Ultra-high energy extragalactic neutrinos interacting with ultra-light dark matter

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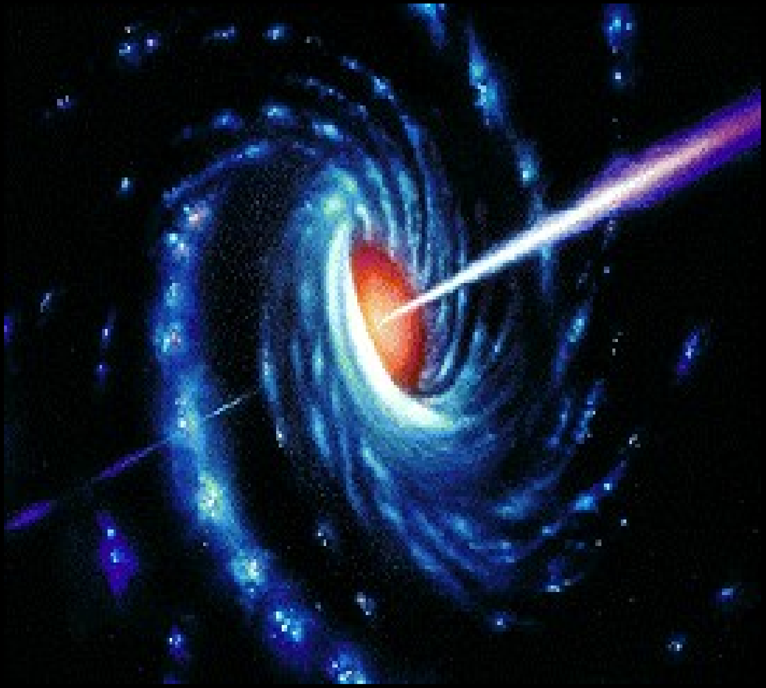
UHE Cosmic Rays' Origin

Topological Defects → Super massive particles decay

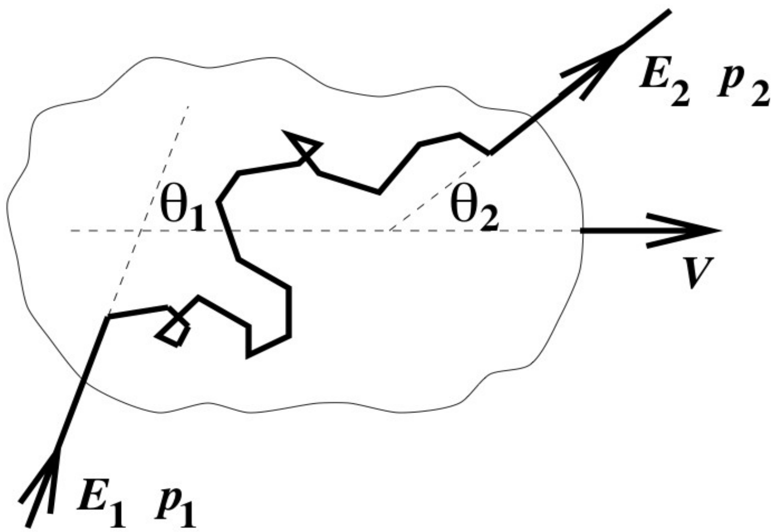
Active Galactic Nuclei; Gamma Ray Bursts → First order Fermi mechanism

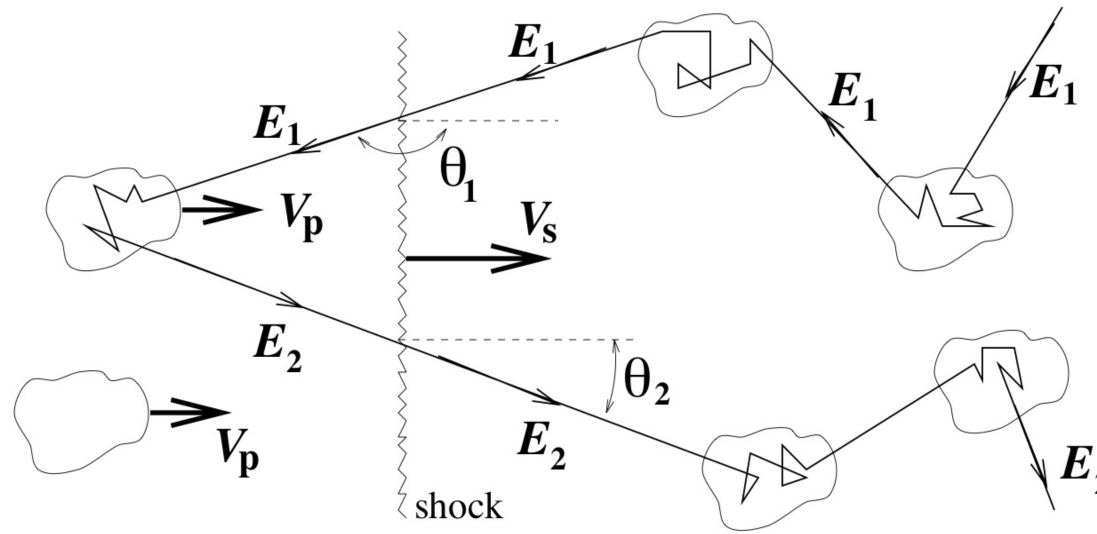


$$E < eZ\,B\,R$$

$$\theta \sim eZBD/E$$

Acceleration Mechanisms





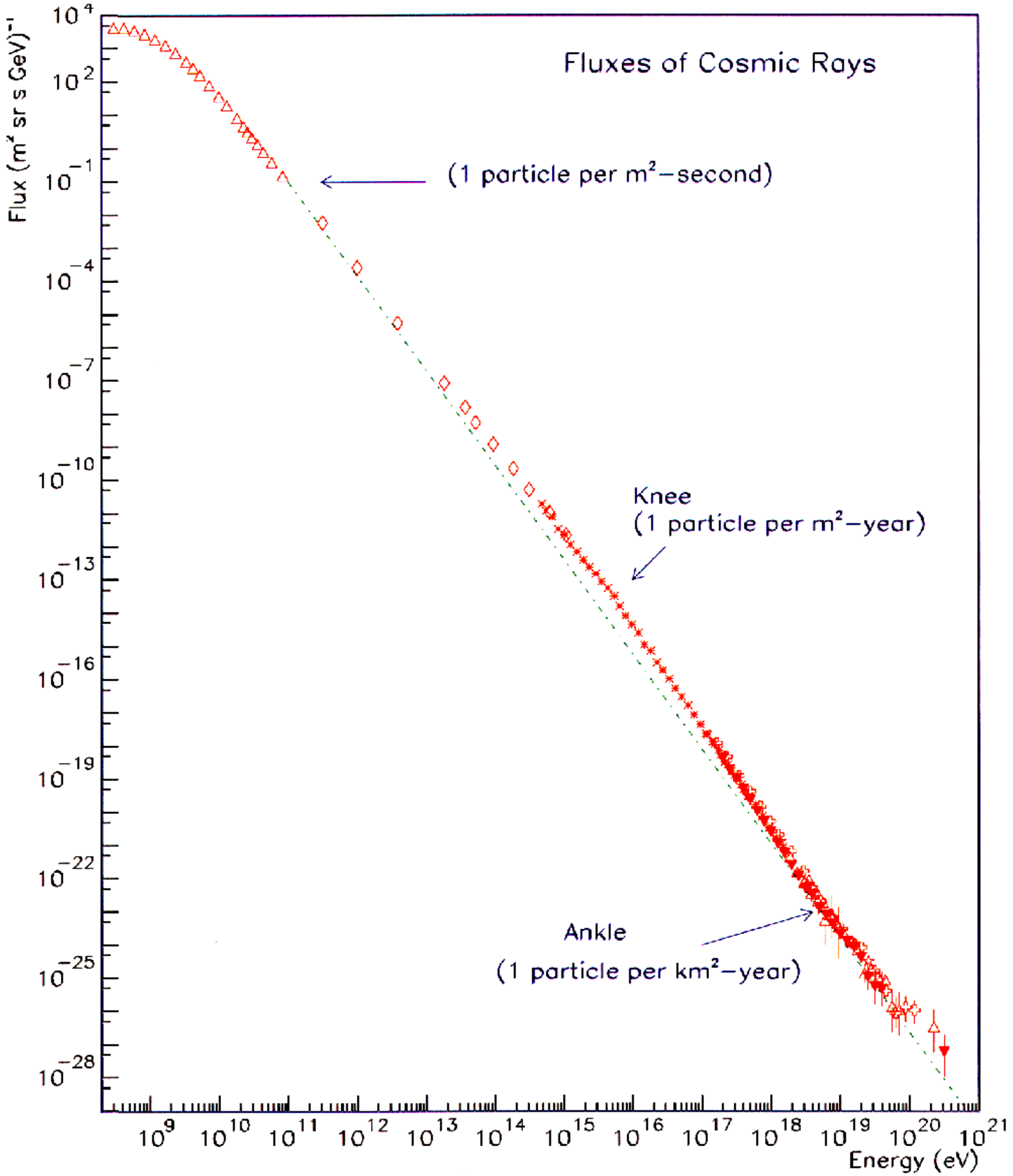
$$\frac{\langle \Delta E \rangle}{E} \sim \beta^2$$

