# Extragalactic high energy neutrinos

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# Cosmic Ray Bound on Extragalactic Neutrino Flux

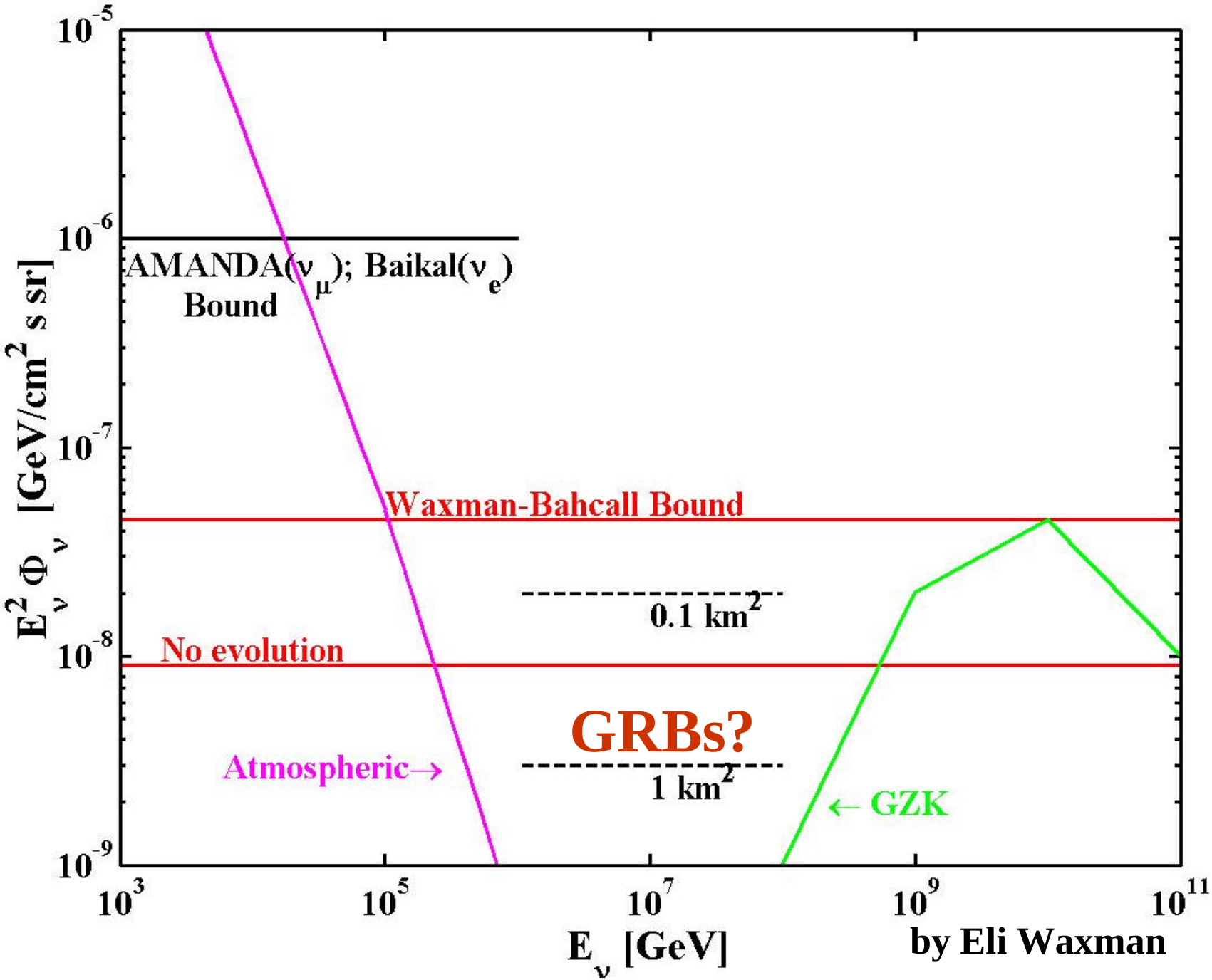
- $g + \mathbf{p} \rightarrow p^{+} + \mathbf{n}$
- Protons observed as cosmic rays
- $p^{+} \rightarrow n_{m}, \bar{n}_{m}$
- Proton flux sets limit on neutrino flux
- Assume protons escape: **optically thin at $10^{19}$eV**

# Effects included

- Energy loss via interaction with CMB
- Energy loss via redshift
- Redshift evolution: like quasars, star formation

# WB Bound (with evolution)

$$E_n^2 f_n = 5 \times 10^{-8}\ \mathrm{GeV/cm^2 s\ sr}$$


AMANDA(ν_μ); Baikal(ν_e)
Bound
Waxman-Bahcall Bound
0.1 km²
No evolution
GRBs?
Atmospheric→
1 km²
← GZK
E²_ν Φ_ν [GeV/cm² s sr]
E_ν [GeV]
by Eli Waxman

