Placing Limits on the Mass of Electron-Neutrinos from SN1987A
Polaris Mentorship Course, Spring 2024

Melanie Zaidel

Several hours before the electromagnetic signal from SN1987A reached the Earth, various ground-based neutrino observatories detected a burst of neutrinos. The Kamiokande II, IMB, and Baksan detectors together measured 25 neutrinos.

The population of neutrinos that were detected ranged in energy $\Delta E = E_2 - E_1$ and were detected over a time range $\Delta t = t_2 - t_1$. Assuming you know the distance to SN1987A, D, place an upper limit on the mass of the electron-neutrino in the following form:

$$m_{\nu_e} = a \text{ eV} \left(\frac{\mathrm{E_1}}{b \text{ MeV}}\right)^{\mathrm{x}} \left(\frac{\Delta \mathrm{t}}{c \text{ s}}\right)^{\mathrm{y}} \left(\frac{\mathrm{D}}{d \text{ kpc}}\right)^{\mathrm{z}}$$

You may use the following assumptions:

- All neutrinos were emitted at the same time
- The region of neutrino production is negligible compared to the distance d
- Neutrinos are highly relativistic ($m_\nu c^2 \ll E_\nu \to \gamma \gg 1$)
- Ignore neutrino oscillations

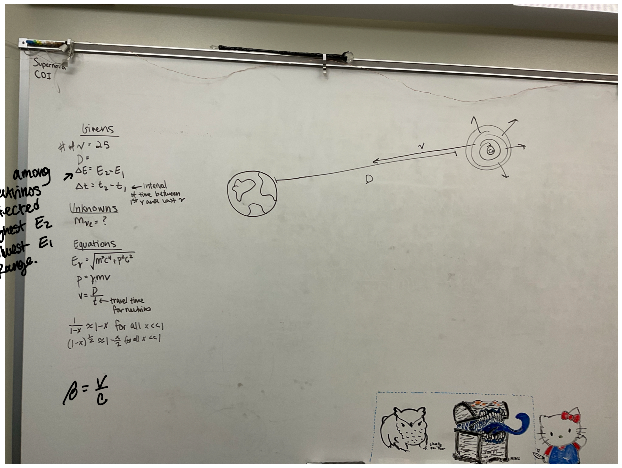
all electron neutrinos

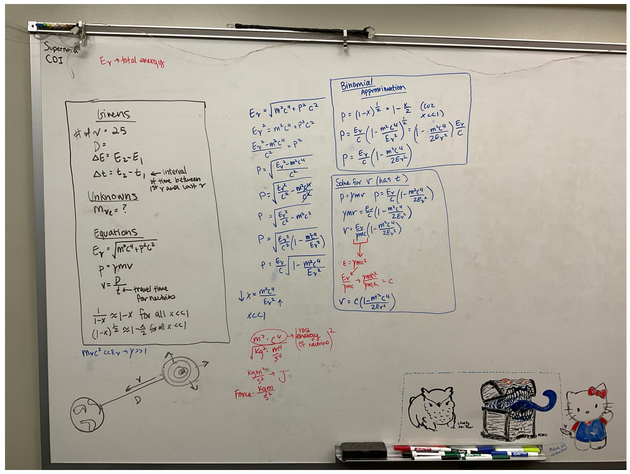
rest energy

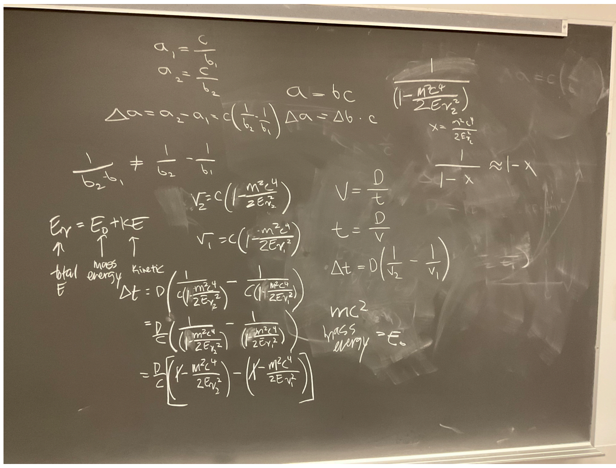
super high

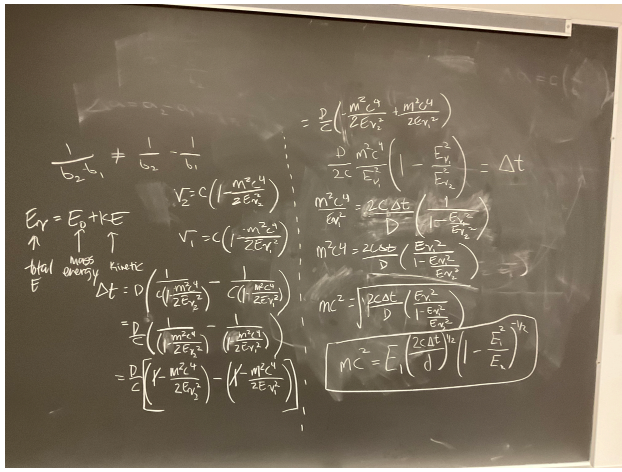
Some helpful expressions that may help you along the way include

