Detecting Supernova ν's

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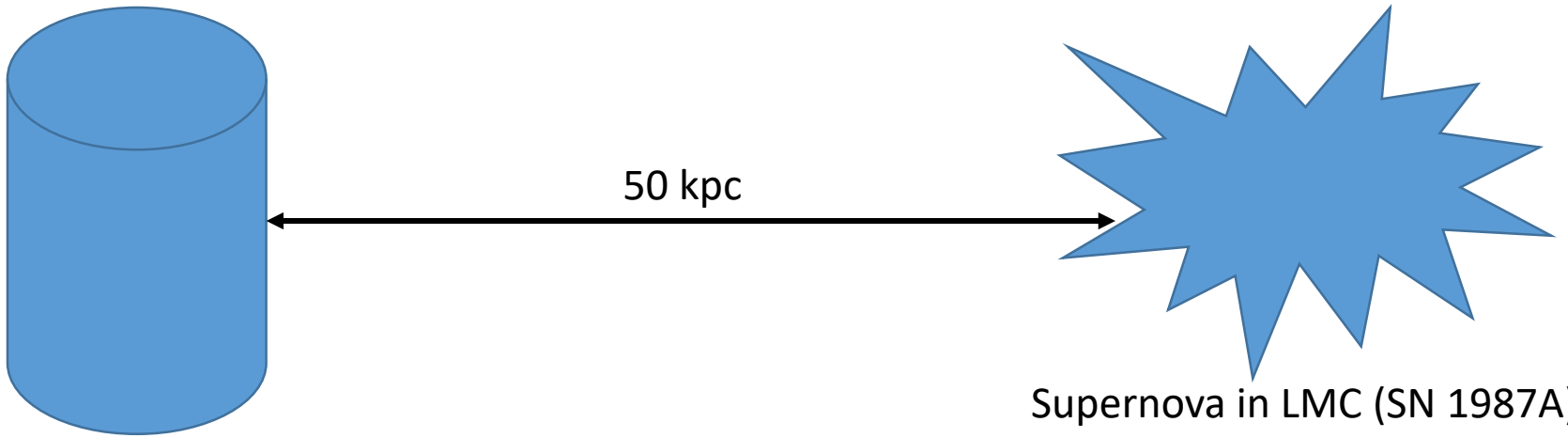
Problem statement

Find amount of energy SN 1987A emits in neutrinos (E_{SN}), estimate total number of neutrinos emitted (N_{emit}), and find the number that will be detected by Kamiokande/Hyper-K (N_{det})



Kamiokande

- Cross-sectional area ~15^2 m^2
- Mass ~3 kton
- Efficiency ~1
- 1 in 10^{15} neutrinos passing through will interact

Supernova in LMC (SN 1987A)

- 1% of energy is emitted via photons
- Remaining 99% emitted via neutrinos (f_ν) over 10 s <Energy per neutrino> ($<E_\nu>$) 12 MeV

(Quoted values are from the problem or simple approximations)

