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2246-12

Workshop on Cosmic Rays and Cosmic Neutrinos: Looking at the Neutrino Sky

20 - 24 June 2011

Sato-upscattering of the CnuB, revisited

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Sato Upscattering of the CνB, Revisited

Tom Weiler
Vanderbilt University

μ

Hara and Sato, 1980 and 1981

Prog. Theor. Phys. Vol. 64, No. 3, September 1980, Progress Letters

Scattering of the Cosmic Neutrinos by High Energy Cosmic Rays

Tetsuya HARA* and Humitaka SATO
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(Received June 23, 1980)

The high energy neutrino flux originated from the scattering of the low energy cosmic neutrinos by the high energy cosmic rays is estimated. The estimation is done for the two cases of massive neutrinos and degenerate massless neutrinos. The flux obtained in this process is small compared with the previous estimations unless the extragalactic cosmic ray flux is more intense in the early stage of $z \sim 4$.

Progress of Theoretical Physics, Vol. 65, No. 2, February 1981

Elastic and Inelastic Scattering of the Relic Neutrinos by High Energy Cosmic Rays

Tetsuya HARA* and Humitaka SATO

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(Received October 6, 1980)

The scattering of the cosmological relic neutrinos by high energy protons is studied in detail both for massive and massless neutrinos. If the energy of a neutrino in a proton rest frame is small enough, the scattering is elastic, but it becomes inelastic for higher energies. Assuming the power law type energy spectrum for the proton, we finally calculate the high energy neutrino generation rate.

and one Fig. (Hara and Sato, 1980):

September 1980 *Progress*

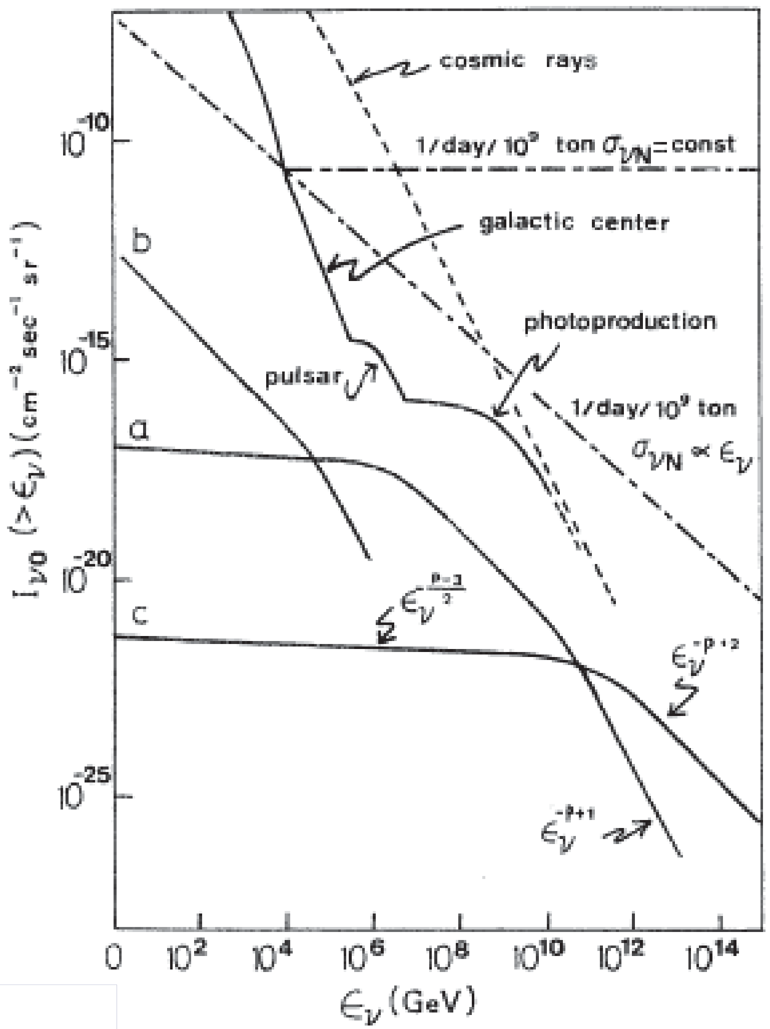


Fig. 1. The integral flux spectra of the scattered neutrinos. The curves a, b and c represent the following three cases about the cosmic neutrinos: (a) $m_\nu = 30\,\mathrm{eV}$, $n_0 = 220\,\mathrm{cm}^{-3}$, (b) $m_\nu = 2\,\mathrm{GeV}$, $n_0 = 6\cdot10^{-6}\,\mathrm{cm}^{-3}$ and (c) $\rho_{D\nu} = 10\cdot\rho_c$, $\epsilon_F = 1.6\cdot10^{-2}\,\mathrm{eV}$. The cosmic ray flux $J(\gamma) \equiv N(\gamma)c/4\pi$ is taken as[2]

$$J = 2.0\gamma^{-2.75} \quad \text{for } \gamma < 10^5$$
$$= 5.1\cdot10^3\gamma^{-3.1} \quad \text{for } \gamma > 10^5,$$

and $H_0 = 100$ km/sec Mpc.

The flux estimates in Ref. 2) are also shown. The dot-bar lines represent the flux which corresponds to one count per day by the 10^9 ton detector, assuming the two cases about the energy dependency for the neutrino-nucleon scattering $\sigma_{\nu N}$.

