Universidad Autónoma de Sinaloa

Assessing the Sensitivity of Hyper-Kamiokande to Different CCSN AND SN Ia models

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XIX Mexican Workshop on Particles and Fields

What kinds of supernovae exist?

Supernovae are events in which stars violently expel their layers, generating large amounts of energy and heavy elements.

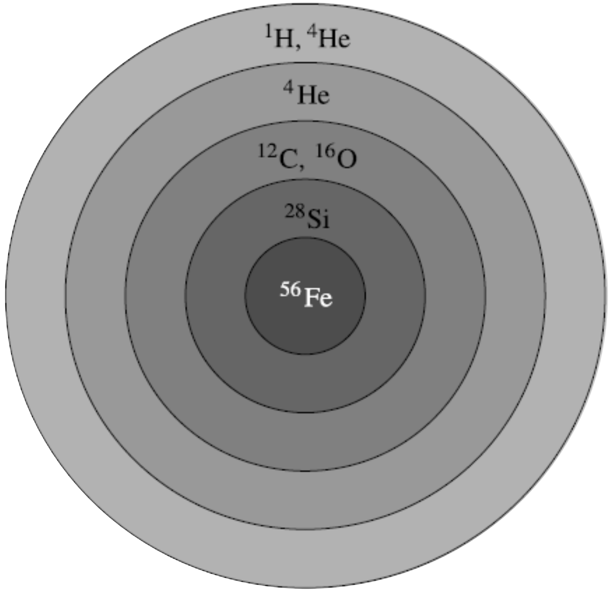
Classification:

SN Ia

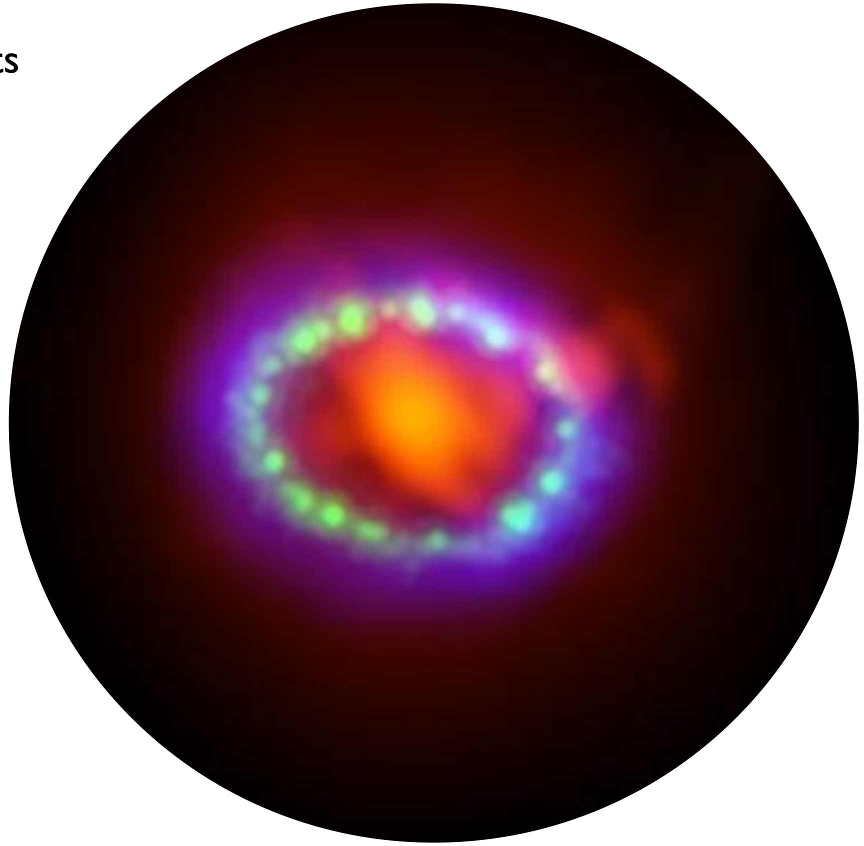
- Silicon Spectral Lines
- Thermonuclear Explosions
- Reproducible
- Lower Neutrino Emission
- No Remnant

SN II, Ic, Ib

- Emissions
  I. Ib : He
  II. Ic: He o Si, sin H
  III. II: H
- Core collapse
- Neutrino emission
- Remnant: Neutrino star, BH



Structure of a massive star $(30M_\odot)$ in a late evolutionary stage. The star consists of layers with different compositions, separated by burning nuclear layers.



This image of Supernova 1987A combines data from different wavelengths: the image shows the shock wave interacting with the surrounding material. [ALMA, ESO, NAO, NRAO, NASA]