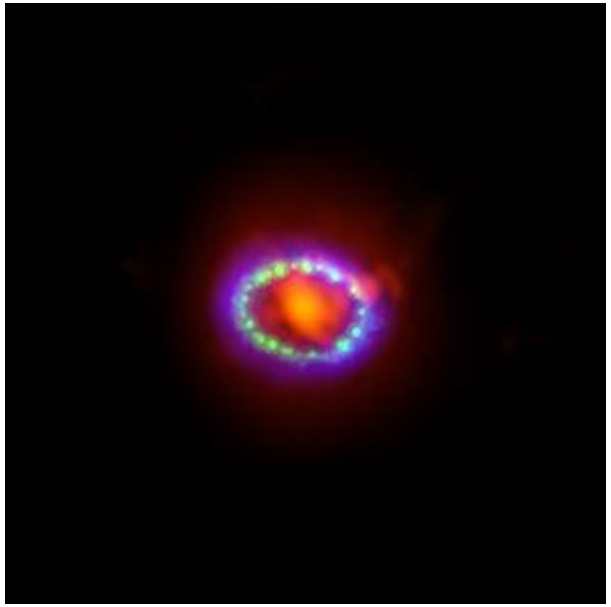
Simple solution

- $E_{SN} = f_{\nu} \cdot L_{\odot} \cdot \tau_{\odot} \cong 1.20 \cdot 10^{44}\, J, or\ 7.50 \cdot 10^{58} MeV$
- $N_{emit} = {}^{E_{SN}}/_{\langle E_{\nu} \rangle} \cong 6.24 \cdot 10^{57}\ \nu's$
- $N_{det} = N_{emit} \cdot \Omega \cdot P_{int} \cdot \varepsilon$
  - $N_{det,K} \cong 49\, neutrinos\ detected$
  - $N_{det,HK} \cong 6{,}000\, neutrinos\ detected$

- Where
  - $\tau_{\odot}$=Sun's lifetime
  - $L_{\odot}$=solar luminosity
  - P_{int}= probability of interaction in the detector
  - Ω=solid angle factor

Discussion of simple solution

- Possible extensions:
  - Emitted neutrino energy spectrum
  - $\bar{\nu}_e$ cross-section
  - Detection efficiency (threshold)
  - Detector dimensions
  - Distance to SN1987A is 51.2 kpc



https://upload.wikimedia.org/wikipedia/commons/thumb/a/af/Composite_image_of_Supernova_1987A.jpg/450px-Composite_image_of_Supernova_1987A.jpg

Detector dimensions

Detector	Kamiokande[1]	Super Kamiokande[2]	Hyper Kamiokande[3]
Height (m)	13.1	42	51.8
Diameter (m)	14.4	39	67.8
Mass (kton)	2,140	50,000	260,000
Threshold (MeV)	7.5	4.5	N/A (used Super-K's value)

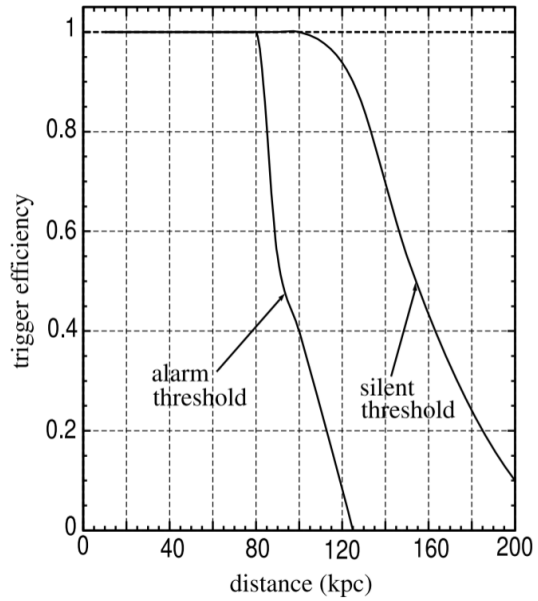
1. https://www.nikhef.nl/~mjg/Leiden/APP-backup/Kamiokande.pdf
2. http://www-sk.icrr.u-tokyo.ac.jp/~masato_s/class/sk-detector.pdf
3. http://www.hyper-k.org/en/detector/detector-detail.html

Detector efficiency

- Super-K has ~100% efficiency for detection of supernova neutrinos at the given distance