Then:

* ν mass totally unknown, number density
* Cosmo Const unknown, CMB temperature,
  Hubble constant ~ 100 (not 73), ...
* Little evolutionary evidence
* z_{max}

Now:

* ν_h mass ~ 0.1 eV, 72% dark energy, 38% matter,
  $54/cm^3$ per spin state per flavor

Hara and Sato (1981):

Lots of supporting Eqns, but ...
wrong neutrino density (6/11xCMB)
no bright phase evolution at z~2-3
(and no reionization phase at z~10-20)

interesting in that
it is “guaranteed”
sensitive to CR flux below GZK energy

3×10^{20} eV = macroscopic 50 Joules = one Clemens

Clemens does this with 10^{27} nucleons;
Nature does this with one nucleon,
10^{27} times better pitcher !

One Federer is similar

Tuesday, June 21, 2011

Similar is the Woods golf ball

and the Eastwood "Dirty Harry" special

and the Westwood .....

Tuesday, June 21, 2011

Encouraged by Y. Takahashi and M. Teshima, my self-assigned “task” for EUSO is to modernize the

$$p + C\nu B \text{ --> } \nu_{scatt} + X$$

neutral current calculations
of Hara and Sato (1980 and 1981).

What’s a Neutrino? (ν)

As close to nothing

as something can be !

Tom Weiler, Vanderbilt University

Some basics:

* mfp = $(n_\nu \text{ sigma}_\nu)^{-1}$= (54/cm^3 x 10^{-38} (E_ν /GeV) cm^2)$^{-1}$

  = $2\text{x}10^{36}$ cm,

  vs. $D_H = 10^{28}$ cm

  so ~ 10^8 D_H

* 1 Linsley = 1 (km^2 century ster)$^{-1}$ = $3\text{x}10^{-20}$ (cm^2 s ster)$^{-1}$

* 1 WB = 10^{-8} GeV (cm^2 s ster)$^{-1}$ = 10 eV (cm^2 s ster)$^{-1}$

  = $3\text{x}10^{20}$ eV Linsley (= 1 FlysEye–Linsley)

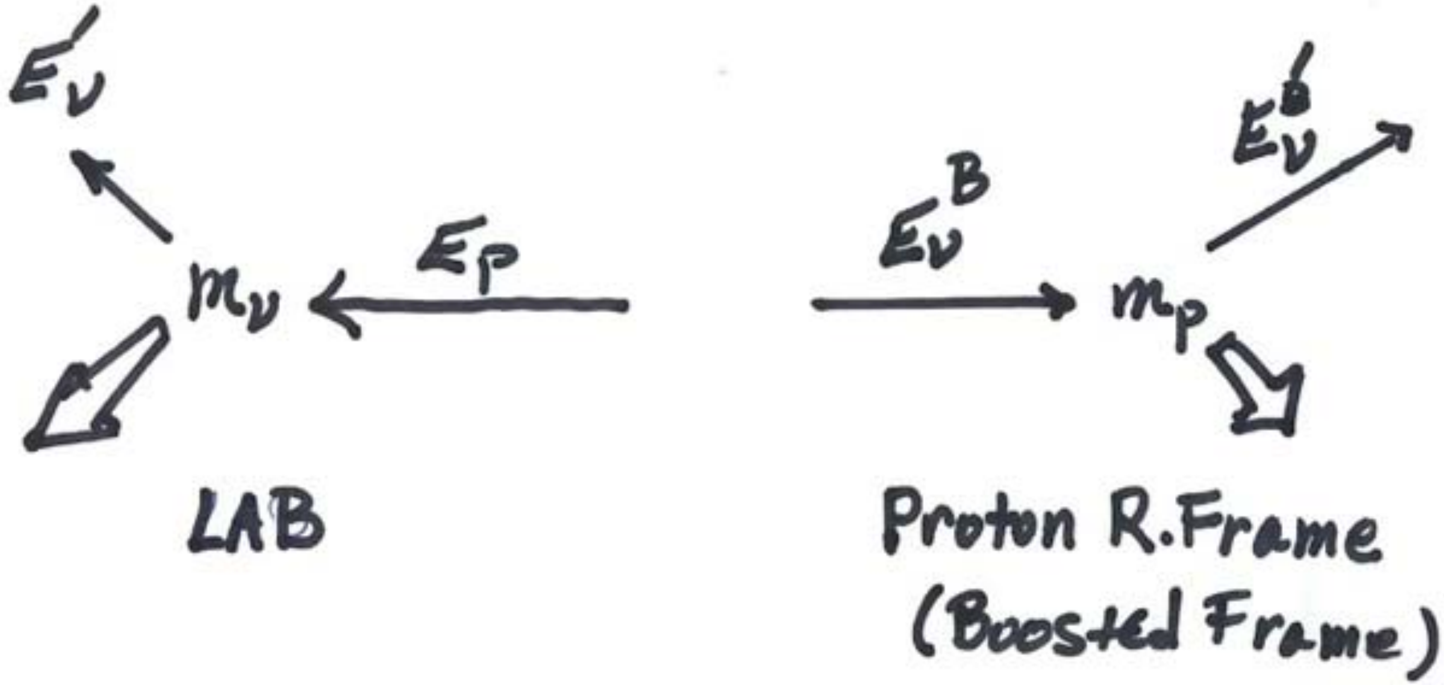
* original WB: local eps_0 above 10 EeV

  ~ $5\text{x}10^{44}$ ergs/Mpc3/yr, and E^{-2} spectrum;

  translates to generation rate of proton flux

Kinematics

$$\text{Boost Factor } \gamma = \frac{E_p}{m_p} = E_\nu^B / m_\nu$$



Jesus and Tom

Cosmic Neutrino Flux from Cosmic-Ray Upscattering of the CνB (an Update)

Jesus Escamilla-Roa[1,*] and Thomas J. Weiler[1,†]

[1] *Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235**

(Dated: June 15, 2011)

blah blah blah

E_2 and E_3 (E_1^B)