# Little known facts about WB limit

**Applies also :** $p + p \rightarrow p + n + p^{+}$

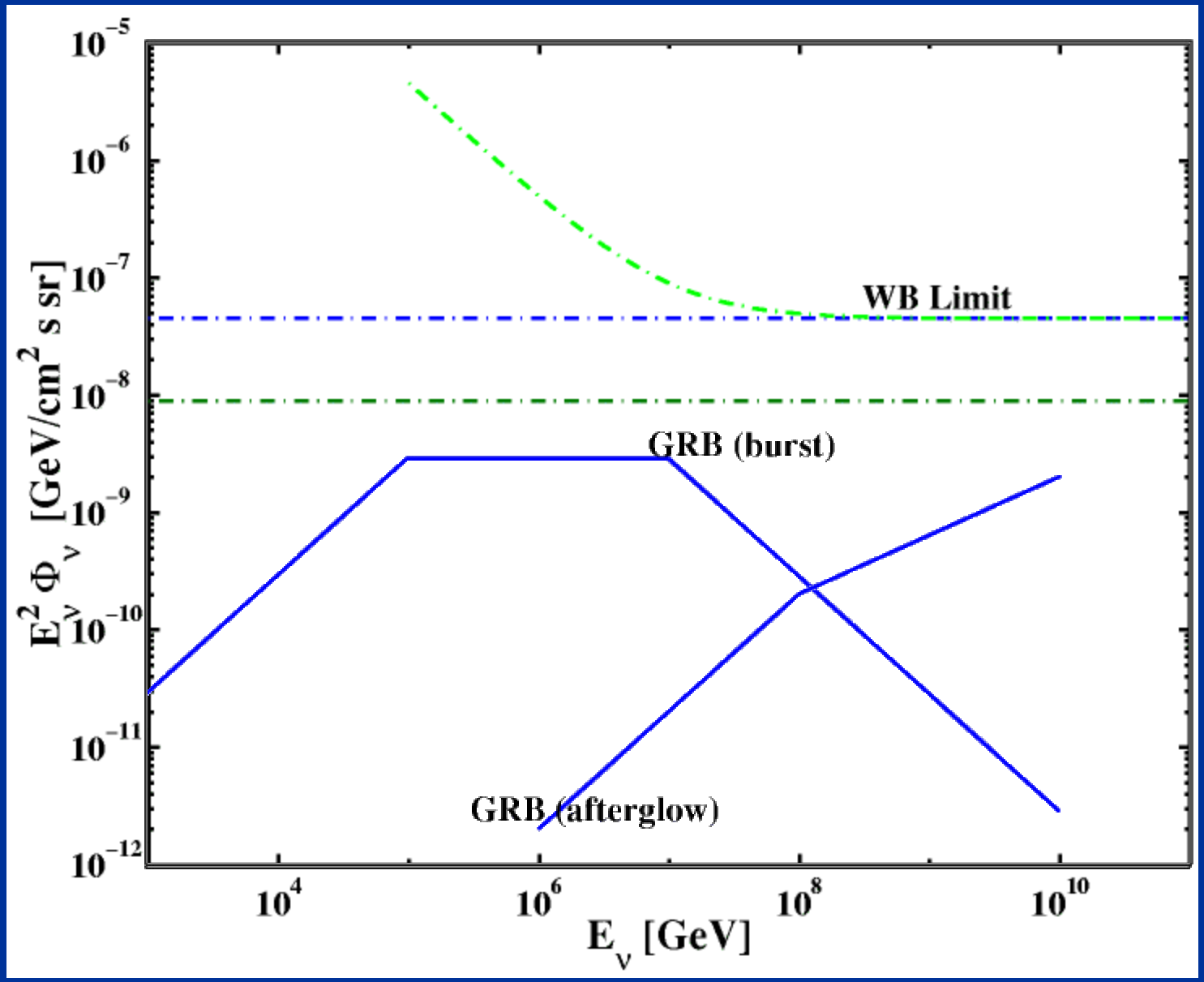
$$p + n \rightarrow n + n + p^{+}$$

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

"The Waxman Bahcall bound overestimates the most likely neutrino flux by a factor ~5/tau, for small optical depths tau." B&W: hep-ph/9902383