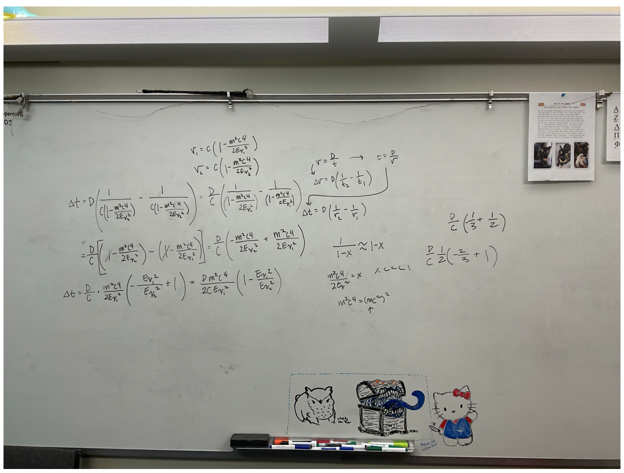
- $\frac{1}{1-x} \approx 1 - x$ for $x \ll 1$
- $(1-x)^{1/2} \approx 1 - \frac{x}{2}$ for $x \ll 1$
- $E = \sqrt{m^2c^4 + p^2c^2}$

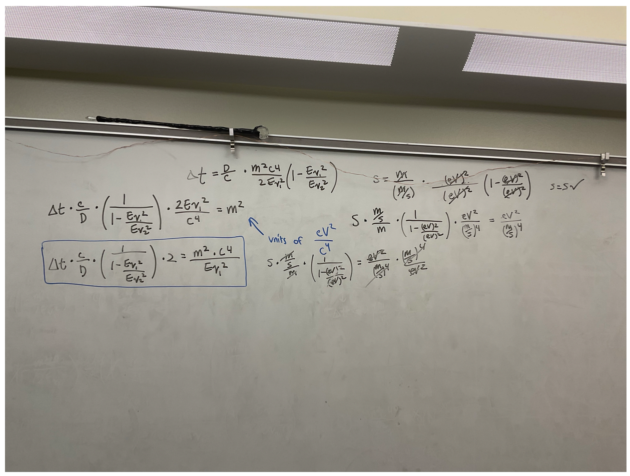

Supernova COI
Givens
among neutrinos detected highest E2 lowest E1 Range.
Unknowns
Equations
travel time for neutrinos

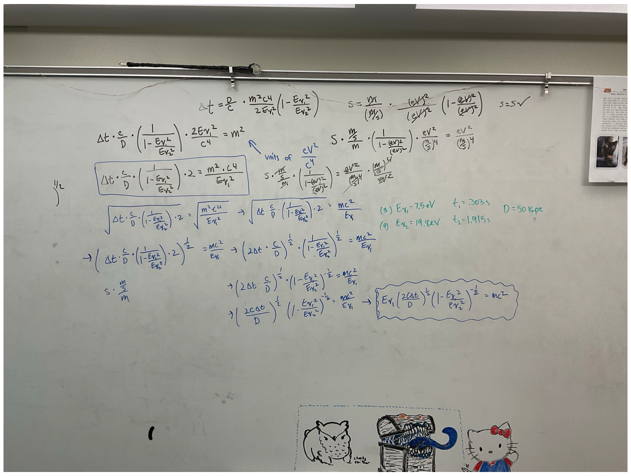

Supernova COI
Ev → total energy
Givens
Unknowns
Equations
Binomial Approximation
Solve for v (has t)


total E
mass energy
kinetic
mass energy


total E
mass energy
kinetic




units of



$$m_\nu c^2 = E_{\nu_1}\left(\frac{2c\Delta t}{D}\right)^{\frac{1}{2}}\left(1-\left(\frac{E_{\nu_1}}{E_{\nu_2}}\right)^2\right)^{-\frac{1}{2}}$$

$$\downarrow$$

$$\frac{1}{\sqrt{\left(1-\left(\frac{E_{\nu_1}}{E_{\nu_2}}\right)^2\right)}}$$

really small

really big

neutrinos w/ big ΔE

small Δt