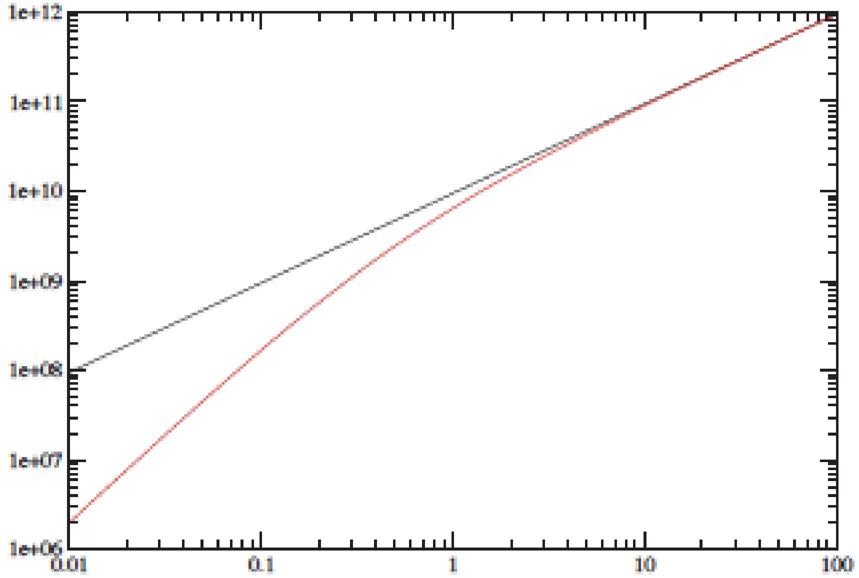


FIG. 1: Energy of cosmic ray E_2 and maximum energy of scattered neutrino $E_{3\,\mathrm{max}}$ as functions of the incident neutrino energy E_1^B in the rest frame of the incident proton. We have taken $m_\nu = 0.1$ eV.

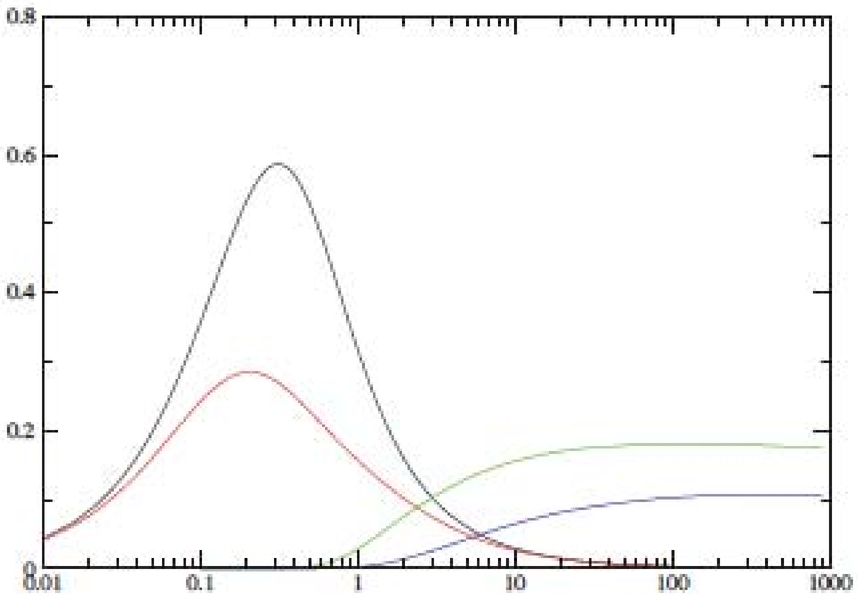


FIG. 2: σ/E_ν versus E_ν (GeV), for the νp (solid black) and $\bar{\nu}p$ (dotted red) elastic and DIS cross sections; DIS dominates elastic above a few GeV.

Formulae:

$$
\begin{aligned}
\frac{dF_3}{dE_3}(E_3) \;&=\; n_1 \int dt \int dE_2\, \frac{dF_2}{dE_2}(E_2) \int dE_1^B \int dE_3^B \int d\cos\theta_3^B \left[\frac{d\sigma(E_1^B, E_3^B, \theta_3^B)}{dE_3^B\, d\cos\theta_3^B}\right] \\
&\qquad \times\, \delta\left(E_1^B - m_1 \frac{E_2}{m_2}\right)\, \delta\left(E_3 - E_3^B \frac{E_2}{m_2}(1-\cos\theta_3^B)\right) \\
&=\; m_2\, n_1 \int dt \int \frac{dE_2}{E_2}\, \frac{dF_2}{dE_2}(E_2) \int dE_3^B \int d\cos\theta_3^B \left[\frac{d\sigma(E_1^B = \frac{m_1}{m_2}E_2, E_3^B, \theta_3^B)}{dE_3^B\, d\cos\theta_3^B}\right] \\
&\qquad \times\, \delta\left(E_3^B\,(1-\cos\theta_3^B) - \frac{m_2\, E_3}{E_2}\right) \qquad\qquad \text{[valid for NR C}\nu\text{B]} \quad (10)
\end{aligned}
$$

Following [6], we normalize the CR flux via today's inferred local energy-density production rate of CR's above 10^{19} eV, given as

$$
\dot{\epsilon}_0\,(>10^{19}\text{eV}) \sim 5\times 10^{44}\ \text{ergs/Mpc}^3/\text{yr}\,. \qquad (32)
$$

The rate of generation of the differential proton flux, $d\dot{F}/dE$, is related to $\dot{\epsilon}_0$ via

$$
\int_{E_{\min}} dE \left(\frac{E\, d\dot{F}}{dE}\right)_0 = \frac{c}{4\pi\,\text{ster}}\, \dot{\epsilon}_0\,(>E_{\min})\,.
$$

