NASA Technical Memorandum 82017

Looking for Antimatter with DUMAND

F. W. Stecker and R. W. Brown

(NASA-TM-82017) HEAVY WEAK BOSONS, COSMIC ANTIMATTER AND DUMAND. 2: LOOKING FOR COSMIC ANTIMATTER WITH DUMAND (NASA) 17 p HC A02/MF A01 CSCL 03B G3/93

N80-33333

Unclas 34235

SEPTEMBER 1980

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

Heavy Weak Bosons, Cosmic Antimatter and DUMAND:

II: Looking for Cosmic Antimatter with DUMAND

F.W. Stecker

Laboratory for High Energy Astrophysics

NASA Goddard Space Flight Center

Greenbelt, Maryland 20771

and

R.W. Brown

Physics Department

Case Western Reserve University

Cleveland, Ohio 44106

Abstract: We discuss various means for using high energy neutrino astronomy to directly test for the existence of cosmic antimatter on a significant cosmological scale. The best future hope for such a test may lie in studies of the ultrahigh energy diffuse neutrino background using acoustic detectors, particularly if high mass Glashow resonances exist. Point source studies are also discussed.

I. Why Look for Cosmic Antimatter with DUMAND?

In a previous paper[1] we have argued the plausibility of expecting a domain structure of baryon and antibaryon excesses to emerge from the early evolution of the big-bang from spontaneous symmetry breaking at the GUT (grand unified theory) level when horizon effects are taken into account. Further work[2,3] has been encouraging, and we feel that a domain type baryon symmetric cosmology provides at least a viable alternative theory to the present orthodox picture where antimatter is assumed to be absent on the macroscopic and astronomical scales.

We therefore feel that one should seriously consider the possibility that we live in a universe where roughly half of the distant galaxies which we see may consist of antimatter. Evidence for such a structure has been given[1,4-6] which we consider to be highly suggestive, but definitive tests remain to be explored. In this regard, we consider that neutrino astronomy is likely to play a key role in the future. This conclusion stems from the basic fact that the photon is its own antiparticle whereas the neutrino is not. Thus, at all wavelengths of the electromagnetic spectrum galaxies and antigalaxies look alike, but such is not the case when one looks with "neutrino telescopes."[7]

The basic physics argument regarding the question of a baryon symmetric versus an asymmetric cosmology hinges on the manner in which CP violation is incorporated into unified gauge theories (and into nature). If the CP violation is spontaneous, it will arise with random sign changes in causally independent regions[2,3] and the universe will naturally split into domains of baryon and antibaryon excesses with no preferred direction of

CP symmetry nonconservation. Aside from philosophical and aesthetic considerations, other motivations for considering that CP violation occurs spontaneously have come from problems involving fundamental gauge theory itself.[8]

The basic scenario envisioned for a viable baryon symmetric cosmology is then outlined in Figure 1. This scenario has profound implications for much of astrophysics including the problems of helium synthesis, galaxy formation[5,10] and a viable explanation of the cosmic γ-ray background radiation[4,5] as shown in Figure 2. Thus, results of a significant neutrino search for cosmic antimatter would have profound implications for our understanding of the large scale evolution and structure of the universe.

II. Looking for an Antimatter Signature in the Diffuse Cosmic Neutrino Background

In order to discuss the possibility of looking for an antimatter signature in the diffuse cosmic neutrino background, we will draw heavily on calculations of diffuse cosmic neutrino fluxes reported previously.[11] A production mechanism of particular importance in this context because of its large inherent charge asymmetry involves the photoproduction of charged pions by ultrahigh energy cosmic rays interacting with the universal 3K blackbody background radiation[12]. The most significant reactions are

$$p + \gamma \rightarrow n + \pi^+ \tag{1}$$
$$\bar{p} + \gamma \rightarrow \bar{n} + \pi^-$$

which occurs in the astrophysical context principally through the resonance channels

$$p + \gamma \to \Delta^+$$
$$\bar{p} + \gamma \to \Delta^- \qquad (2)$$

because of the steepness of the ultrahigh energy cosmic ray spectrum.[13]