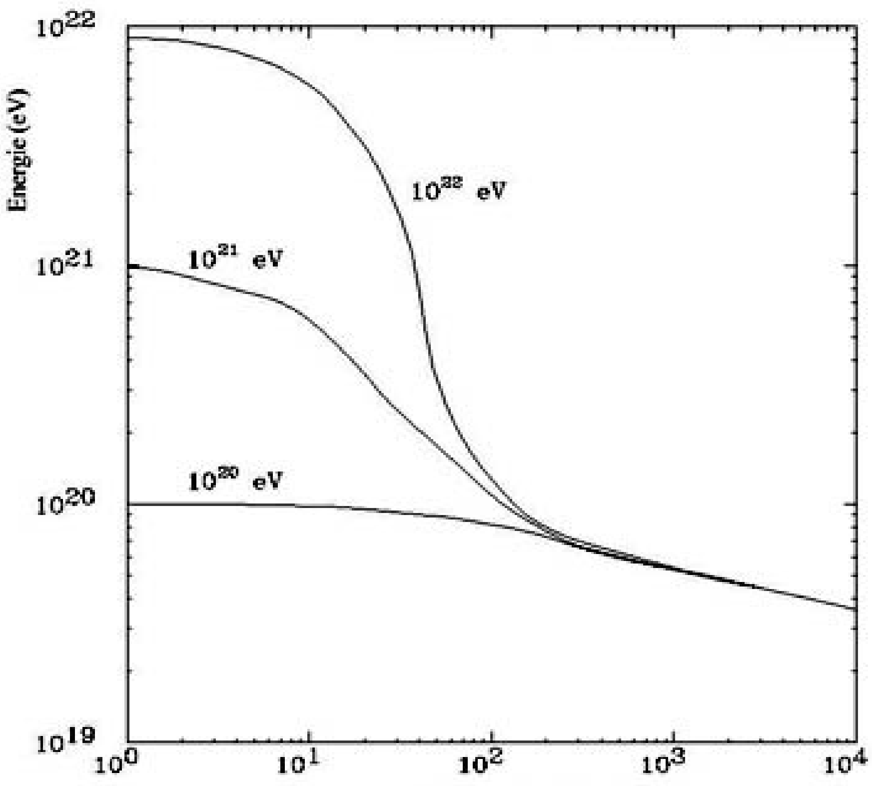
$$\frac{\langle \Delta E \rangle}{E} \sim \beta$$

Mecanismo (original) de aceleração de Fermi (de segunda ordem).

Mecanismo de aceleração de Fermi de primeira ordem.

Neutrinos and Cosmic Rays





Distancia (Mpc)

$$4\,E\,\epsilon \quad > \quad (2\,m_e)^2\,,$$
$$4\,E_p\,\epsilon \quad > \quad (m_\Delta^2 - m_p^2)\,.$$

UHE Neutrinos production mechanism

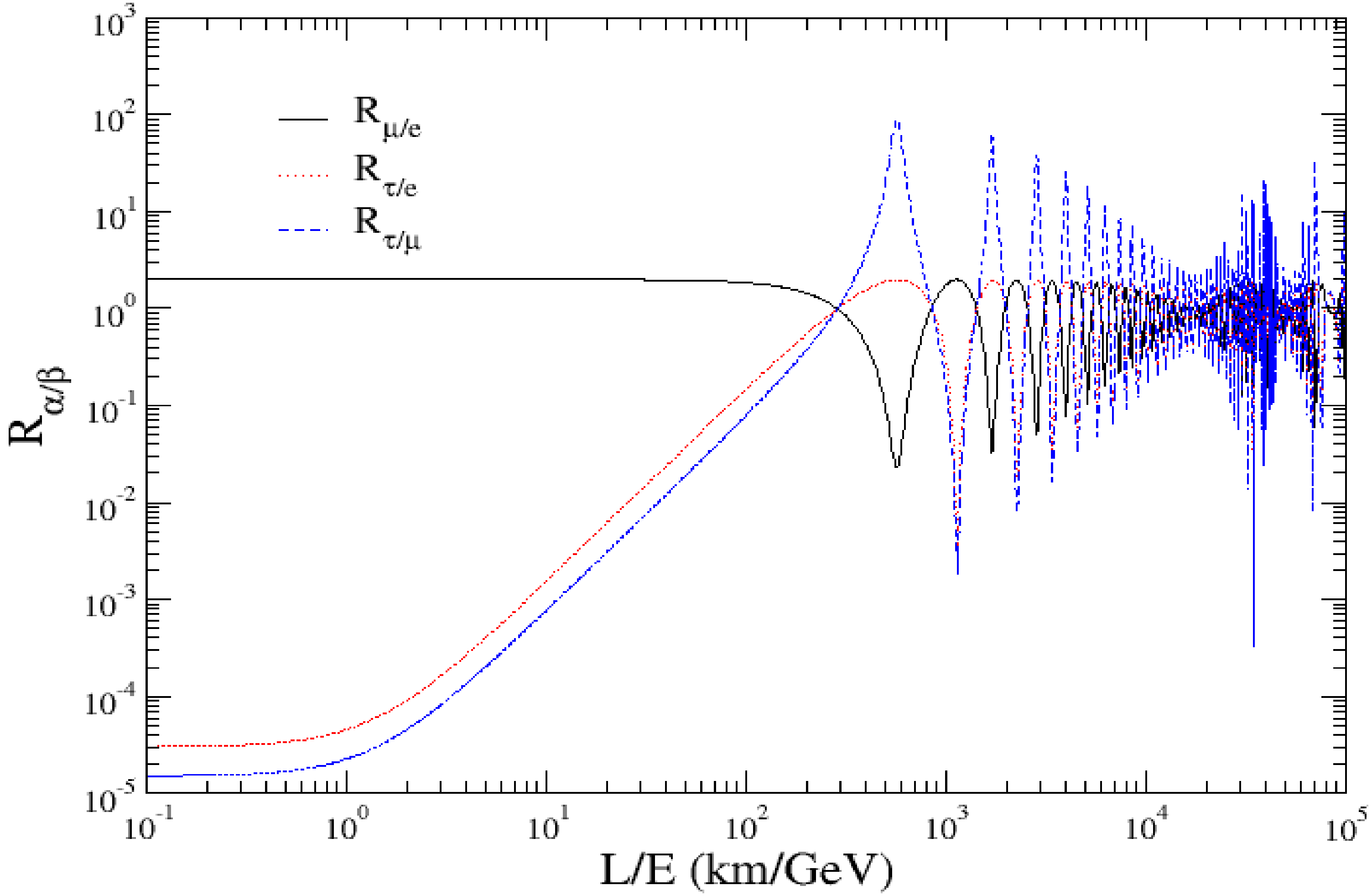
$$p + \gamma \rightarrow \Delta^{+} \begin{cases} p + \pi^{0} \\ n + \pi^{+} \end{cases}$$

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

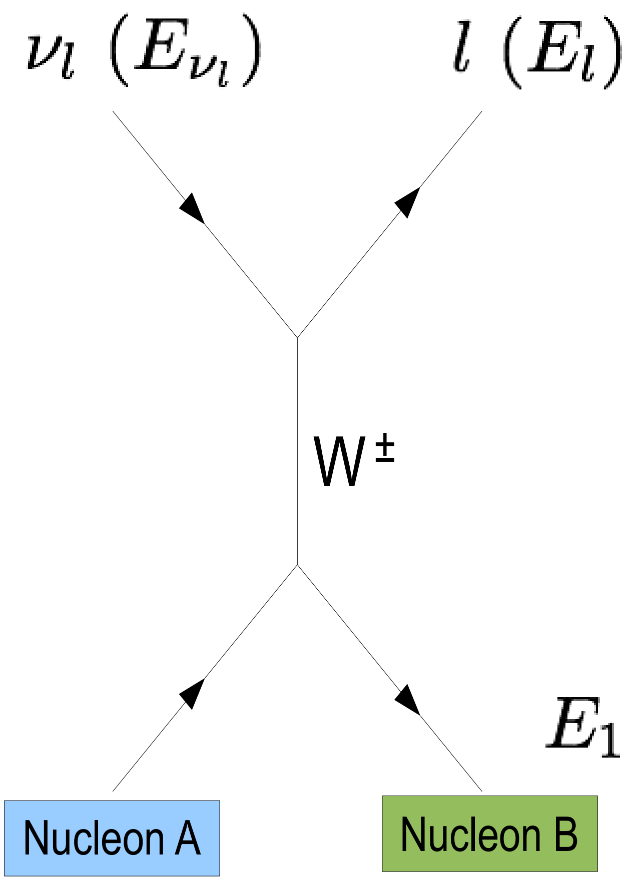
$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}$$

- Neutrinos have neutral charge;
- Very small mass limits;
- Very small magnetic moment limits;
- In principle, they propagate through cosmological distances with very little energy loss and deflection.