Implementing cosmology

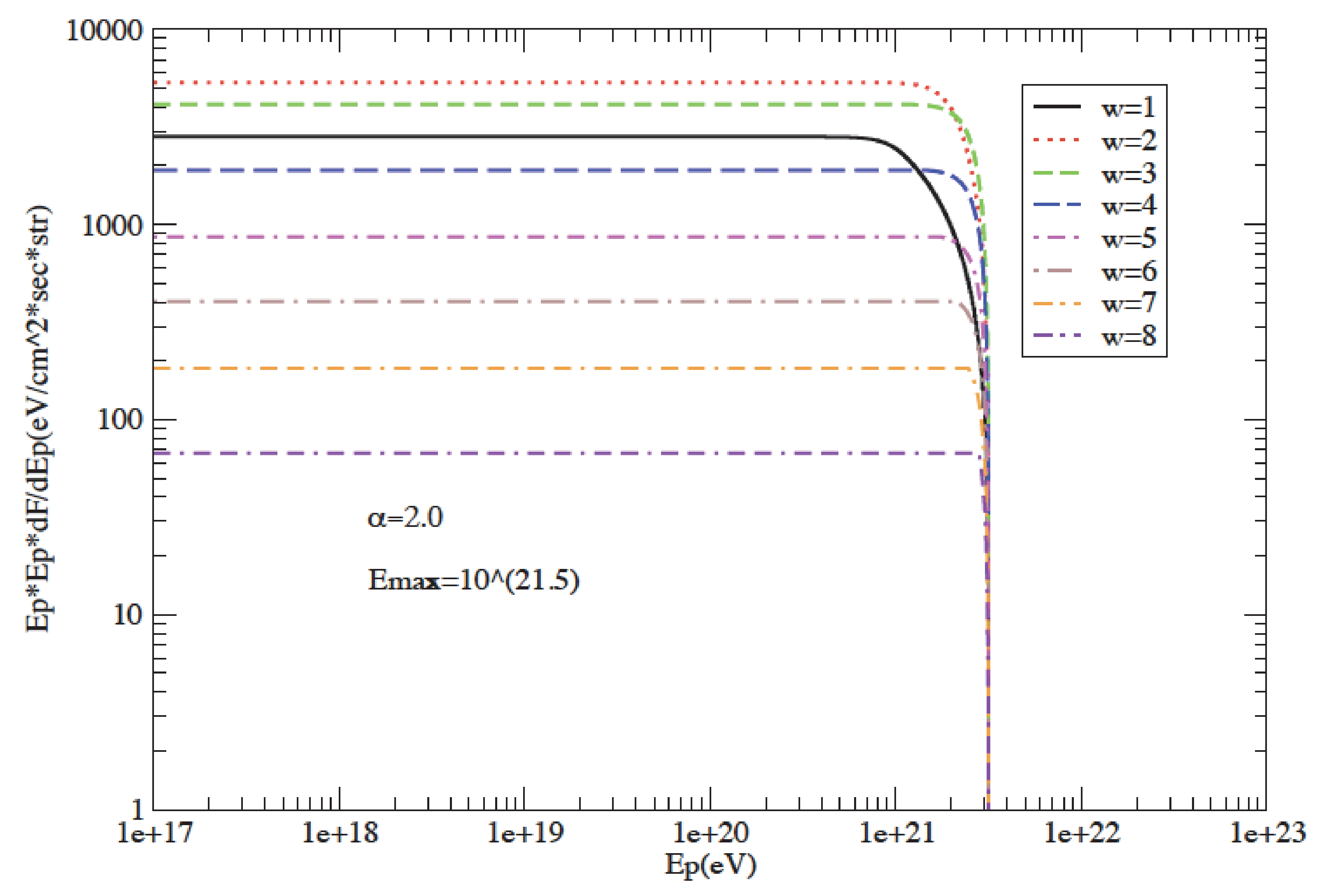
A. High-Energy Proton Flux, Historical to Present

The possibility that the Universe has gone through a brighter phase of CR creation early on is suggested by analogies with observed evolution for Quasars and star-forming regions. A common assumption is that the "source evolution function" $f(\omega_s)$ for CR creation matches the inferred luminosity density evolution of Quasars (similar to the inferred evolutionary history of the star-formation rate):

