Neutrino and Other Bursts as Probes in Cosmology

If Neutrinos had a Mass...

(They DO !!!)

$$v_\nu \neq c = 1$$

$$v_\nu(E) = P/E \approx 1 - m^2/2E^2$$

<u>Zatsepin (1968)</u>

One neutrino type, but spread of energies

(Then limit of 200 eV could be reduced to 2 eV)

<u>1980's</u>

Different ν types with mass, time separated pulses, hopefully

$$\delta t \approx d\ \frac{m_2^2 - m_1^2}{2E^2}$$

Two smearing time scales: length of event, and flight time dispersion $\frac{d\ m^2}{E^2}\ \frac{\Delta E}{E}$

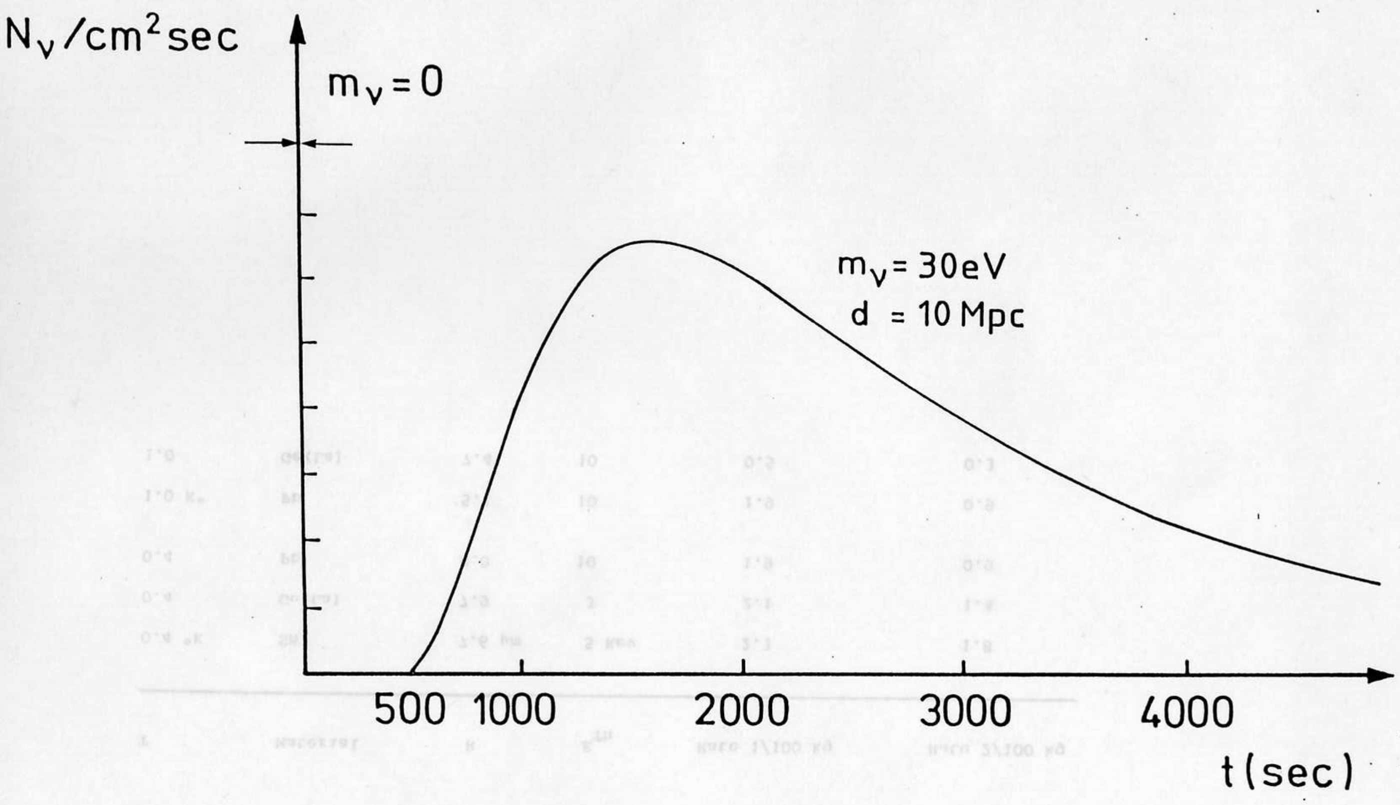


FIG. 1

Look Even *further* Back?