Flavor Ratios



Charged current neutrino interaction with nucleons



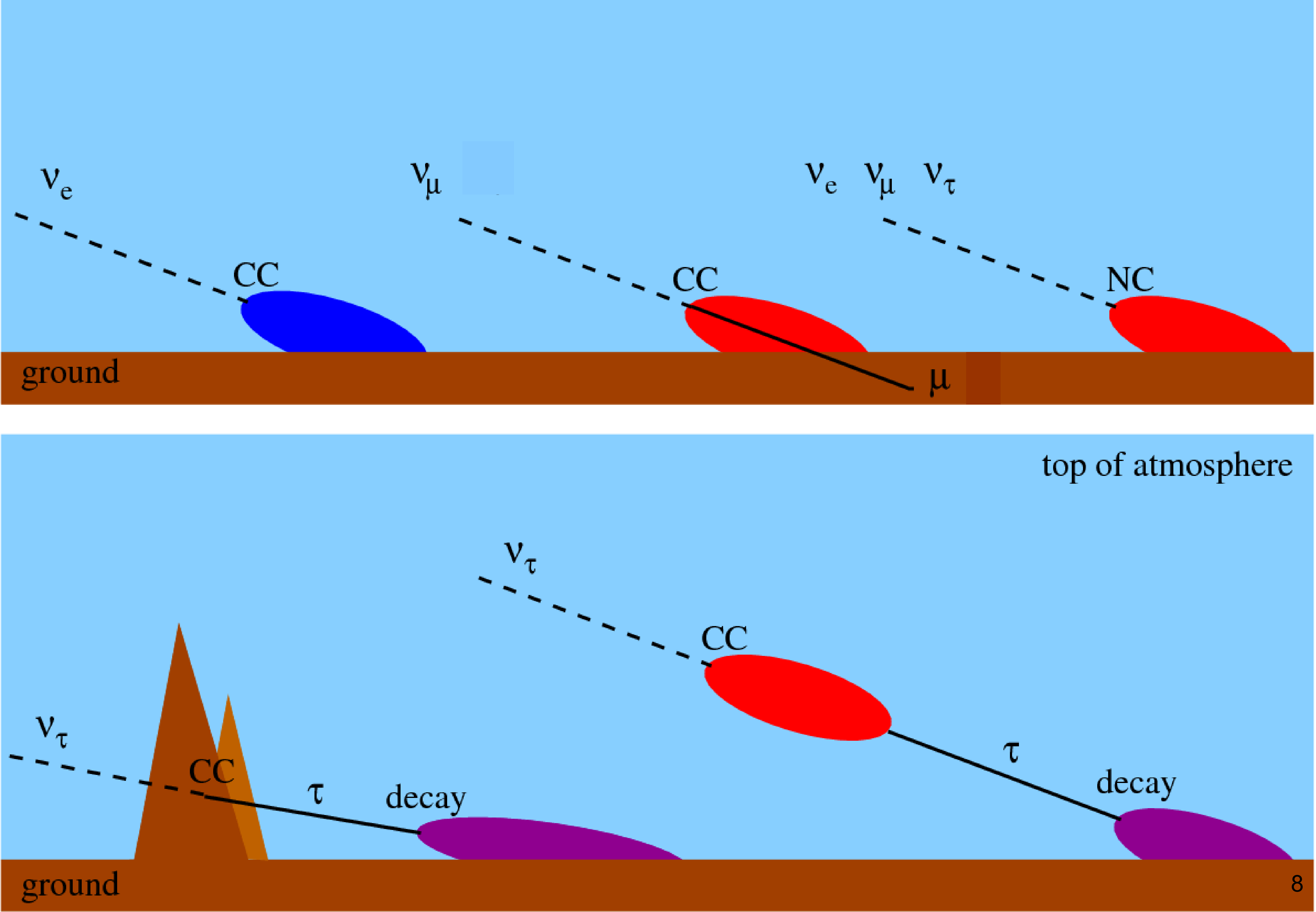
$$E_\nu = E_1 + E_l$$

$$y = \frac{(E_\nu - E_l)}{E_\nu}$$

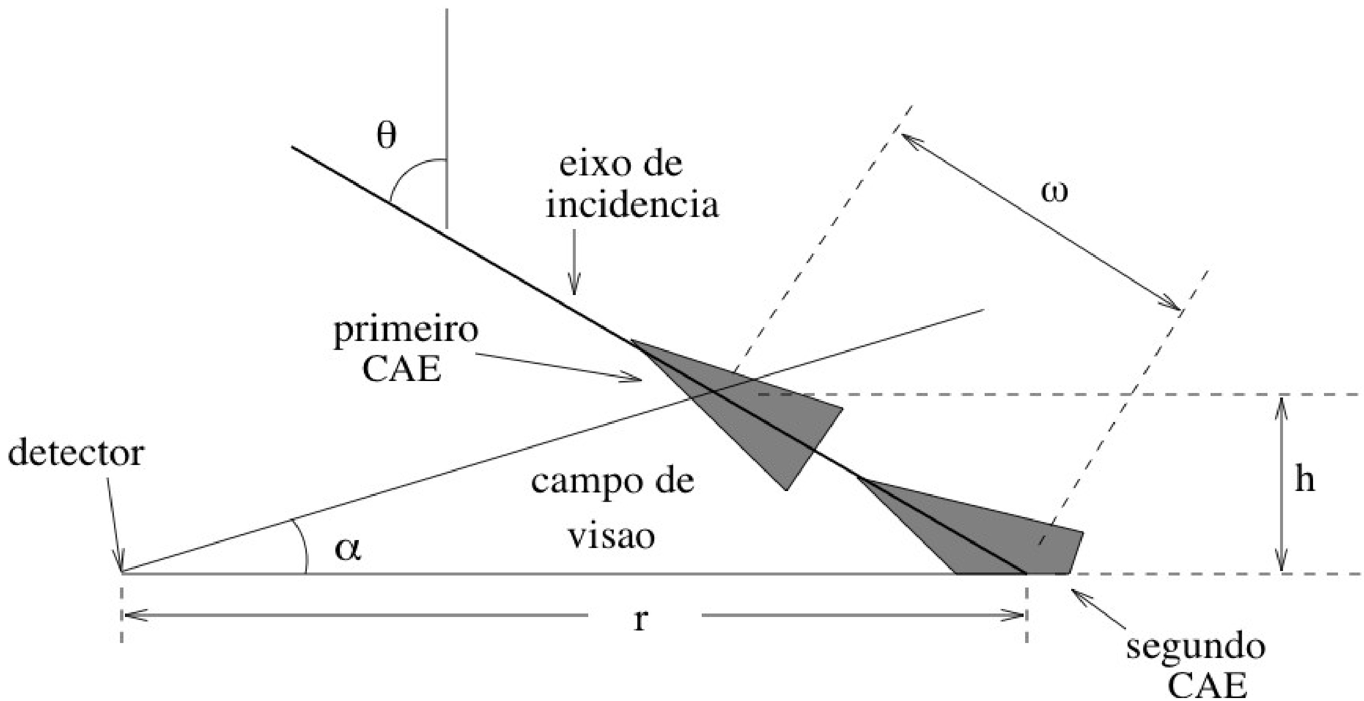
$$E_1 = yE_\nu$$

$$E_l = (1-y)E_\nu$$

Down-going neutrino channels at Auger



Prediction of Double Bang events in the atmosphere

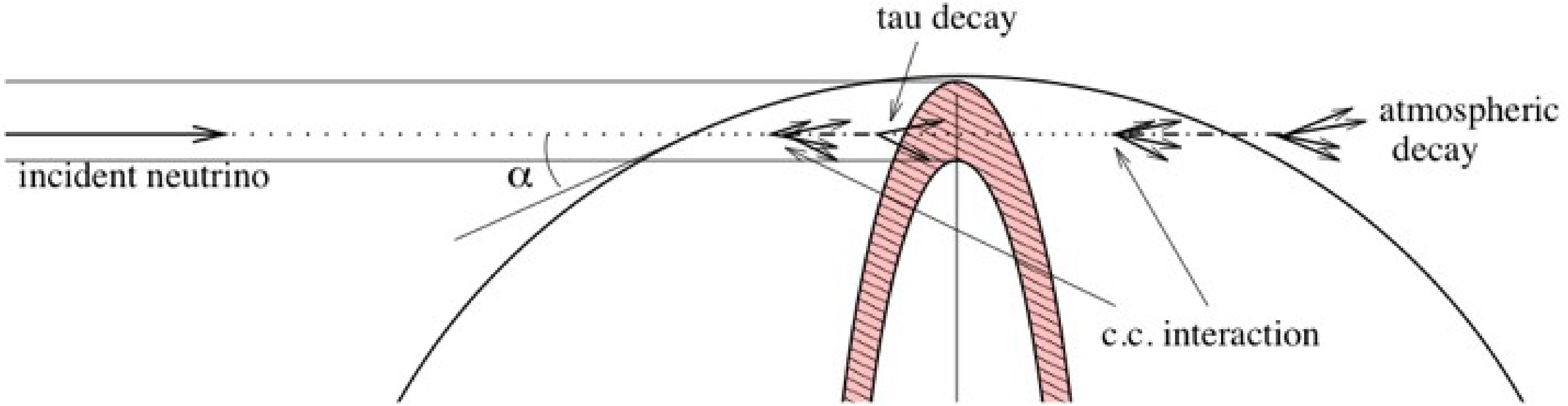


$$L \simeq \frac{E_\tau}{[\text{EeV}]} \times 49 \text{ km}$$
$$\simeq (1-y)\frac{E_\nu}{[\text{EeV}]} \times 49 \text{ km}$$

$$E_2 \approx 2E_\tau/3$$
$$\approx \frac{2}{3}(1-y)E_\nu$$

See: M. M. Guzzo and C. A. Moura, Astropart. Phys. 25, 277 (2006) [arXiv:hep-ph/0504270].