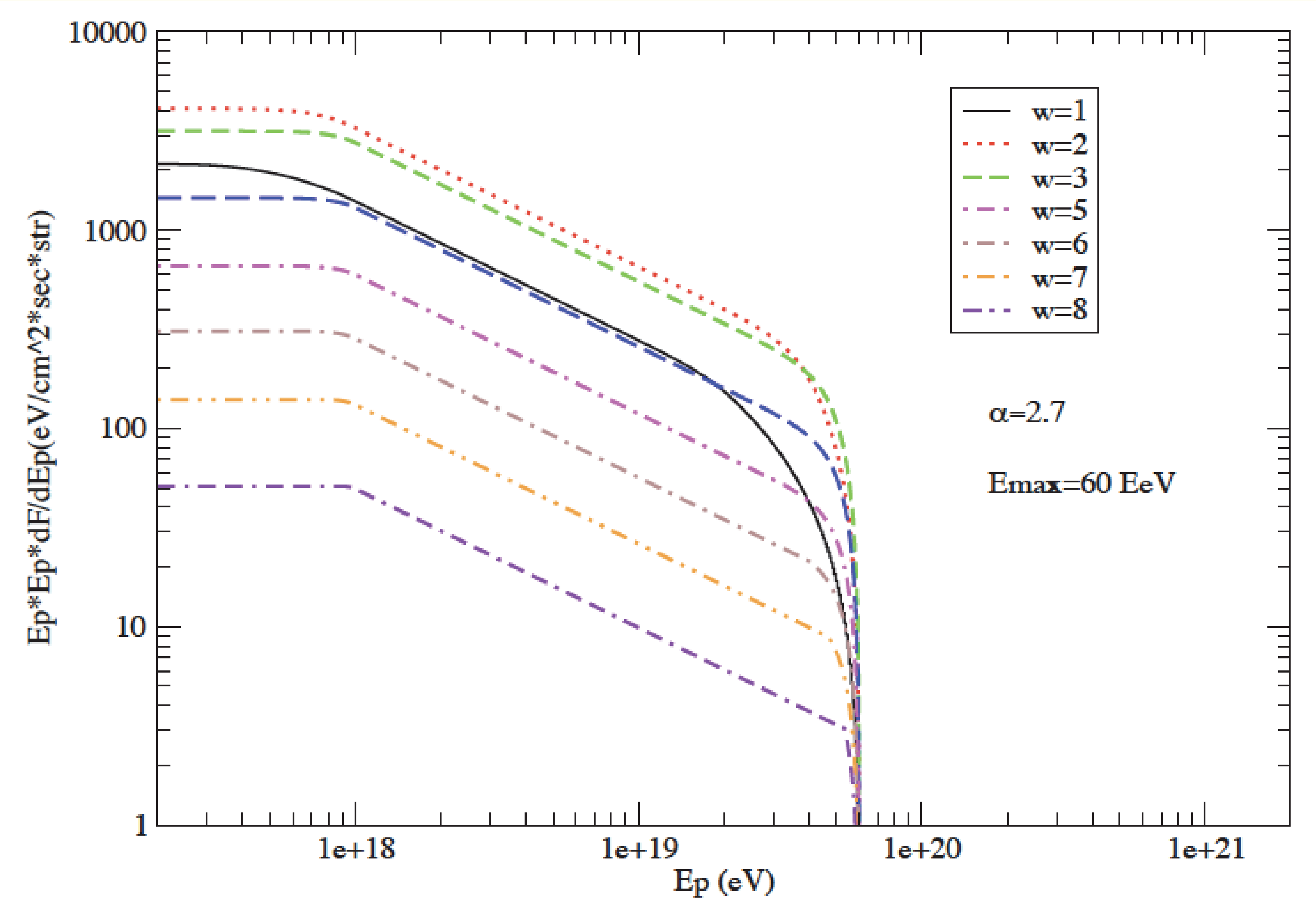
$$f(\omega) = \begin{cases} \omega_s^\beta \,, & \text{for} \quad \omega_s \le 2.9 \,, \\ (2.9)^\beta \,, & \text{for} \quad 2.9 \le \omega_s \le 3.7 \,, \\ (2.9)^\beta \, e^{-\frac{(\omega_s - 3.7)}{2.7}} \,, & \text{for} \quad \omega_s \ge 3.7 \,, \end{cases} \tag{48}$$

The value of $\frac{dF}{dE_p}(\omega_i, E_p)$ now becomes

$$\frac{dF}{dE_p}(\omega_i, E_p) = \frac{1}{H_0} \int_{\omega_i}^{\omega_{\max}} \frac{d\omega_s \; f(\omega_s)}{\omega_s \sqrt{\Omega_M \omega_s^3 + \Omega_\Lambda}} \int_{E_{\min}}^{E_{\max}} dE_p^s \;\; \delta\left(E_p^s - E_p \frac{\omega_s}{\omega_i}\right) \left(\frac{d\,\dot{F}}{dE_p^s}(E_p^s)\right)_0 \,.$$



10000
1000
100
10
1
1e+17
1e+18
1e+19
1e+20
1e+21
1e+22
1e+23
Ep(eV)
Ep*Ep*dF/dEp(eV/cm^2*sec*str)
w=1
w=2
w=3
w=4
w=5
w=6
w=7
w=8
α=2.0
Emax=10^(21.5)


10000
1000
100
10
1
1e+18
1e+19
1e+20
1e+21
Ep (eV)
Ep*Ep*dF/dEp(eV/cm^2*sec*str)
w=1
w=2
w=3
w=5
w=6
w=7
w=8
α=2.7
Emax=60 EeV

Putting all the cosmological factors together, one gets for elastic scattering the expression

$$\left(\frac{dF_3}{dE_3}(E_3)\right)_0 = \frac{m_1}{m_2}\frac{c}{H_0}n_1^0\int_1^{\omega_{\max}}\frac{d\omega_{\rm i}\,\omega_{\rm i}^3}{\sqrt{\Omega_m\omega_{\rm i}^3+\Omega_\Lambda}}\int dE_2\left(\frac{dF_2}{dE_2}(\omega_{\rm i},E_2)\right) \quad \text{[valid for elastic scattering]}$$

$$\times\int dE_1^B\int dE_3^B\left[\frac{d\sigma(E_1^B,E_3^B)}{dE_3^B}\right]\delta\left(E_1^B-\frac{m_1}{m_2}E_2\right)\,\delta\left(E_3^B-\frac{m_1}{m_2}(E_2-E_3^0\,\omega_{\rm i})\right)\,, \qquad (52)$$

with $\Omega_m+\Omega_\Lambda=1$. Factors of $\omega_{\rm i}$ contributing in the integrand arise from (a) replacing comoving $dF_3/dE_3 = \frac{c}{4\pi}\frac{dn_3}{dE_3}$ with physical $(dF_3/dE_3)_0$ today, which gets a contribution $\omega_{\rm i}^{-2}\,dF_3(\omega_{\rm i},E_3)/dE_3$ from each slice of $\omega_{\rm i}$; and (b) two factors of $\omega_{\rm i}^3$ from replacing comoving n_1 and $dF_2=\frac{c}{4\pi}dn_2$ with their physical values needed for the scattering rate expressed in $d\sigma$.