The principal charged pion decay modes are, of course

$$\pi^+ \to \mu^+ + \nu_\mu, \quad \mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e \qquad (3)$$

$$\pi^- \to \mu^- + \bar{\nu}_\mu, \quad \mu^- \to e^- + \nu_\mu + \bar{\nu}_e \qquad (4)$$

The four leptons resulting from pion decay split the pion rest energy almost equally and there is no asymmetry in ν_μ versus $\bar{\nu}_\mu$ production. However, the π^+ decays produce ν_e's whereas the π^- decays produce $\bar{\nu}_e$'s . Thus, if one can distinguish ν_e's and $\bar{\nu}_e$'s in one's detector, in principle the diffuse neutrino background can tell us the ratio of ultrahigh energy protons to antiprotons in the universe. (The universe is transparent to ν_e's and $\bar{\nu}_e$'s coming from all observable distances.) It has been pointed out that there is a significant and potentially useful way of distinguishing $\bar{\nu}_e$'s from ν_e's, namely through their interactions with electrons.[14] The ν_e's have an enhanced cross section through formation of weak intermediate vector bosons such as the W^-,

$$\bar{\nu}_e + e^- \to W^- \quad , \qquad (5)$$

the Glashow resonance effect.[15] For electrons at rest in the observer's system, the resonance occurs for cosmic $\bar{\nu}_e$'s energy

$$E^W = M_W^2/2m_e = 6.3 \times 10^3 \text{ TeV} \qquad (6)$$

for $M_W \simeq 80$ GeV corresponding to $\sin^2\theta_W \simeq 0.23$.

For our purposes here, we will not restrict ourselves to this W^- above, but we will also entertain the possibility of higher mass intermediate vector bosons, B^- (see Brown and Stecker, these proceedings)

$$\bar{\nu}_e + e^- \rightarrow B^- \tag{7}$$

and resonance energies

$$E^B = M_B^2/2m_e > E^W \tag{8}$$

The cosmic and atmospheric fluxes for $\bar{\nu}_e$'s , based on the calculations in Reference 11, are shown in Fig. 3. Assuming that there is no significant enhancement in the flux from production at high redshifts, the integral $\bar{\nu}_e$ spectrum from $\nu_{\bar{p}}$ interactions is expected to be roughly constant at 10^{-}[illegible] to 10^{-17} ν_e's cm^{-2} sr^{-1} up to an energy of $\sim 2 \times 10^7$ TeV (2×10^{19} eV) above which it is expected to drop steeply. Fig. 3 shows the estimated upper limit (VL) and lower limit (LL). It is expected that the largest competing background flux of $\bar{\nu}_e$'s will be prompt $\bar{\nu}_e$'s from the decay of atmospherically produced charmed mesons. The estimated upper and lower limits for this flux are also shown in Fig. 3 and the position of the W^- resonance is indicated by an arrow. It can be seen that a cosmic $\bar{\nu}_e$ signal may be heavily contaminated by prompt atmospheric $\bar{\nu}_e$'s at the resonance energy E^W . The cosmic flux is expected to dominate the higher energies so that the existence of higher mass bosons B^- may be critical to any proposed test for cosmic antimatter using diffuse fluxes. In the following discussion, we will assume that such bosons exist. (It may be possible to test for their existence independently using DUMAND (see Brown and Stecker, these proceedings) or future colliding beam accelerators.)