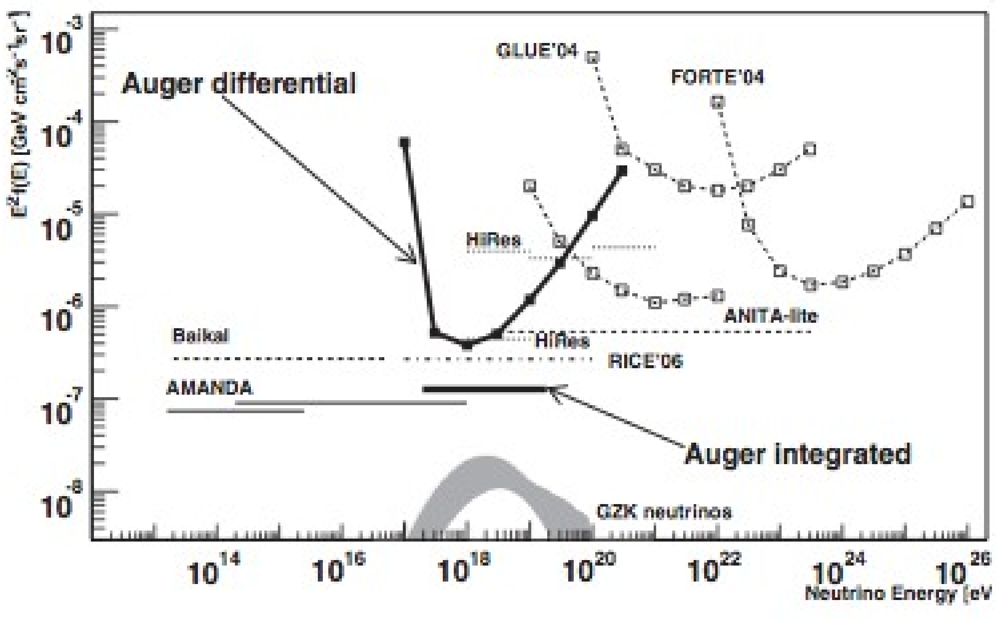
Skimming Tau Neutrinos

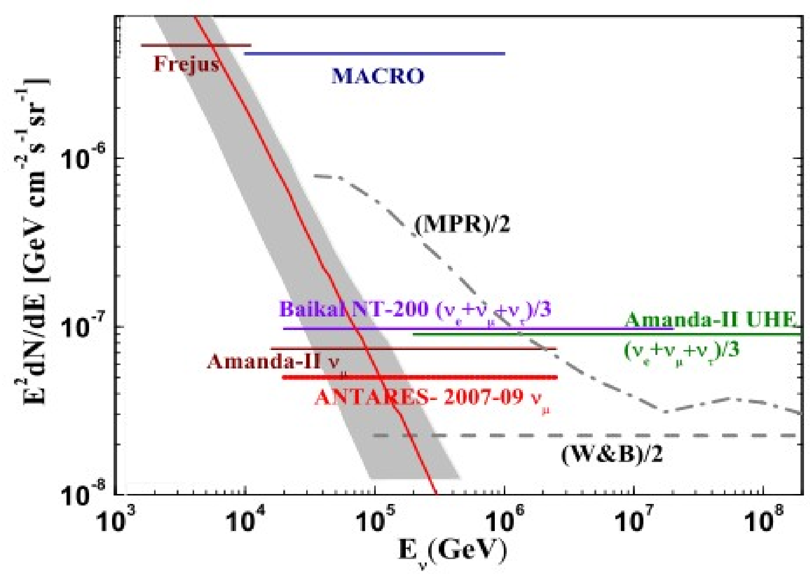


Other experimental possibilities

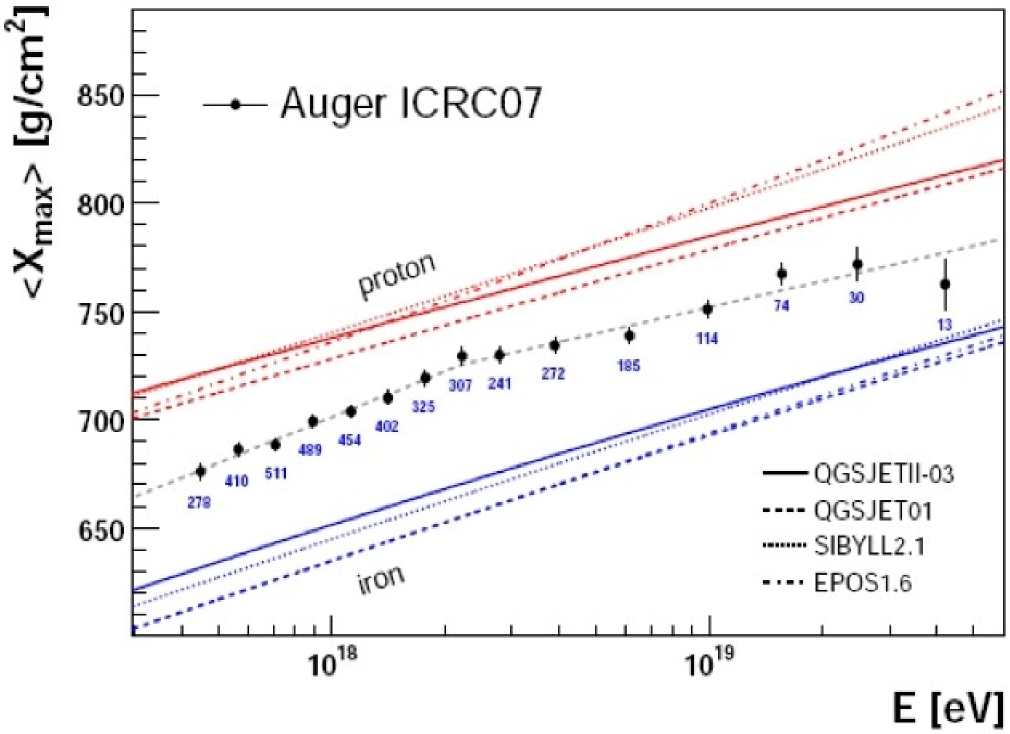
- None extragalactic neutrino have been detected yet;
- Auger extensions:
  - HEAT: High Elevation Telescopes;
  - AMIGA: Muons and Infill for the Ground Array.
- JEM-EUSO: 50 to 200 Auger aperture;
- IceCube; ANTARES, NEMO, NESTOR: KM3NeT

Extragalactic UHE Neutrino Flux Limits





Neutrinos and Composition



- What happens with neutrino flux if UHE cosmic rays are not protons?

Some evidences for Dark Matter

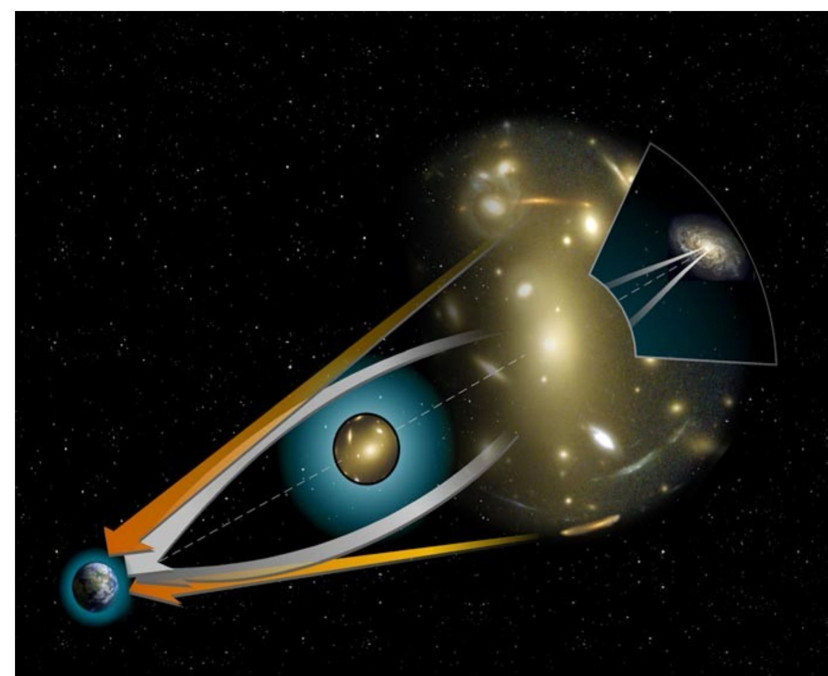
- Ratio mass / luminosity:
  - M/L (stars) close to the sun: ~0.7 $M_\odot/L_\odot$
  - Oort's limit (1932) for galaxies: ~ 3 $M_\odot/L_\odot$
  - Coma cluster M/L ~ 300 $M_\odot/L_\odot$:

