflatons scenario with curvature-driven phase transition (V.B. and Vilenkin 2000) there can be:

$$\rho'_{\rm matter} \ll \rho_{\rm matter}, \quad \rho'_{\rm TD} \gg \rho_{\rm TD}$$

HE mirror ν's are produced by mirror TDs and oscillate into visible ν's.
All other HE mirror particles which accompany neutrino production remain invisible.

The upper limit on HE neutrino flux, due to

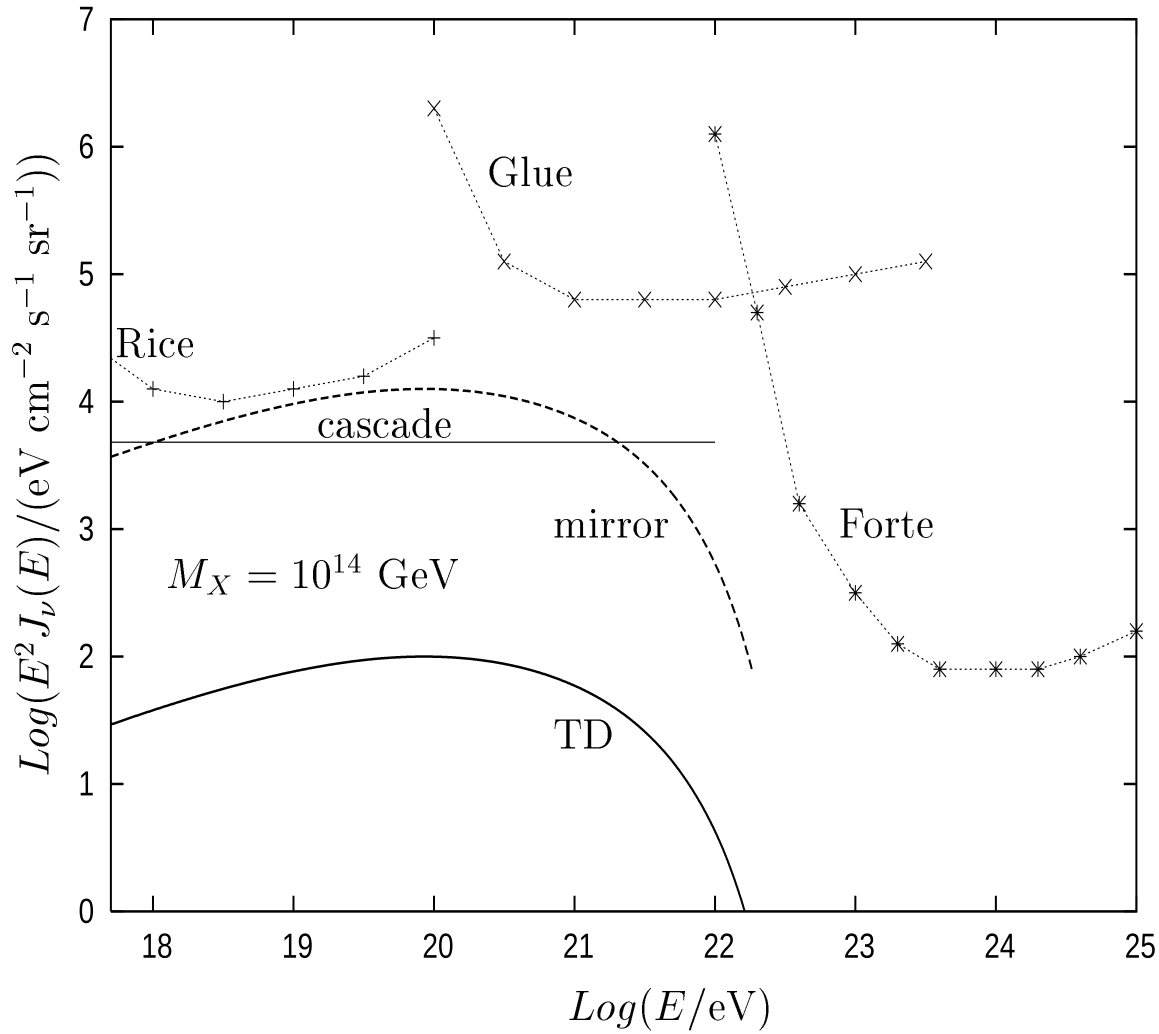
$$\nu + \nu_{\rm DM} \to Z^0 \to e, \gamma \to {\rm cascade}$$

is very weak.

It can be constrained only observationally (e.g. by GLUE, RICE, FORTE).

Signature: diffuse flux exceeds cascade upper limit.

UHE NEUTRINOS FROM MIRROR TDs



CONCLUSIONS

ACCELERATOR (COSMOGENIC) NEUTRINOS

- **Energies are up to $E_\nu \sim 1 \times 10^{21}$ eV. Acceleration to $E_p^{\rm max} \sim 1 \times 10^{22}$ eV is a problem in astrophysics.**
- **The observed UHECR flux does not guarantee the detectable flux of superGZK neutrinos.**
- **SuperGZK neutrino fluxes are detectable in case of evolutionary sources with $E_p \gtrsim 1 \times 10^{22}$ eV**
- **They are small/undetectable in case of non-evolutionary sources with $E_p \leq 1 \times 10^{21}$ eV.**

NON-ACCELERATOR NEUTRINOS

- **SHDM can produce neutrinos with energies $E_\nu \gtrsim 1 \times 10^{22}$ eV and with fluxes of order of the observed UHECR at $E \sim 10^{20}$ eV.**
- **TDs, e.g. necklaces, monopole-string network, cusps of superconducting strings etc, can produce large fluxes of superGZK neutrinos with energies $E_\nu > (1 - 100) \cdot 10^{20}$ eV and up to $E_{\rm Pl}$.**

FLUX UPPER LIMIT

In all above cases the diffuse flux is constrained by the cascade upper limit:

$$I_\nu(E) \le \frac{c}{4\pi}\frac{\omega_{\rm cas}}{E^2}, \quad \text{or } I_\nu(>E) \le 10\,{\rm km}^{-2}{\rm yr}^{-1}{\rm sr}^{-1}E_{20}^{-1}$$

MIRROR superGZK NEUTRINOS

The energies can be very large with flux unconstrained by ordinanary cascade upper limit