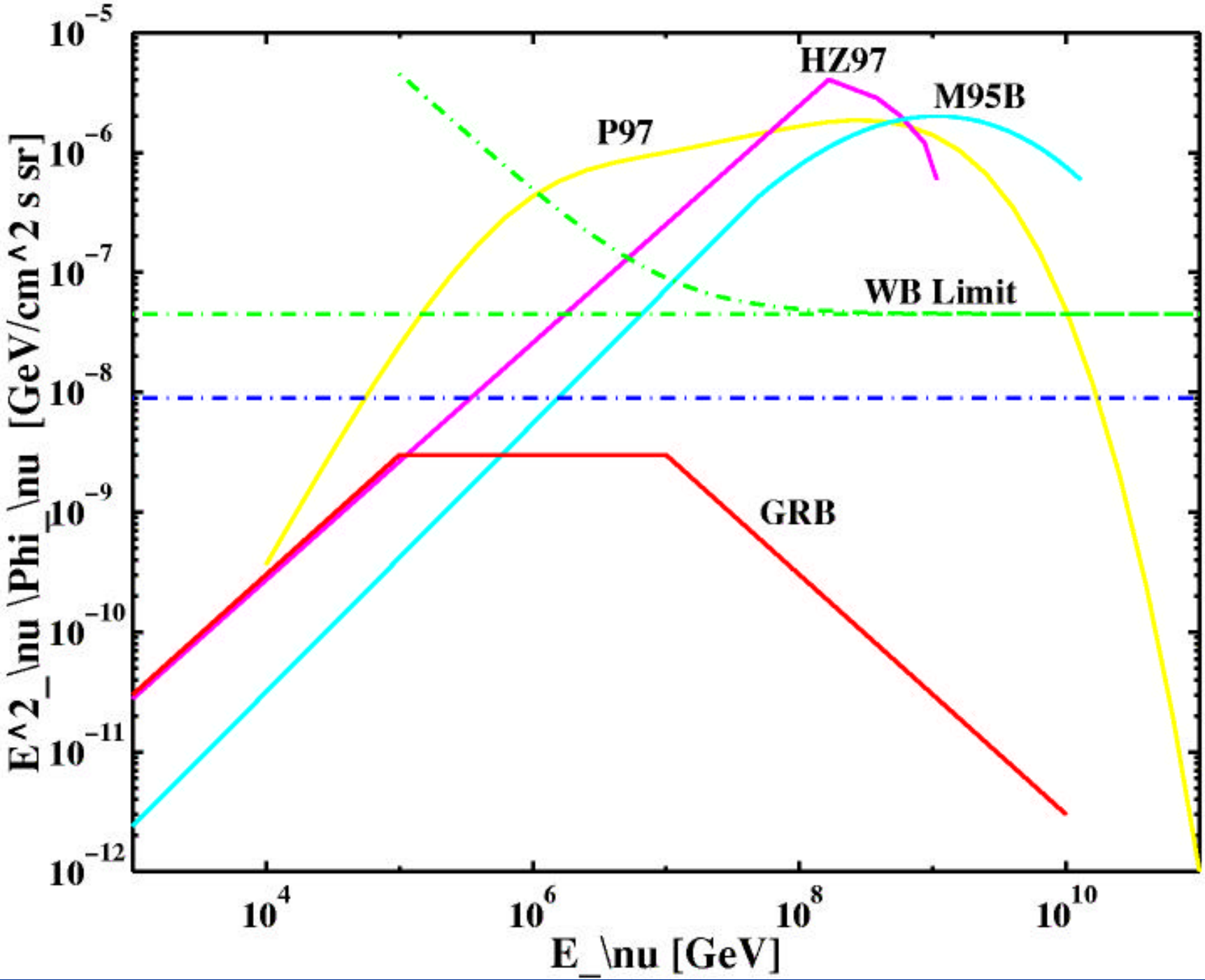
# Lower energies

$$\text{Max. protons} \mu E^{-2}[1 + 0.1(10^{17}\text{eV}/E)]$$


WB Limit
GRB (burst)
GRB (afterglow)
$E_\nu^2 \Phi_\nu$ [GeV/cm$^2$ s sr]
$E_\nu$ [GeV]
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^4$
$10^6$
$10^8$
$10^{10}$

# Ways out

- Decays of supermassive dark matter
- Topological defects
- Superheavy relic neutrinos
- Ultrahigh-energy photons


HZ97
M95B
P97
WB Limit
GRB
E^2_\nu \Phi_\nu [GeV/cm^2 s sr]
E_\nu [GeV]
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^4
10^6
10^8
10^10

# Predicted Characteristics of GRB ν's

1) $E^2\Phi_n(E) = 3\times10^{-9}$ **GeV cm$^{-2}$s$^{-1}$sr$^{-1}$** $g(E)$

$$E_c = 10^{+2}\ \textbf{TeV}$$

$$g(E) = \begin{cases} 1, E > E_c \\ (E/E_c), E < E_c \end{cases}$$

2) $t(n) = t(g)(\sim 1\,\textbf{sec})$

$$g(E) = \begin{cases} 1, E > E_c \\ (E/E_c), e < e_c \end{cases}$$

3) Direction(ν) = Direction(γ)

# Detection signatures

*) Direction of GRB

*) $t_n = t_g$ (~10 **sec)**

*) Flux ~ 10 $km^2$ / yr