  Astronomer Fritz Zwicky 1933

- Coma Cluster:
  - Masa total = 1.6 x 10^{15} $M_\odot$
  - Masa en rayos-X = 0.96 x 10^{14} $M_\odot$

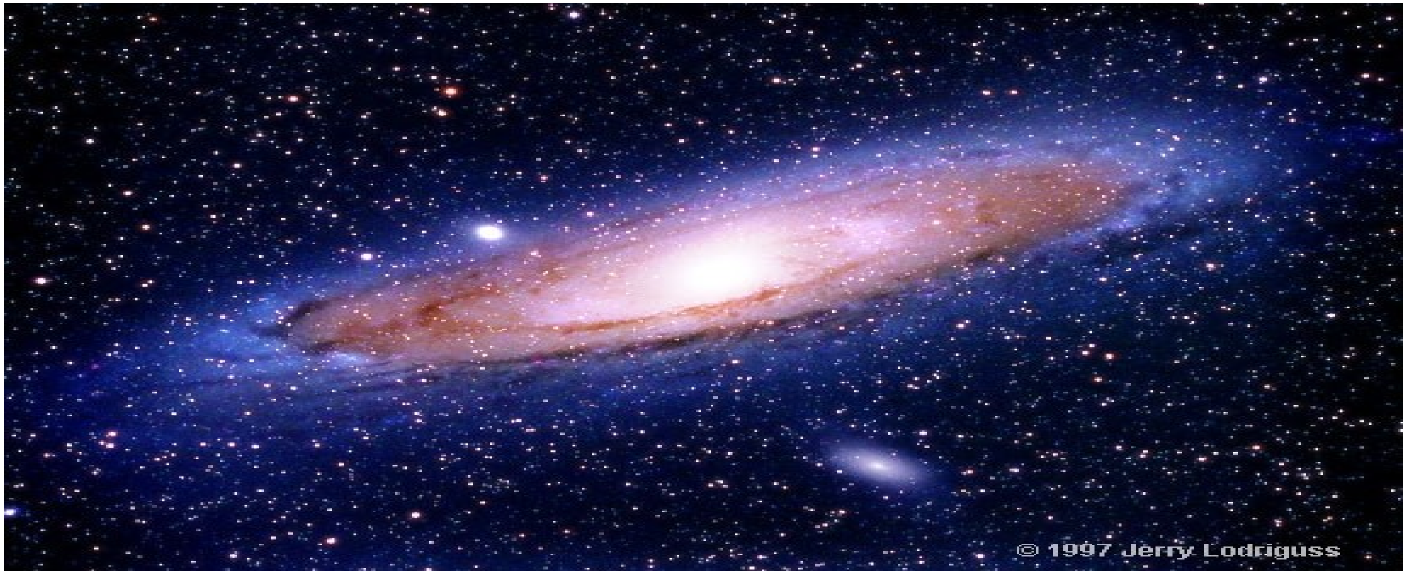
Some evidences for Dark Matter

- Faber & Gallagher (1979)
  - M/L in galaxy clusters~ 80-400 $M_\odot/L_\odot$
- Confirmation via gravitational lancing
  - ~ 5% optically visible (stars)
  - ~ 15% X-rays (plasmas)
  - ~ 80% DM-DE

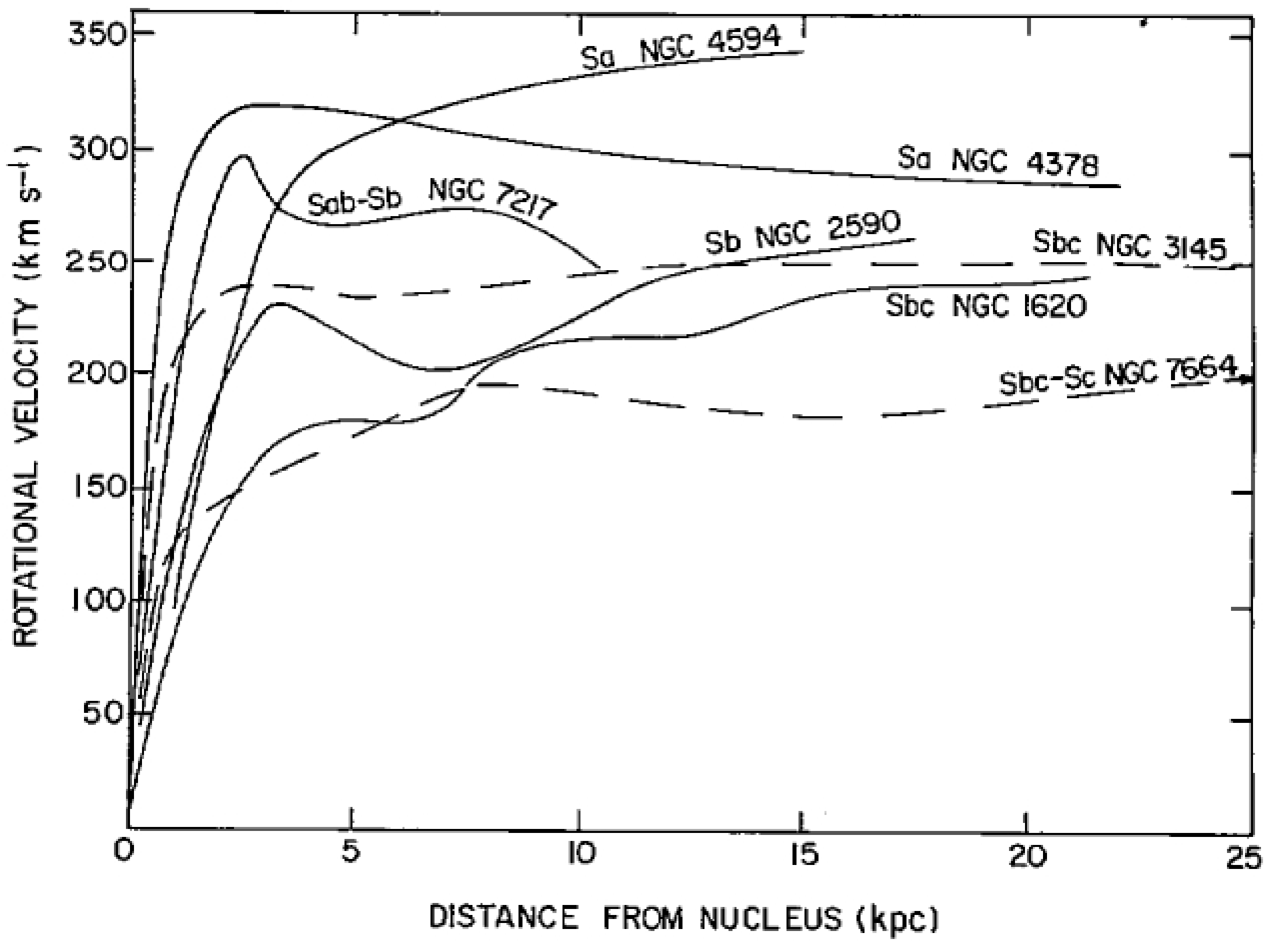


Some evidences for Dark Matter

- Galaxy rotation curves:
  - M31: Babcock (1939)
  - M31: Roberts & Whitehurst (1975)
  - Various galaxies: Rubin, Thonnard & Ford (1978)