The generalization of Eq. (28) to include red-shifting is

$$1-\cos\theta_3^B = \frac{m_2^2\,E_3^0\,\omega_{\rm i}}{m_1\,E_2\,(E_2-E_3^0\,\omega_{\rm i})}\,, \qquad (53)$$

which leads to the $\omega_{\rm i}$-dependent lower bound on E_2 of

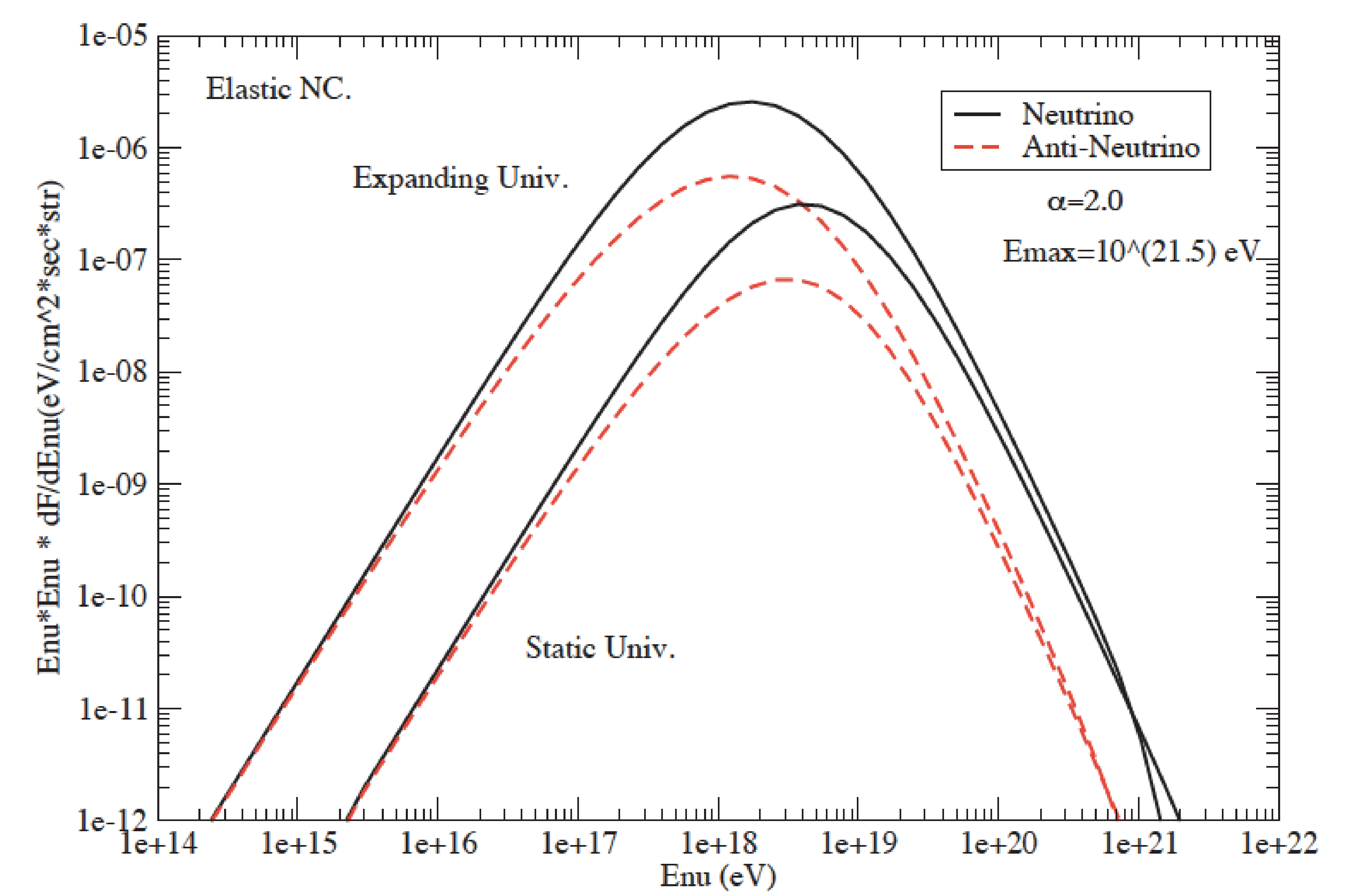
$$E_2 \geq \frac{1}{2}\,(E_3^0\,\omega_{\rm i})\left(1+\sqrt{1+\frac{2m_2^2}{m_1\,(E_3^0\,\omega_{\rm i})}}\right)\equiv(E_2)_{\min}(\omega_{\rm i})\,. \qquad (54)$$