The total cross section

$$\sigma(\bar{\nu}_e e^- \to B^- \to \text{all}) = 24\pi \frac{\Gamma\,\Gamma_\ell}{(s-M_B^2)^2 + \Gamma^2 M_B{}^2} \qquad (9)$$

where Γ is the total width, Γ_ℓ the width for a leptonic channel and s is the square of the center-of-mass energy of the $\bar{\nu}_e e^-$ system. The integrated cross section is

$$\int \sigma_{res}\, ds = 24\pi^2 \frac{\Gamma_\ell}{M_B} \qquad (10)$$

Assuming three generations of quarks and leptons, $\Gamma \simeq 12\,\Gamma_\ell$. QCD corrections give a more exact relation

$$\Gamma \simeq 9\,\Gamma_\ell \left(1 + \frac{\alpha_s}{\pi}\right) + 3\,\Gamma_\ell \simeq 12.43\,\Gamma_\ell \qquad (11)$$

For the W^- resonance

$$\Gamma_\ell = \frac{G_F}{\sqrt{2}} \frac{M_W^3}{6\pi} = 0.226 \text{ GeV}$$

and $$\int \sigma_W ds = 2.58 \times 10^{-28} \text{cm}^2\, \text{GeV}^2 \qquad (12)$$

The background event rate per electron (and nucleon) from $\sigma^{\nu_\mu N}$ integrated over the width of the resonance energy

$$\Delta E^W = \frac{M_W \Gamma}{2m_e} \qquad (13)$$

provides the "noise" over which the resonance "signal" must be seen. The "signal/noise" ratio is then

$$R = \frac{\int_{\Delta E^W} \sigma_W\, d\bar{E}}{\int_{\Delta E^W} \sigma^{\nu N} dE} = \frac{\frac{1}{2m_e}\int \sigma_W ds}{<\sigma^{\nu N}> \frac{M_W \Gamma}{2m_e}} = 24\,\pi^2 \left(\frac{\Gamma_\ell}{\Gamma}\right)/M_W^2 \quad <\sigma^{\nu N}> = 3.6 \times 10^3 \qquad (14)$$

For the generalized Glashow resonance B^- where $M_B^2 \equiv \kappa M_W^2$, $\kappa > 1$, we find (see Brown and Stecker, these proceedings)

$$R = \frac{3.6 \times 10^3}{\kappa} \tag{15}$$

The event rate expected for $\bar{\nu}_e$ induced B^- events is quite low using the "conservative" estimates for the $\bar{\nu}_e$ flux shown in Figure 3. For example, with

$$I_{\bar{\nu}_e}^{\bar{p}\gamma} = 10^{-26} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}^{-1}$$

and with
$$\int_{-\Gamma/2}^{\Gamma/2} \sigma_B dE = \frac{1}{2m_e} \int \sigma_B ds \simeq 3 \times 10^{-24} \text{ cm}^2 \text{ GeV} \tag{16}$$

(where we have assumed a factor of 10 increase over $\int \sigma_W dE$), we find an event rate

$$r_{B^-} = 4\pi I_{\bar{\nu}_e} N_e \int \sigma_{B^-} dE \simeq 1 \text{ event/yr} \tag{17}$$

for a 10^{11} ton acoustic detector. (Note: Acoustic detectors can be much more efficient at ultrahigh energies than optical detectors.[17]) However, two points may be noted regarding this low event rate: 1) It may be possible that $I_{\bar{\nu}_e}$ is significantly higher (perhaps $\sim 10^{-25}$ cm^2 s^{-1} sr^{-1} GeV^{-1}) due to cosmic ray production at high redshifts,[18] and 2) No significant signal is expected otherwise (within the level given by equation (17)) unless there is significant $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$ mixing. Such a significant $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$ mixing is not supported by present data.[19] Also, owing to the very low probability for helicity flipping,[20] $\bar{\nu}_e \leftrightarrow \nu_e$ oscillations, if they occur, will not produce a significant left-handed signal (See Brown & Stecker, these proceedings).