Consider cosmology Something Interesting

Happens.... Lag of Neutrino relative to photon (or among ν types) depends on cosmological epoch.

Universe is Expanding, ν's slow down, photons not

Usual metric $ds^2 = dt^2 - a^2(t)(d\mathbf{x})^2$

Useful fact: $P_i \sim \partial_i$ is conserved (nothing depends on $\mathbf{x}$)

$$\frac{dx}{dt} \approx \frac{1}{a(t)} - a(t)\frac{1}{2}\frac{m^2}{P^2(now)}$$

Find for difference between two

$$\frac{d(\Delta x)}{dt} \approx a(t)\frac{1}{2}[\frac{m_1^2}{P_1^2(now)} - \frac{m_2^2}{P_2^2(now)}]$$

At present where $a = 1$, Δx is physical distance between pulses.

Integrating, cosmological effect is given by $\int a(t)\ dt$

Compare with formula for redshift parameter z, re-express in terms of observable z

Time Delay

$$\Delta t \approx \frac{z}{H}[1 - \frac{3+q}{2}z + ...]\frac{1}{2}[\frac{m_1^2}{P_1^2(now)} - \frac{m_2^2}{P_2^2(now)}]$$

Burst Spreading

$$\Delta t \approx \frac{z}{H}[1 - \frac{3+q}{2}z + ...]\frac{1}{2}m^2[(\frac{1}{P(now)})^2 - (\frac{1}{P'(now)})^2]$$

Two Observables, Δt, z, two unknowns, H, q

***Large Scale Properties of Universe found by "Physics" instead of "Geometry".

*** Don't need to know distance, as with "Standard Candles".

*** Two good events, and H, q are determined

Physical Msmt of Hubble constant

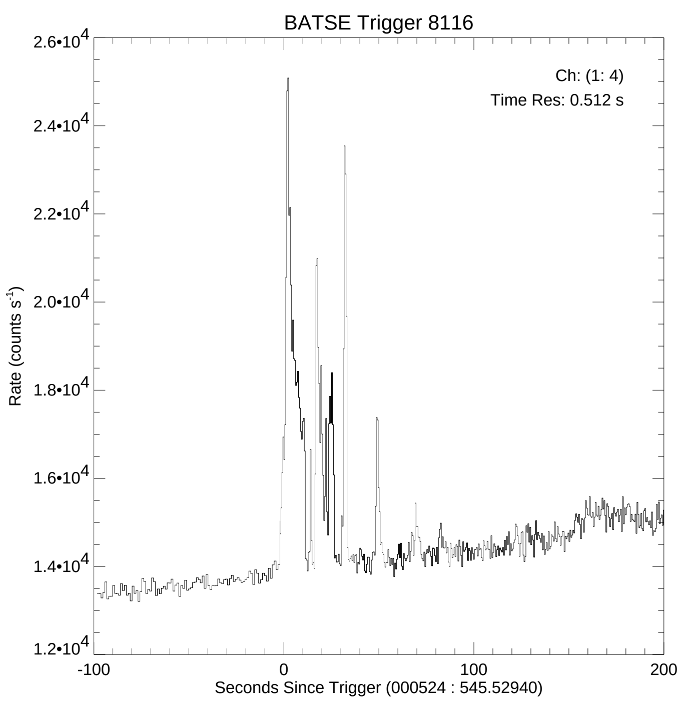
*** Sharp Timing Problem

Must resolve or extract time delay info. in burst

$$\frac{(m/\mathrm{eV})^2}{2(P/\mathrm{GeV})^2} \approx 50\mu\mathrm{sec/Mpc}.$$

Thousand Mpc $\sim$msec.