Some evidences for Dark Matter



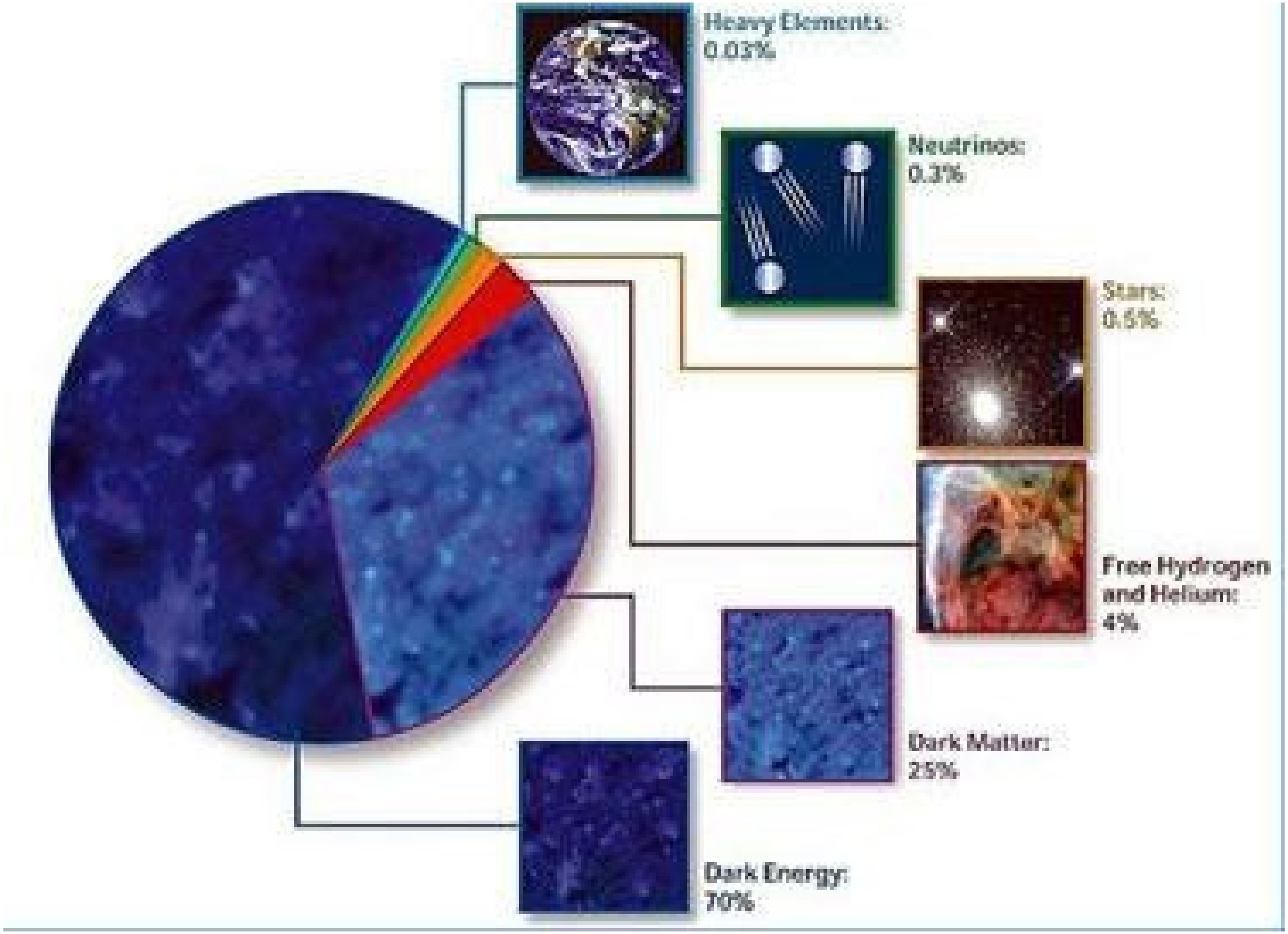
Rubin, Thonnard & Ford ApJL (1978)

Some Evidences for Dark Matter

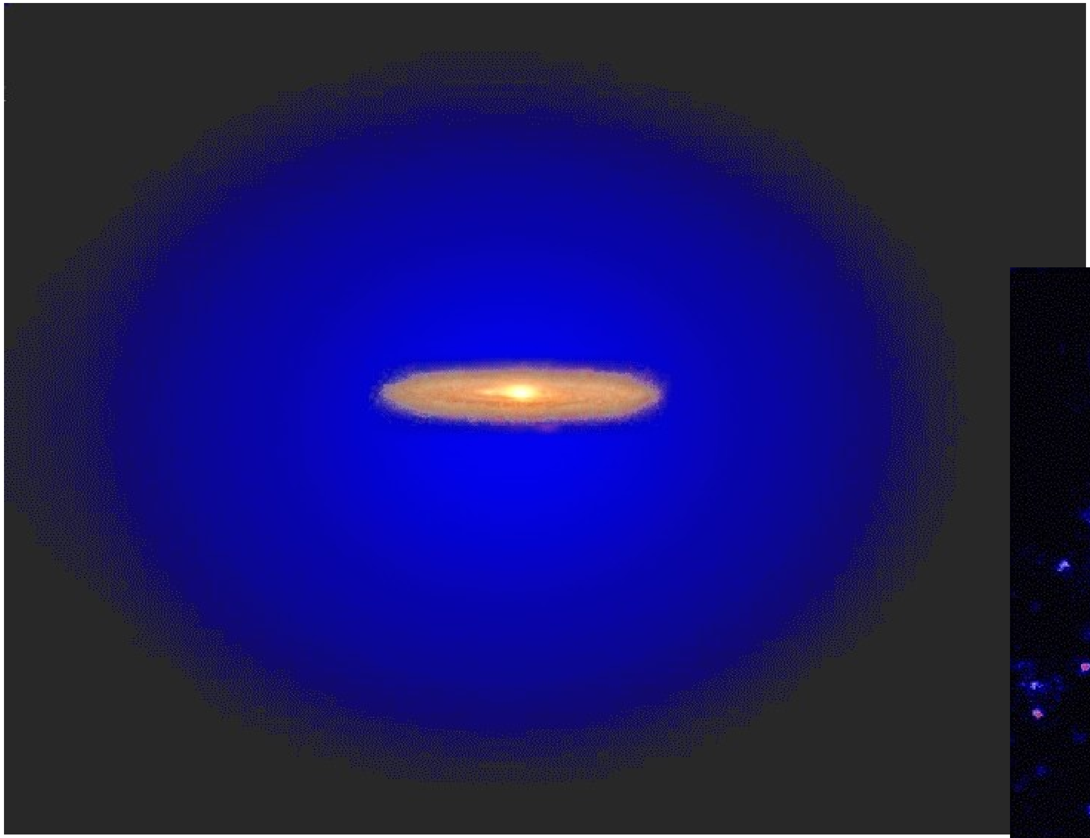
- Lambda Cold Dark Matter (ΛCDM) model explains very well:
  - CMBR;
  - Large scale structure formation;
  - Universe expansion.

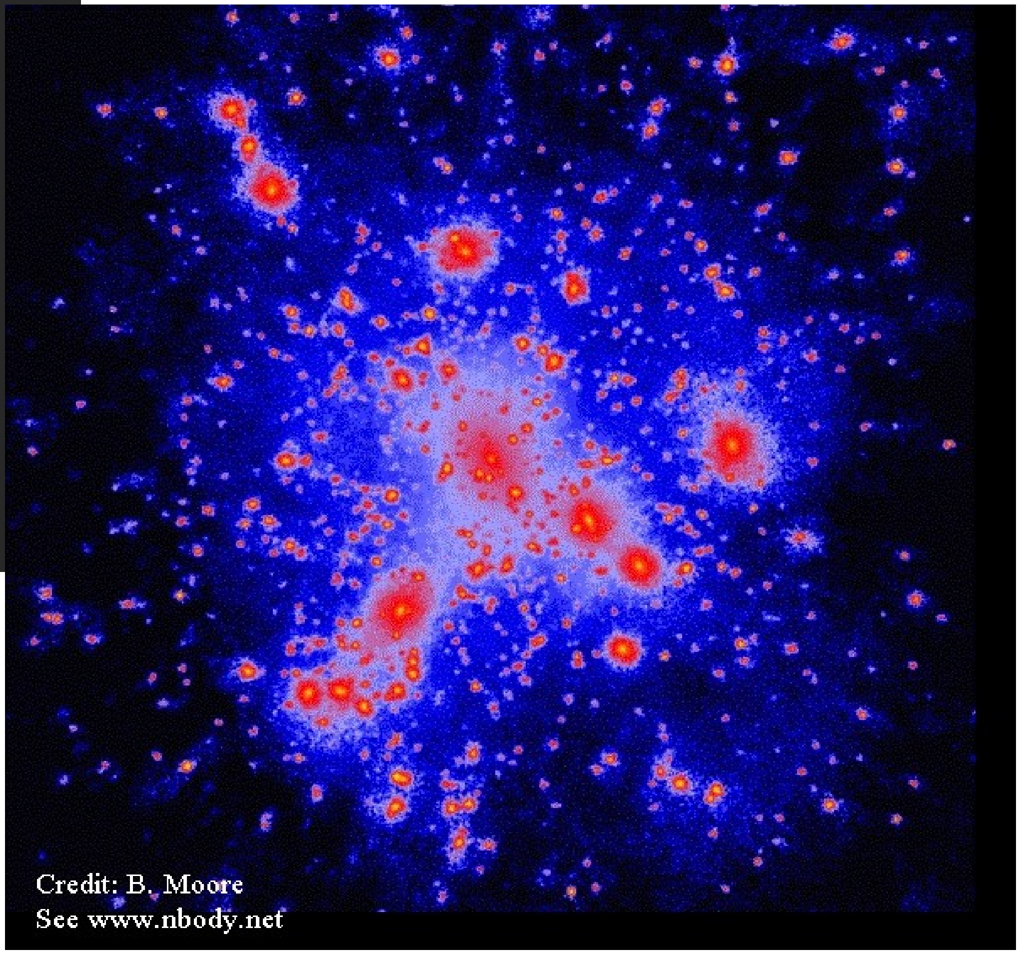
The Bullet Custer

The energy distribution in the Universe



Dark Matter distribution





What would be the DM?