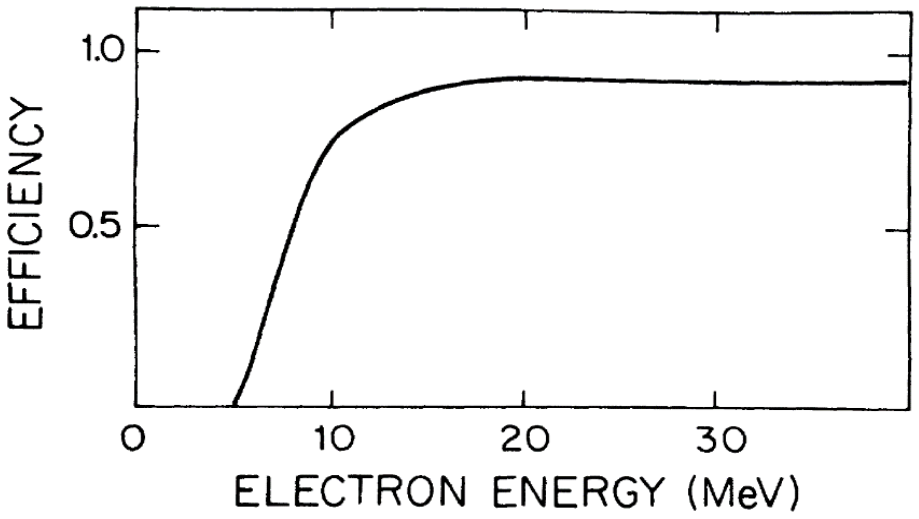
- Kamiokande presented the efficiency as a function of electron energy
  - Convolved this with the energy spectrum of the supernova for a more accurate result

Super-Kamiokande



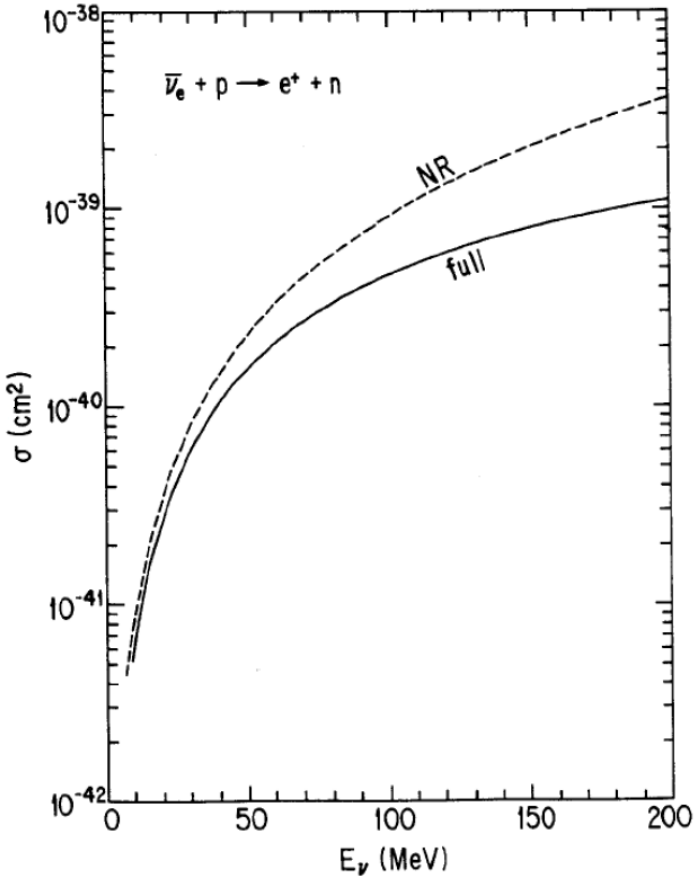
http://www-sk.icrr.u-tokyo.ac.jp/~masato_s/class/sk-detector.pdf

Kamiokande



https://www.nikhef.nl/~mjg/Leiden/APP-backup/Kamiokande.pdf

$\bar{\nu}_e$ cross section correction



- This graph gives a cross section of approximately 9.3 x 10^{-42} cm^2 for a ~10 MeV $\bar{\nu}_e$ interacting with a proton[1]
- Combining number density of water nuclei and path length of the neutrinos in the detector (14.4 m), $P_{int}=5x10^{-16}$