Bursts , Flares



Possibility sharp timing signal from collapse to Black Hole (Beacom, Boyd, and Mezzacappa)

Heavier particles (e.g. WIMPS) could help. Or maybe one neutrino is “heavy”?

Note ν mixing probably helps (explain)

Getting Behind the Big Bang

First Light—– some 300,000 yrs

Ifffff There Are Early Bursts, then:

First Neutrinos—–some seconds

First Universe—????????????????????????????

Formation of Baby Universe leads to detectable burst of weakly interacting particles???

Above effects would allow study of very early geometry

Bizarre Feature/Difficulty: "Events" that Last a long time

Enormous redshift $\sim 10^{10}$ at T=1 MeV, dilution of energy, flux

Amusing Thought: "1msec burst" will last a year!

Maybe your detector is not drifting......

Some further speculations...,with J. Silk

Bursts from the Very Early Universe

With ever more weakly interacting "messengers" we can look further back:

photons$\sim 10^5$ yr

neutrinos $\sim sec\,(\nu_e)$, or $\sim msec\,(\nu_\mu, \nu_\tau)$

WIMPS $\sim 10^{-9} sec$

. . .

gravitons $\sim 10^{-35} sec$

Could “see”–at least in principle– QCD phase transition(s), formation of “Baby U’s” , Transplanckian regime,.....??

Important point:

Length of burst not expected to increase indefinitely with red shift.

Natural timescale for burst is Hubble parameter– shortening at early times.

One finds, after redshift to present,
$\tau_{burst} \sim 9 \times (10^9 sec)(t_{em}/s)^{1/2}$

About a year at the QCD phase transition, $10^{-12}s$ at the Planck time.

Flux dilution:

Number crossing unit area $\approx N \cdot \frac{1}{4\pi}(\frac{1}{3t_{now}})^2$

$\sim N \cdot 6 \times 10^{-59}/cm^2$

N=initial number of particles in burst

Interesting: stops decreasing at high z

"Distance" to BB is finite

Size/ Present Energy Flux

Seemingly biggest possible burst is energy contained in a casually connected region ("within the horizon") at the time of emission. Gets small at very early times.

$$E^{now}_{horizon}/cm^2 = 3 \times 10^3 (t_{em}/s)^{3/2}\ \mathrm{eV/cm^2}$$

Enormous number of causally independent regions—tends to compensate small energy and small burst probability.

$\mathcal{P}$ = probability of a burst per unit Hubble 4-volume at emission time t_{em}

$$d\ (energy\ flux)_{now} = d\ (energy\ flux)_{cmb}\, \mathcal{P}\, \frac{1}{2}\, \frac{dt_{em}}{t_{em}}$$

Obtain

Leads to "Olbers paradox"? With $\mathcal{P}$ constant $\sim ln\, t_{em}$

A Curious new issue

M Can there be an arbitrarily weakly interacting particle???

Why: As would be expected, a graviton, can just reach us from the planck time $t_{em} = 1/m_{pl} = \sqrt{G}$.

$$\sigma \sim G^2 S^2 \qquad\qquad 1/\lambda \sim G^2 E u$$

To estimate from what “depth” a graviton would reach us:

$$\int_{t_{em}}^{t_{now}} (1/\lambda) dt \approx \int_{t_{pl}}^{\infty} (1/\lambda) dt = 1$$

Since only parameter is m_{pl}.

The transPlanckian epoch ??

If we want to see the transplanckian or quantum gravity epoch,

EEEasy

Invent a particle more weakly interacting than the graviton.

BUT Wrong!!

In GR the "charge" is the energy. All particles are universally coupled to it–all particles have energy.

No particle can interact more weakly than the graviton!!

Hence cannot see the transplanckian or quantum gravity epoch.

(Way out suggested by V. Zakharov: A string could be more weakly interacting than its constituents. Maybe a kind of shielding a la antigravity is posssible.)