- *Weak interacting particles*
  - Neutralinos, gravitinos, axinos?
  - Micro BH?
  - Scalar Fields (including very (ultra) light ones)?
  - Et cetera...
- *Laws of gravitation not well understood:*
  - MOND (Milgrom 1983)
  - TeVeS (Bekenstein PRD 2004)
  - STVG (Moffat JCAP 2005)

And if neutrinos interact with DM?

GIANPIERO MANGANO *et al.* PHYSICAL REVIEW D **74,** 043517 (2006)

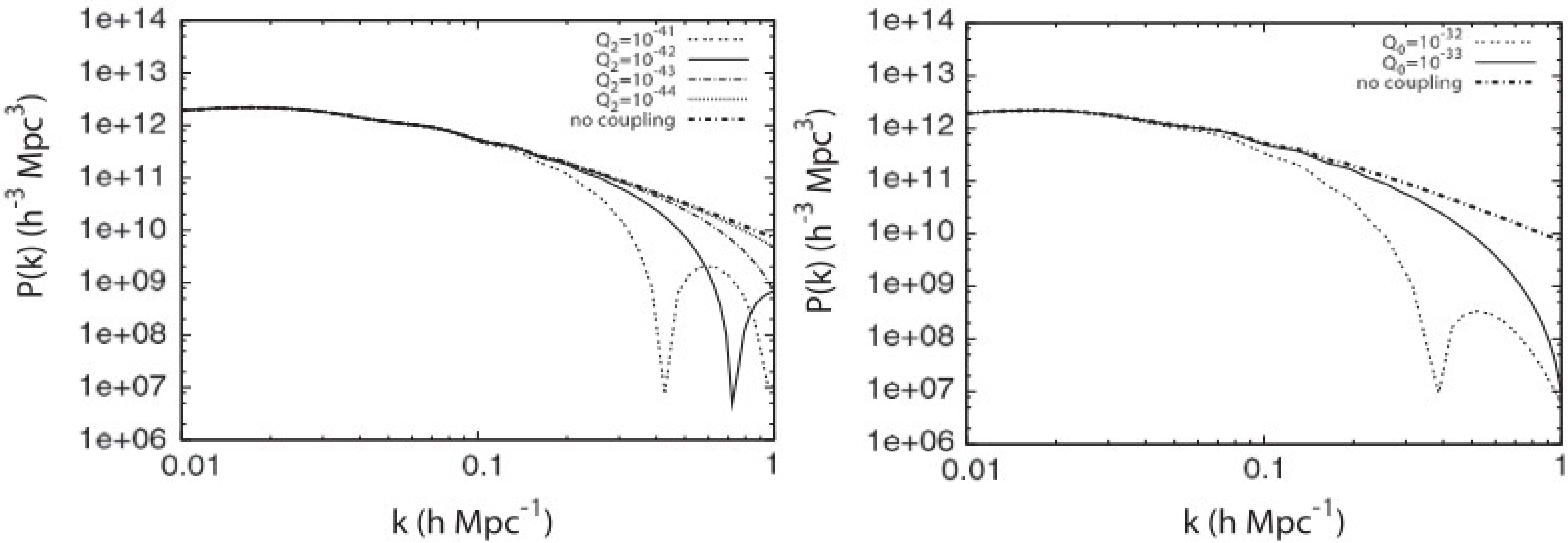


FIG. 2. Several matter power spectra with different opacities Q_2 (top panel) and Q_0 (bottom panel) between dark matter and neutrinos; Q_2 and Q_0 are in units of $\mathrm{cm}^2\,\mathrm{MeV}^{-1}$.

And if neutrinos interact with DM?

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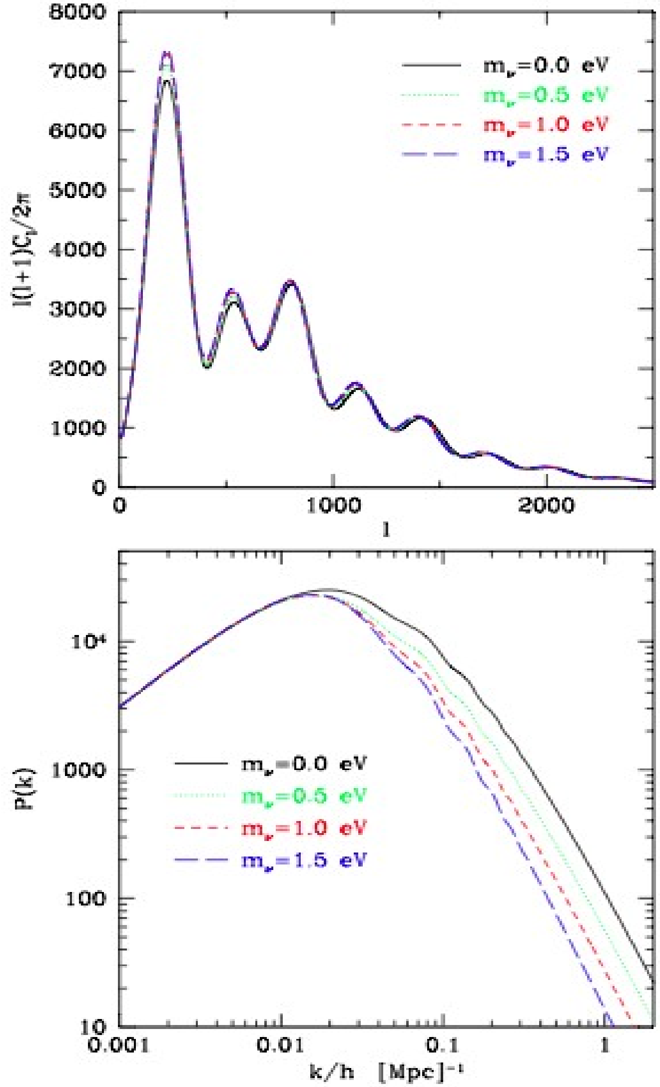


FIG. 7 (color online). The CMB and matter power spectra, for varying values of m_ν, for model B1 (one interacting neutrino and two standard neutrinos). The power spectra are normalized (to an arbitrary value) at large scale.

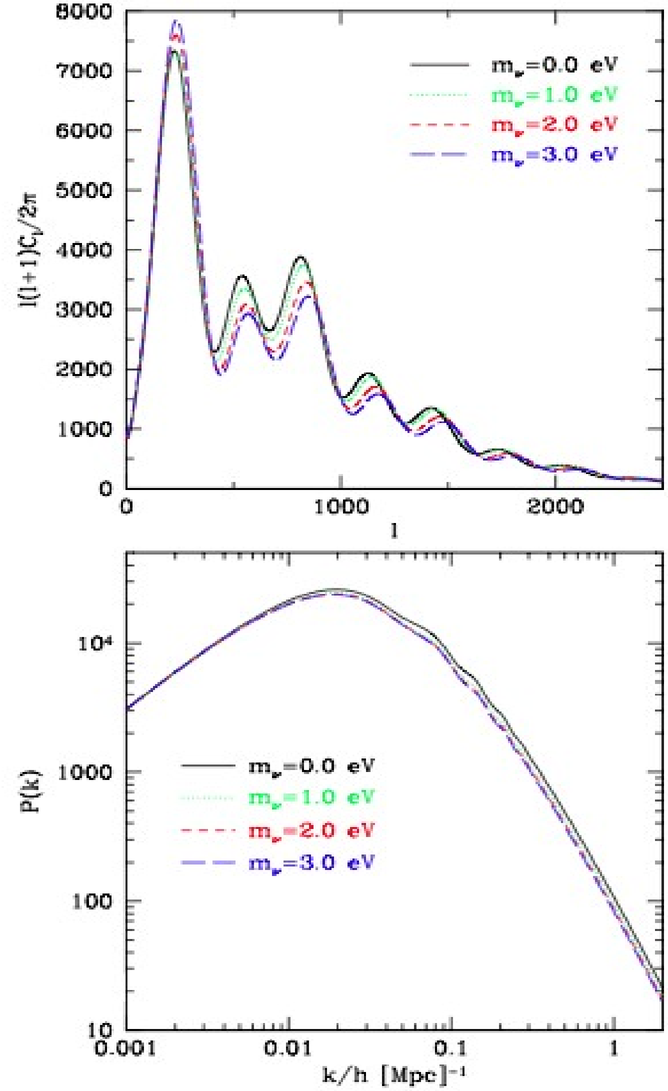
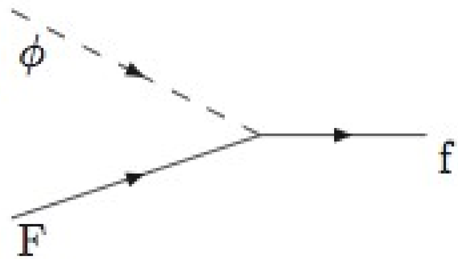


FIG. 8 (color online). The CMB and matter power spectra, for varying values of m_ν, for model B3 (three interacting/annihilating neutrinos). The power spectra are normalized (to an arbitrary value) at large scale.