M. Fukugita, T. Yanagida. Physics of Neutrinos: And Applications to Astrophysics. Page 100.

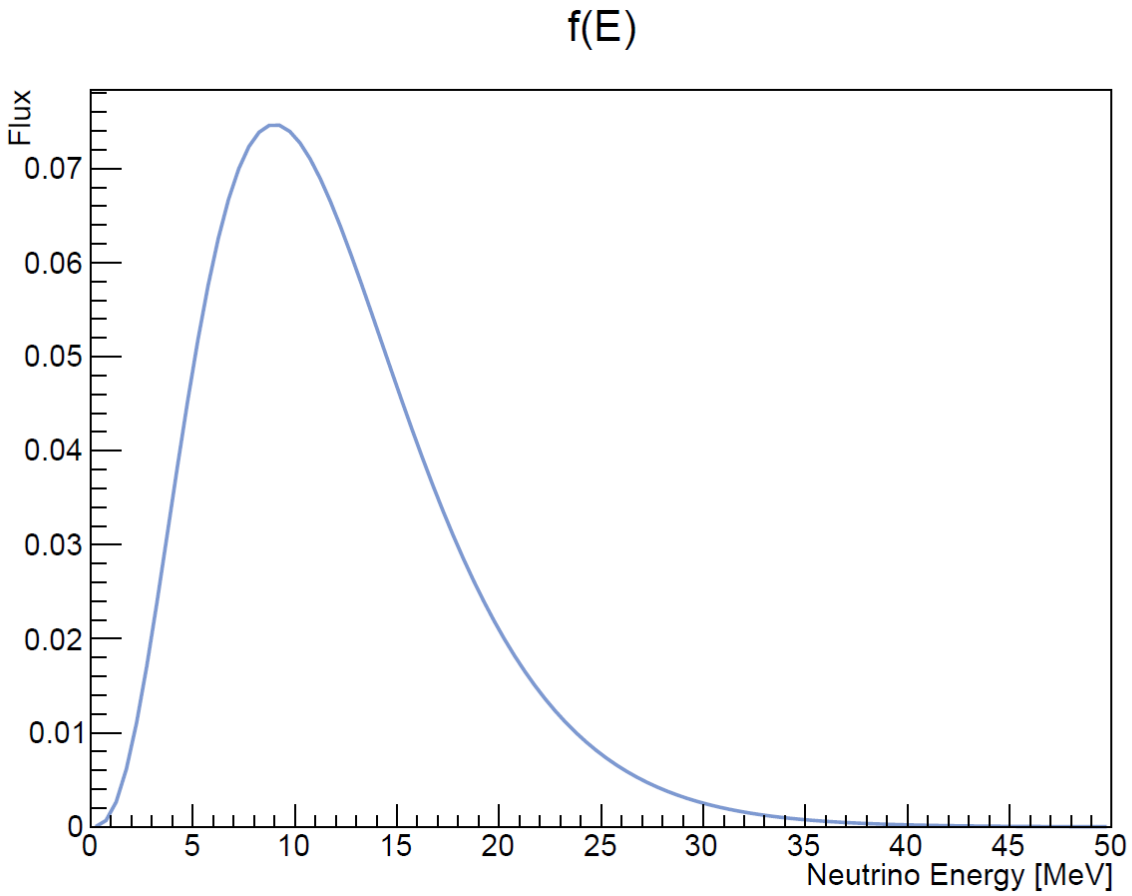
1. https://nuss.fnal.gov/html.07/lectures/Nakaya_1.pdf

Energy spectrum

- For a given flavor, the energy spectrum has the functional form[1]:

$$f_\nu(E) \propto E^{\alpha} e^{-(\alpha+1)E/E_{av}}$$

- Where E_{av} is the average energy, and α is a numerical parameter that describes the amount of 'spectral pinching'



1. https://arxiv.org/pdf/1211.3920.pdf

Simple Simulation

- Extending calculation robustness, we simulate many “universes”
- Each universe Poisson fluctuates the number of arriving neutrinos
- Pull from the energy spectrum, apply the efficiency for each neutrino
- Using an average of 10,000 universes we expect ~12 neutrinos