An acoustic deep underwater neutrino detector may provide the best hope for testing for cosmic antimatter by studying the diffuse background neutrinos. The practical threshhold for such devices appears to be in the neighborhood of $10^3 - 10^4$ TeV[17], where the W^- resonance occurs. For higher mass resonances B^-, the relevant neutrino resonance energy $E^B \propto M_B^2$ and the effective detection volume $V_{eff} \propto M_B^6$. Considering that the incident flux is expected to be roughly constant up to energies $\sim 2 \times 10^7$ TeV, one gains much in looking for higher mass Glashow resonances at higher energies. Acoustic detectors of effective volume $>>10$ km^3 (10^{10} tons) may be economically feasible and consequently event rates of $\sim 10^2 - 10^4$ yr^{-1} may be attained in time.

III. Looking for Antimatter Signatures in Cosmic Point Sources

The asymmetry in the production of charged pions in matter versus antimatter sources is reflected in cosmic-ray pp and $\bar{p}\bar{p}$ interactions as well as $p\gamma$ and $\bar{p}\gamma$ interactions. Through the principal decay mode (equation (3)), this asymmetry is again reflected in a $\nu_e - \bar{\nu}_e$ asymmetry and thus in the characteristics of events produced in deep underwater neutrino detectors. For ν-sources, these effects may be measurable at energies $\sim$ 1-10 TeV with optical detectors. The details of this possibility have been discussed by Learned and Stecker.[7]

The possibility that $p\gamma$ and $\bar{p}\gamma$ in sources interactions would produce significant fluxes of $\bar{\nu}_e$'s, detectable through the W^- resonance, has been suggested by Berezinsky and Ginzburg (these proceedings) as a way of looking for cosmic antimatter. Hopefully, this interesting suggestion will be explored in more detail as our understanding of the nature of cosmic-ray production in compact objects increases. The relevant interactions here would involve $\sim 10^5$ TeV cosmic rays and ultraviolet photons in sufficient quantities.

Another possible $\nu_e - \bar{\nu}_e$ asymmetry which may provide a future test for cosmic antimatter involves lower energy (30-50 MeV) neutrinos produced during the gravitational collapse of astrophysical objects. Neutrinos from gravitational collapse events are expected to exhibit significant $\nu_e - \bar{\nu}_e$ asymmetries[21] which can be used to determine whether the collapsing object consists of matter or antimatter by separately determining the fluxes of ν_e's and $\bar{\nu}_e$'s . However, the bursts expected from a <u>stellar</u> collapse in a neighboring supercluster will be 10^8 times weaker than the $\bar{\nu}_e$ burst previously reported[22], making detection of extragalactic antimatter collapses very difficult unless the masses involved are on a much larger scale.

IV. Conclusion

Neutrino telescopes can be used to distinguish between matter and antimatter sources of cosmic neutrinos and thus provide a direct test of baryon symmetric cosmologies. Perhaps the most promising form of test may lie in studies of ultrahigh energy photomeson-produced neutrinos using acoustic detectors. A two stage program is suggested in which the existence of heavy Glashow resonances B^- is first independently established.

References

1. R.W. Brown and F.W. Stecker, Phys. Rev. Lett. 43, 315 (1979).
2. K. Sato, Nordita Preprint (1980).
3. G. Senjanović and F.W. Stecker, Physics Letters B, in press.
4. F.W. Stecker, D.L. Morgan, Jr. and J. Bredekamp, Phys. Rev. Lett. 27, 1469 (1971).
5. F.W. Stecker, Nature 273, 493 (1978).
6. F.W. Stecker and R.W. Brown, Proc. Neutrino 79 Intl. Conf., Ed. A. Haatuft and C. Jarlskog, Univ. of Bergen, Norway 2, 409 (1980).
7. J. Learned and F.W. Stecker, Proc. Neutrino 79, ibid. 2, 461 (1980); see also Proc. 1979 DUMAND Summer Workshops, Ed. J. Learned, 274 (1980).
8. M.A.B. Bég and H.S. Tsao, Phys Rev. Lett. 41 278 (1978); R.N. Mohapatra and G. Senjanović, Phys. Lett. 79B, 283 (1978); H. Georgi, Hadronic J 1, 155 (1978); G. Segré and A. Weldon, Phys. Rev. Lett. 42, 1191 (1979); S.M. Barr and P. Langacker, Phys. Rev. Lett. 42, 1654 (1979).
9. F.W. Stecker, Phys. Rev. Lett. 44, 1237 (1980), see also F.W. Stecker, these proceedings.
10. F.W. Stecker and J.L. Puget, Astrophys. J. 178, 57 (1972).
11. F.W. Stecker, Proc. 1978 DUMAND Summer Workshop, Ed. A. Roberts, Scripps Inst., La Jolla 2, 267 (1979); F.W. Stecker, Astrophysical Journal 228, 919 (1979).
12. The authors thank V.S. Berezinsky (private communication) for bringing this to our attention.
13. F.W. Stecker, Phys. Rev. Lett. 21, 1016 (1968); Astrophys. and Space Science 20, 47 (1973).
14. L.G. Dedenko, V.A. Kuz'min, E.A. Tainov and I.M. Zhelezhnykh, Proc. 1978 DUMAND Summer Workshop, ibid 2, 81 (1979).