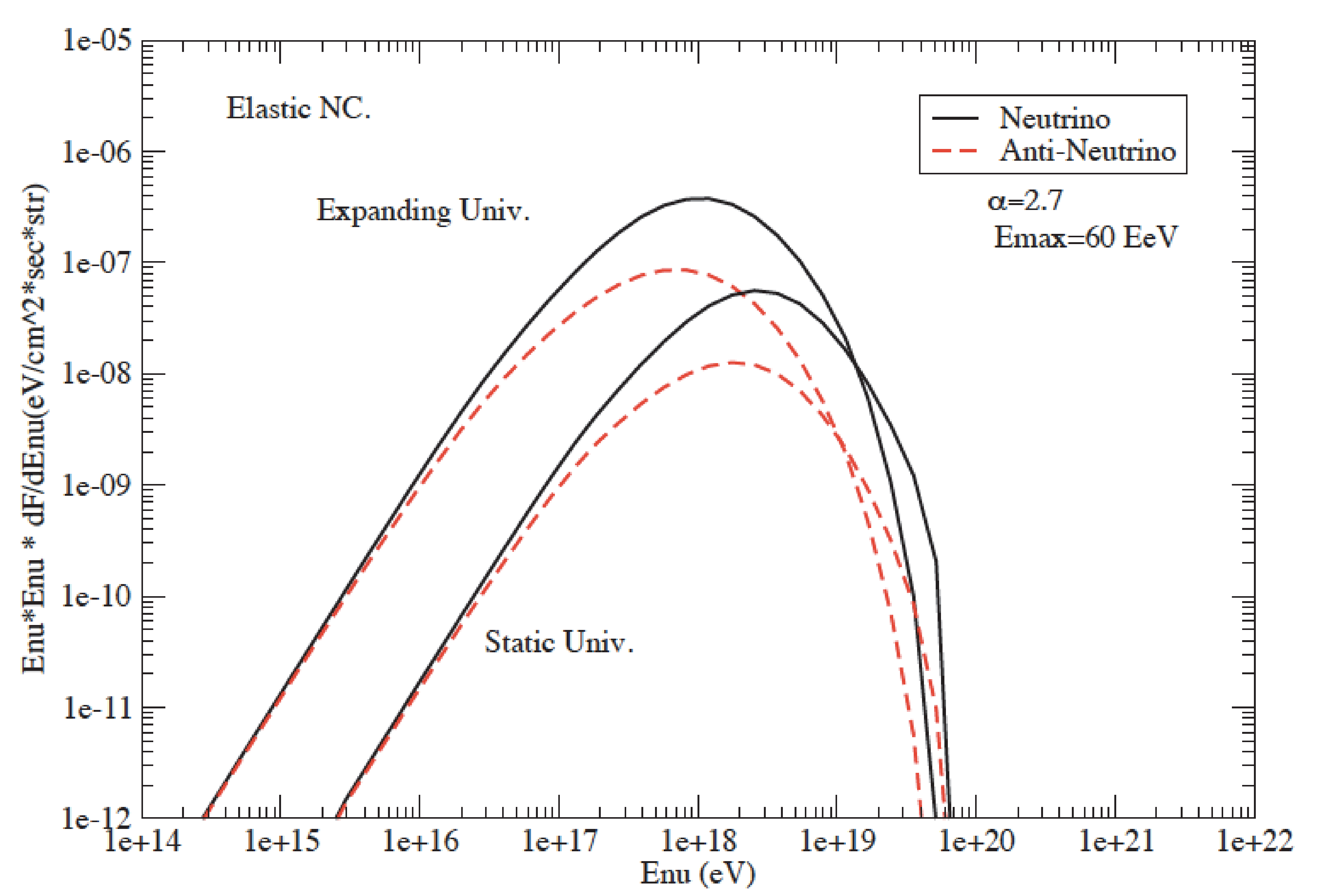
For comparison, “static model”

For the “static” model, we take the Hubble time $\tau_H \equiv H_0^{-1} \sim 13$ Gyr to be the epoch of cosmic ray production. The expression for the differential proton flux in Eqs. (11) or (21) or (29) now becomes

$$\frac{dF}{dE_p^s}(t_i, E_p^s) = \int_{t_i}^{H_0^{-1}} dt_s \left(\frac{d\,\dot{F}}{dE_p^s}(E_p^s)\right)_0 P(E_p^s, t_s; E_p, t_i) = (\tau_H - t_i)\left(\frac{d\,\dot{F}}{dE_p^s}(E_p^s)\right)_0 , \qquad (45)$$

with the lookback time of the interaction is bounded by $0 \le t_i \le \tau_H$. We have inserted into the evolution integral the probability $P(E_p^s, t_s; E_p, t_i)$ that a proton produced at its source at time t_s with energy E_p^s propagates to have energy E_p at the time of interaction t_i. In other words, the modifications of the primary proton spectrum due to energy losses from GZK photo-pion production and e^+e^- pair production on the CMB reside in $P(E_p^s, t_s; E_p, t_i)$. Since we are omitting these losses in our calculations, we wet P to unity.


Elastic NC.
Neutrino
Anti-Neutrino
Expanding Univ.
α=2.0
Emax=10^(21.5) eV
Static Univ.
Enu*Enu * dF/dEnu(eV/cm^2*sec*str)
Enu (eV)
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-12
1e+14
1e+15
1e+16
1e+17
1e+18
1e+19
1e+20
1e+21
1e+22



Elastic NC.
Neutrino
Anti-Neutrino
α=2.7
Emax=60 EeV
Expanding Univ.
Static Univ.
Enu*Enu * dF/dEnu(eV/cm^2*sec*str)
Enu (eV)
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-12
1e+14
1e+15
1e+16
1e+17
1e+18
1e+19
1e+20
1e+21
1e+22