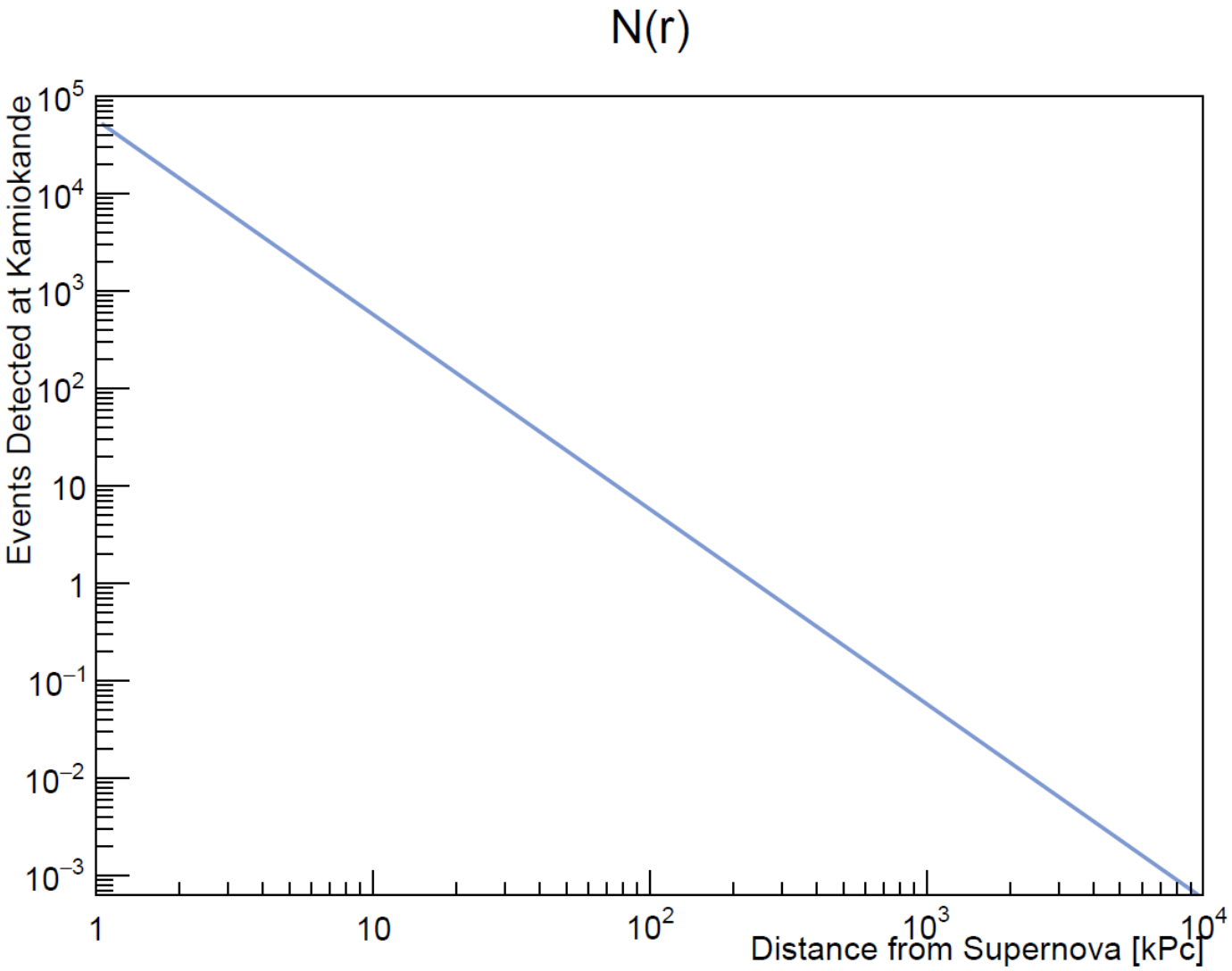
Final result

Detector	Kamiokande	Hyper-K
Simple calculation	49	6,000
Modified calculation	12	1,457
Observed value	12	N/A

We more accurately estimated the number of neutrinos observed by Kamiokande using extensions to parameters in the problem

Fun facts

- This plot shows the expected number of events from a SN1987A-like supernovae at Kamiokande for various distances
- It is estimated that there should be 1.9±1.1 core-collapse supernova events in the Milky Way every century[1]



1. https://www.nature.com/nature/journal/v439/n7072/full/nature04364.html

Thanks for listening!