V.S. Berezinsky, D. Cline and D.N. Schramm, Phys. Lett. 78B, 635 (1978); K.O. Mikaelian and I.M. Zheleznykh, preprint OSU-106 (1980).

15. S.L. Glashow, Phys. Rev. 118, 316 (1960).
16. D. Albert, W.J. Marciano and D. Wyler, preprint COO-2232B-190 (1979).
17. T. Bowen and J.G. Learned, Proc. 16th Int'l Cosmic Ray Conf Kyoto, Japan 10, 386 (1979); H. Bradner and J. Learned, Proc 1978 DUMAND Summer Workshop 1, 227 (1979).
18. V.S. Berezinsky and G.T. Zatsepin, Proc. 1976 DUMAND Summer Workshop, Ed. A. Roberts, Fermilab, pg. 215 (1977); See, however, the caveat in F.W. Stecker, Proc. Neutrino 79 Intl. Conference Ed. A. Haatuft and C. Jarlskog Univ. of Bergen, Norway 2, 475 (1980), also Astrophys. J. 228, 919 (1979).
19. A. De Rújula, M. Lusignoli, L. Maiani, S.T. Petcov, and R. Petronzio, Nuc. Phys. B168, 54 (1980).
20. S.L. Shapiro S.A. Teukolsky and I. Wasserman, Cornell Preprint CESR-746 (1980).
21. D. Schramm, Proc. 1976 DUMAND Summer Workshop, ibid. pg. 87 D.K. Nadyozhin and I.V. Otroshenko, Astron. Zh 57, (1980).
22. K. Lande, G. Bozoki, W. Frati, C.K. Lee, E. Fenyves and O. Saavedra, Nature 251, 485 (1974).

Figure Captions

Fig. 1. No Caption

Fig. 2. The cosmic gamma-ray background spectrum predicted for matter-antimatter annihilation in a baryon symmetric big-bang cosmology shown together with Apollo 15 (AP) and SAS-2 satellite data (shading) and upper limits from balloon data. A separate X-ray background component (X) is also shown.

Fig. 3. Cosmic and atmospheric $\bar{\nu}_e$ fluxes.