Neutrino Dark Matter Interaction



$g_{\nu\phi} P_R$

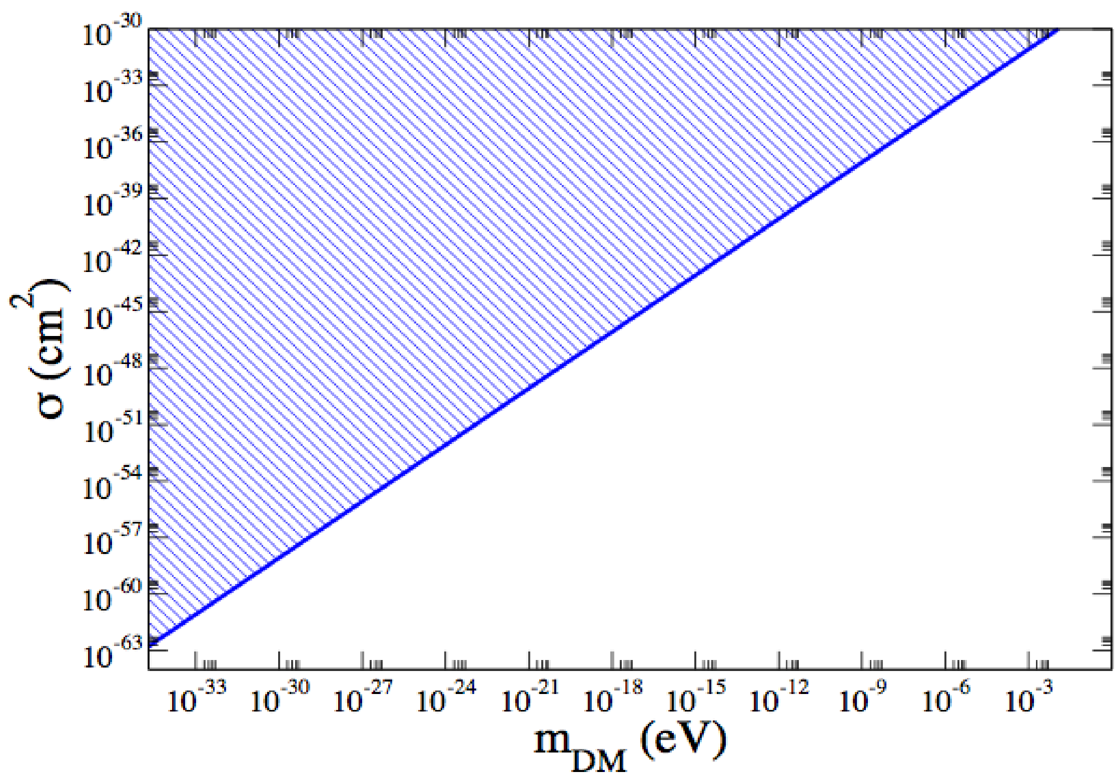


Figure 2. Neutrino cross section inducing a 95% neutrino flux suppression, as a function of the DM particle's mass $m_{\rm DM}$. The shaded area shows the suppression parameters' space. We consider a density $\rho_{\rm DM} = 1.2 \times 10^{-6}\,{\rm GeV/cm^3}$ and a mean source distance of $L = 100$ Mpc.

$$\lambda = (n\sigma)^{-1}$$

$$F(L) = F_0 e^{-L/\lambda}$$

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Neutrino Dark Matter Interaction

$$\mathcal{L} = g_{\nu\phi}\,\bar{\nu}\,\phi\,P_R F + H.c.$$

$$\sigma \simeq \left(\frac{g_{\nu\phi}}{M_I}\right)^4 \frac{m_\phi E_\nu}{16\pi}\,.$$

$$\begin{aligned}\lambda &= 16\pi \left(\frac{M_I/g_{\nu\phi}}{\mathrm{GeV}}\right)^4 \left(\frac{\mathrm{GeV}}{E_\nu}\right) \left(\frac{\mathrm{GeV/cm^3}}{\rho_\phi}\right) \mathrm{GeV^2 cm^3} \\ &\simeq L_0 \left(\frac{M_I/g_{\nu\phi}}{\mathrm{GeV}}\right)^4 \left(\frac{10^{18}\mathrm{eV}}{E_\nu}\right) \left(\frac{\mathrm{GeV/cm^3}}{\rho_\phi}\right),\end{aligned}$$

$$\frac{g_{\nu\phi}}{M_I} \gtrsim \left[\ln\left(\frac{F_0}{F}\right)\frac{L_0}{\rho_\phi E_\nu L}\right]^{\frac{1}{4}}$$

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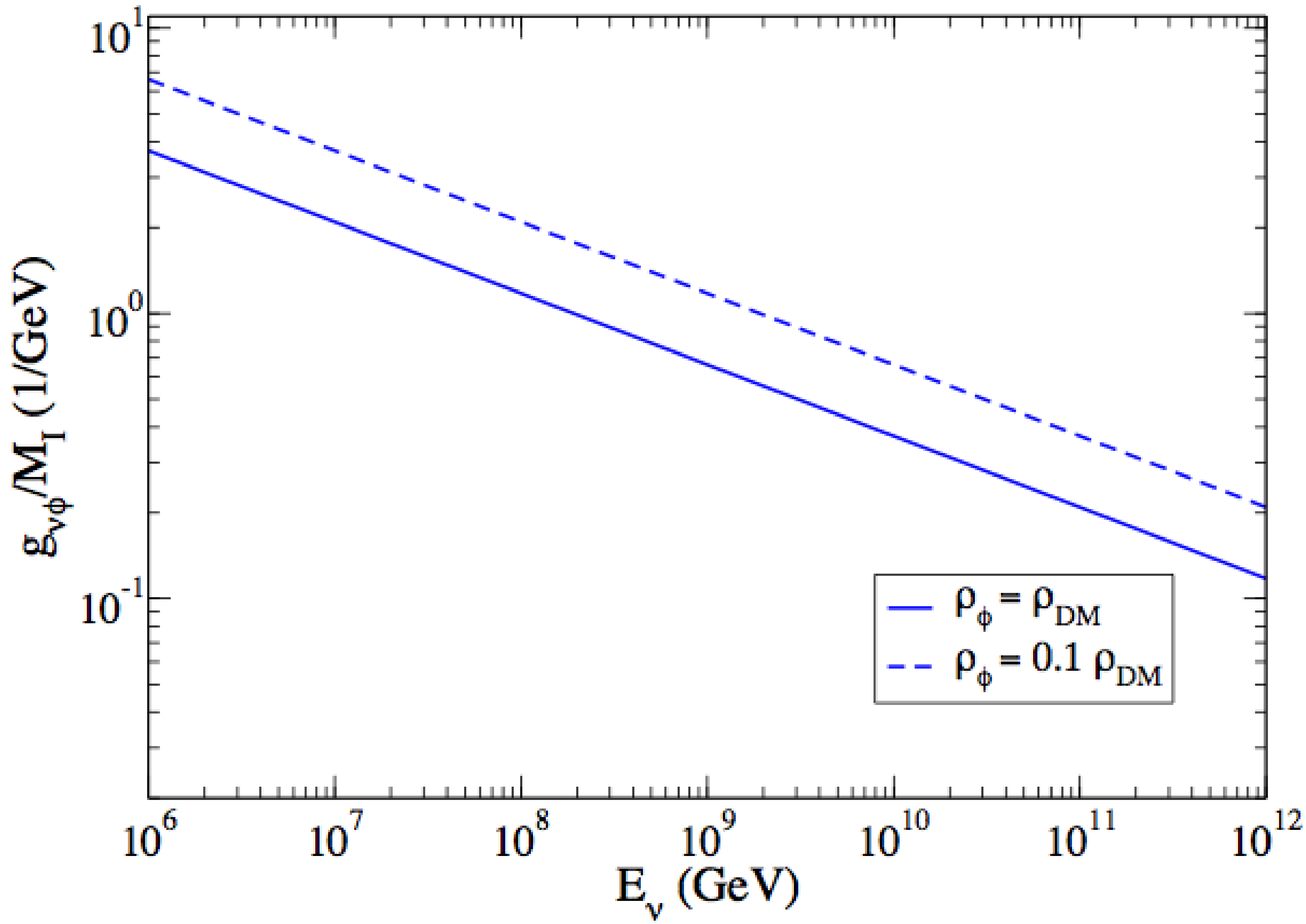
Neutrino Dark Matter Interaction



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Conclusions

- In spite of all the predictions, an extragalactic flux of UHE neutrinos have not been observed yet;
- In addition, there is a compelling evidence of a nonstandard matter in the universe, i.e., Dark Matter:
  - Neutrino-DM interaction may exist and lead to absorption of neutrino flux for specific kind of DM;
- Despite the neutrino flux limit may be due to the acceleration mechanism, we raise the possibility of a propagation effect.