Summary

Preliminary: upscattered neutrino flux peaks around 10^{17} eV, at a micro-WB or less,

but,

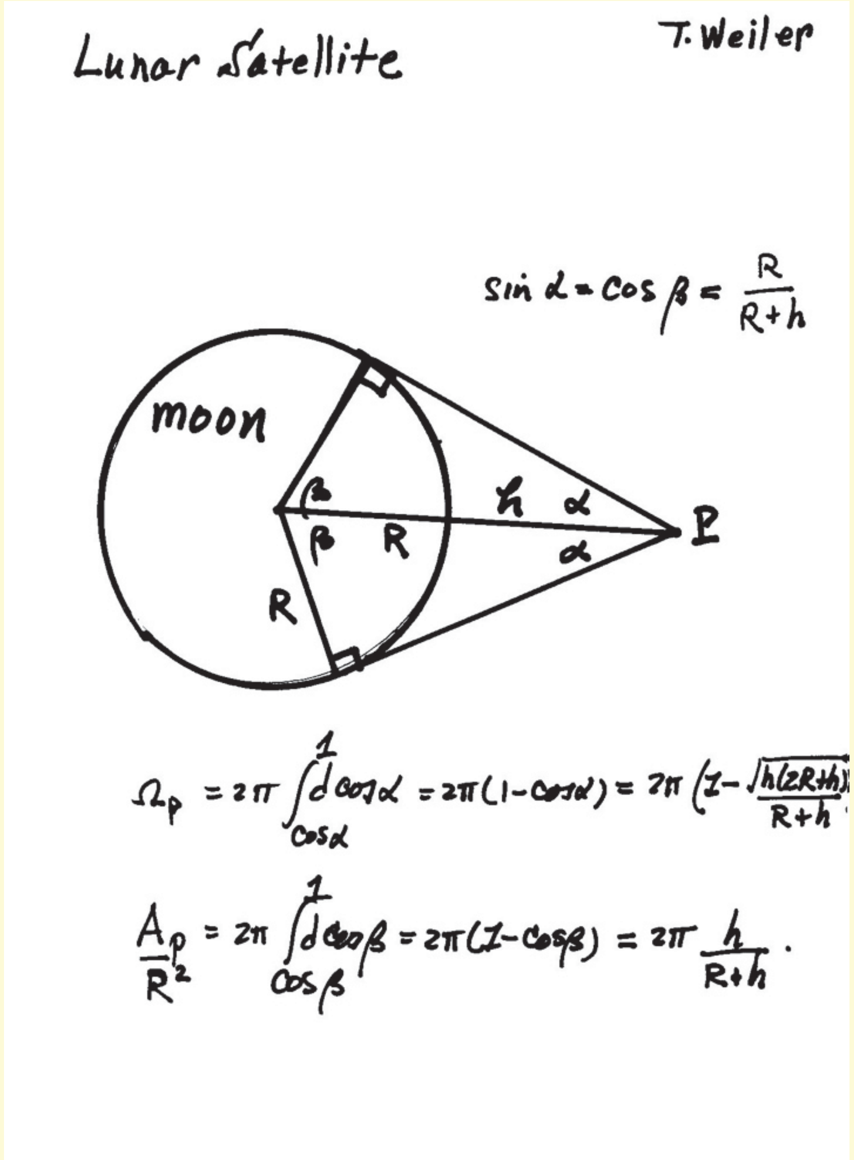
we are working on making the flux larger!

(some flux guaranteed, but not necessarily interesting/measurable.)

IceCube is gigaton detector,
EUSO is teraton (but with 20% duty factor),
Lunar satellites are ~petaton.

JEM-EUSO: Extreme Universe Space Observatory

Data moon and theory moon:



Jim Adams and Moon Traffic

Subject: **RE: lunar satellites**
Date: June 17, 2011 8:15:21 AM CDT
To: Thomas J Weiler <tom.weiler@Vanderbilt.Edu>

Tom,

As I recall, all the early missions were designed to crash into or land on the moon. There was lunar Orbiter satellite series (1, 2, 3, 4 and 5) from the US that mapped the moon before the Apollo landings. I think some of the Russian Luna missions were orbiters. There was also Explorer 35 that orbited the moon during the Apollo era.

The Apollo capsules of course orbited the moon briefly beginning with Apollo 11. Then there was Clementine from the DoD that was in orbit of the moon for a long time before being sent of to chase a comet. I had an experiment on that one.

The US Lunar Prospector mission orbited the moon in the late 1990s.

Recently there were several, SMART-1 from ESA, Selene from Japan, Chandrayaan-1 from India, Chang'e-2 from China, Lunar Reconnaissance Orbiter from the US

I think the list at http://the-moon.wikispaces.com/Lunar+Missions is probably complete.

Jim

Extra slides

Auger and EUSO FoV

Table D.2-3. Comparison of EUSO Baseline Mission relative to present data (2010)

Experiment	Geometry (km2 sr)	Status	Start	Livetime (years)	Duty Cycle	Cloud impact	Exposure (km2 sr yr)	Relative
Auger	7,000	Operational	2006	4	1.0		18,000	0.7
AGASAHiRes		Stopped					4,800	0.2
TA	1,200	Operational	2008	2	1.0		1,600	0.1
TUS	30,000	Developed	2012	5	0.2	0.7	21,000	1.2
JEM-EUSO (E>70 EeV)	285,000	Proposed	2017	3	0.2	0.7	110,000	4.5
JEM-EUSO (E>100 EeV)	455,000	Proposed	2017	3	0.2	0.7	180,000	7.4

*Includes both nadir and tilt mode

Auger and EUSO FoV

Table D.7-1 Comparison of EUSO STEO Mission relative to future data (2022)

Experiment	Geometry (km2 sr)	Status	Start	Livetime (years)	Duty Cycle	Cloud impact	Exposure (km2 sr yr)	Relative
Auger	7,000	Operational	2006	16	1.0		95,000	0.8
TA	1,200	Operational	2008	14	1.0		19,200	0.2
TUS	30,000	Developed	2012	5	0.2	0.7	21,000	0.3
JEM-EUSO (E>100 EeV)	470,000	Proposed	2017	5	0.2	0.7	310,000	2.5
JEM-EUSO (E>300 EeV)	1,300,000	Proposed	2017	5	0.2	0.7	870,000	7.0

*Includes both nadir and tilt mode