SIMPLEST BARYON SYMMETRIC BIG-BANG SCENARIO

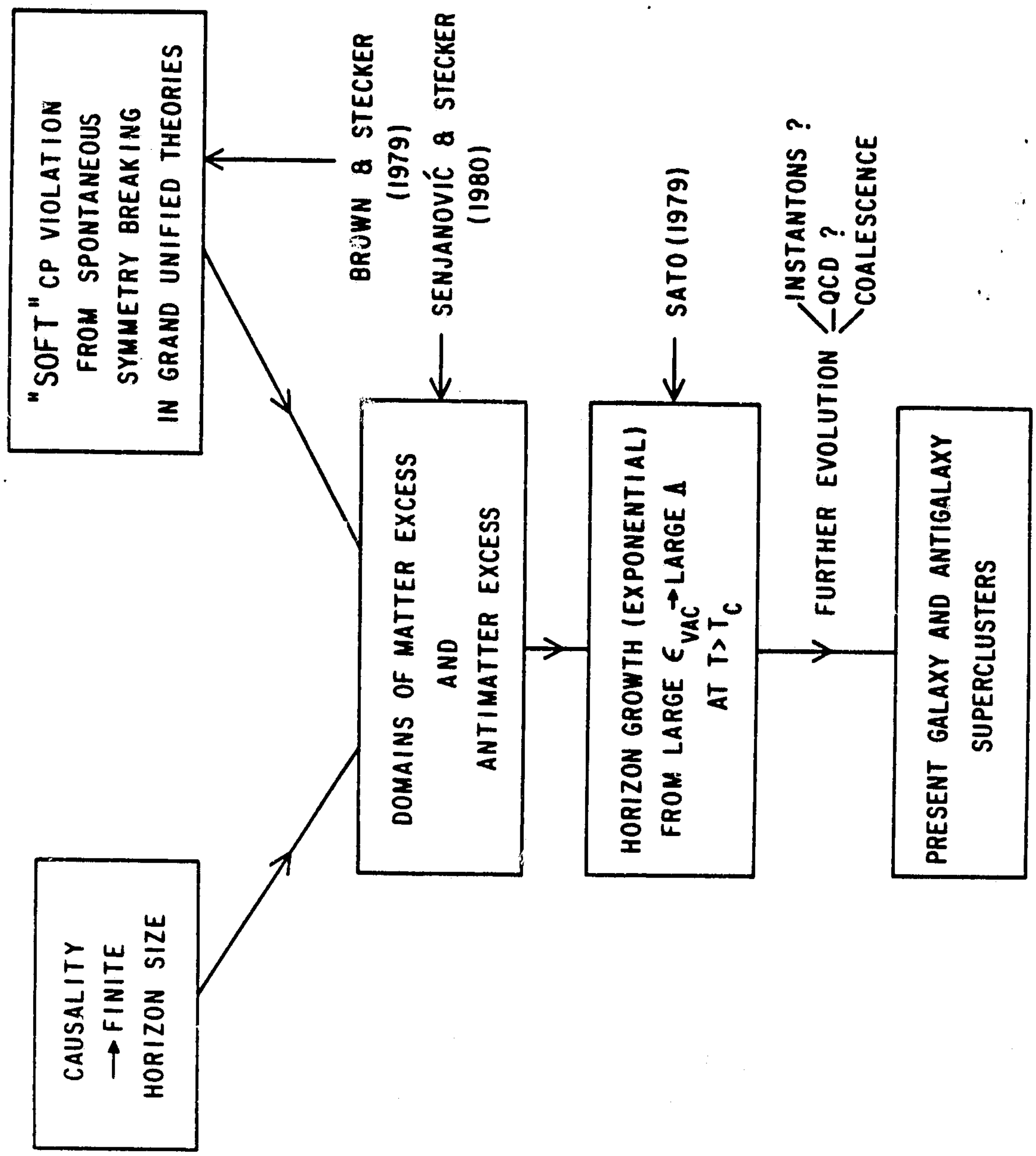


Fig. 1

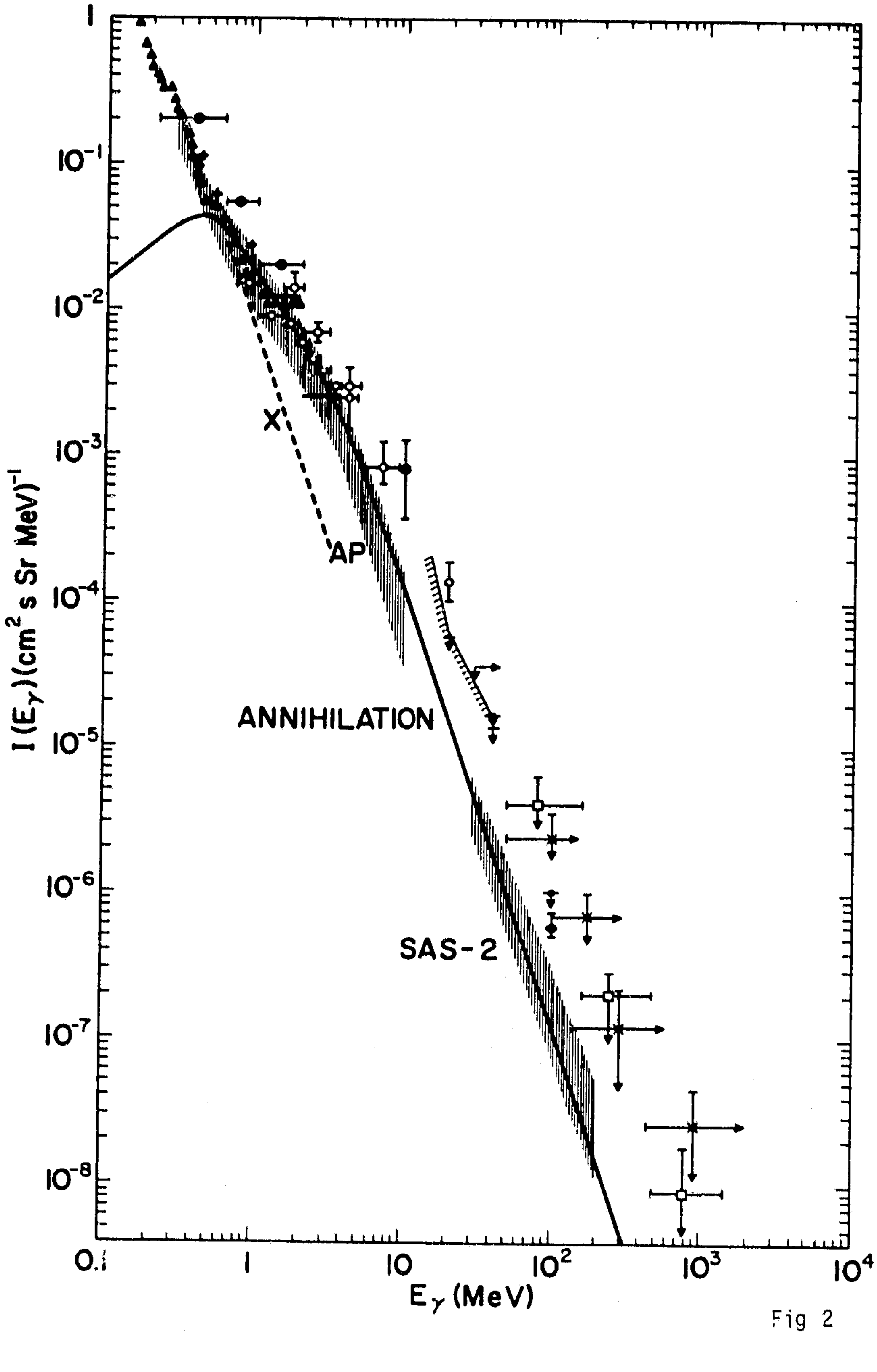
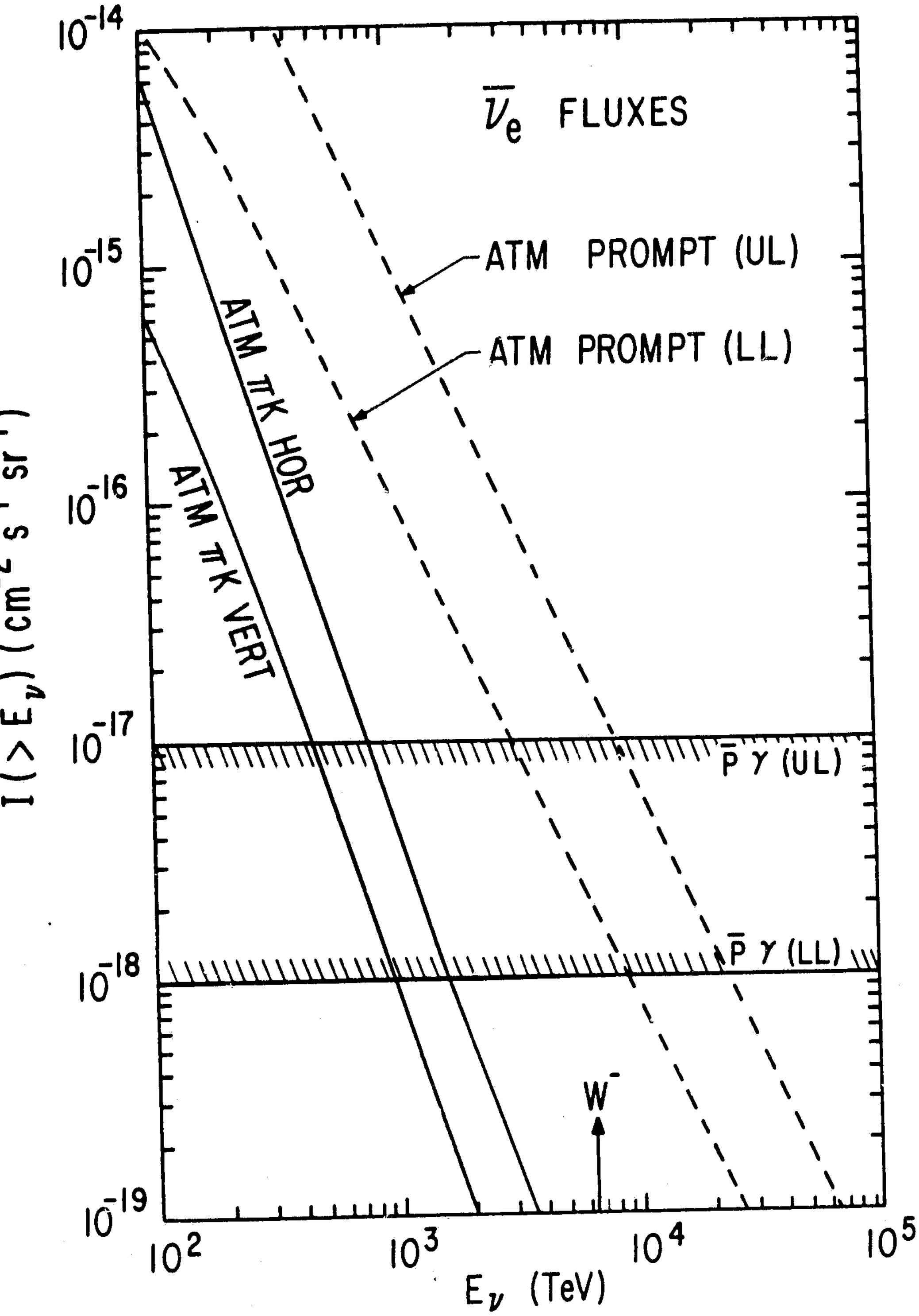

1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
10-8
I (Eγ) (cm² s Sr MeV)⁻¹
X
AP
ANNIHILATION
SAS-2
0.1
1
10
10²
10³
10⁴
Eγ (MeV)

Fig 2


$\overline{\nu}_e$ FLUXES
ATM PROMPT (UL)
ATM PROMPT (LL)
ATM πK HOR
ATM πK VERT
$\overline{P}\ \gamma$ (UL)
$\overline{P}\ \gamma$ (LL)
W^-
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{2}
10^{3}
10^{4}
10^{5}
$I(>E_\nu)$ ($cm^{-2}\ s^{-1}\ sr^{-1}$)
E_ν (TeV)