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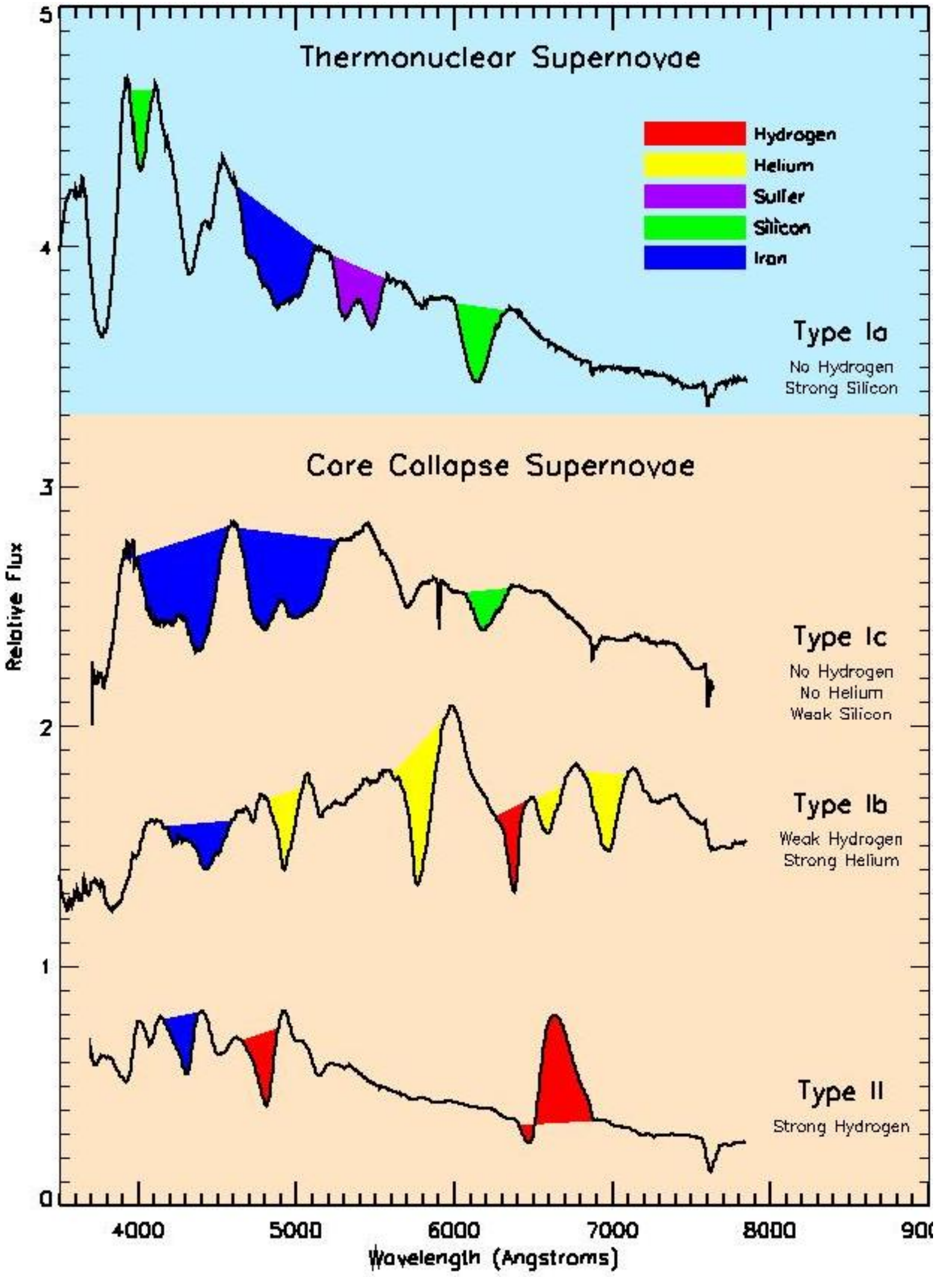

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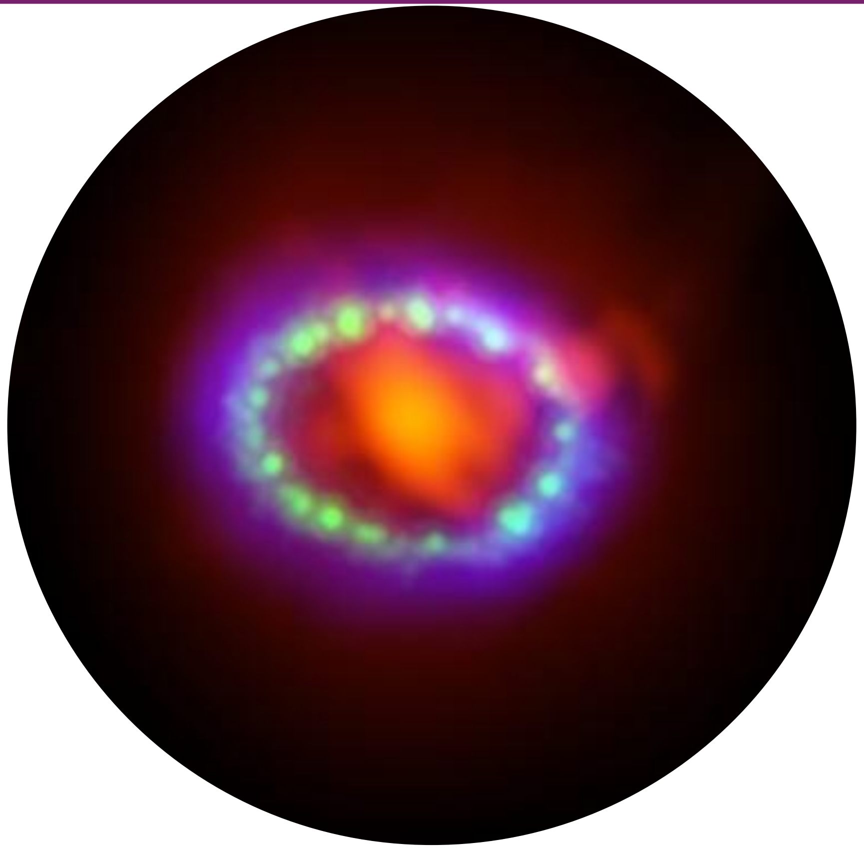
Diagram of the spectral lines of different supernovae.



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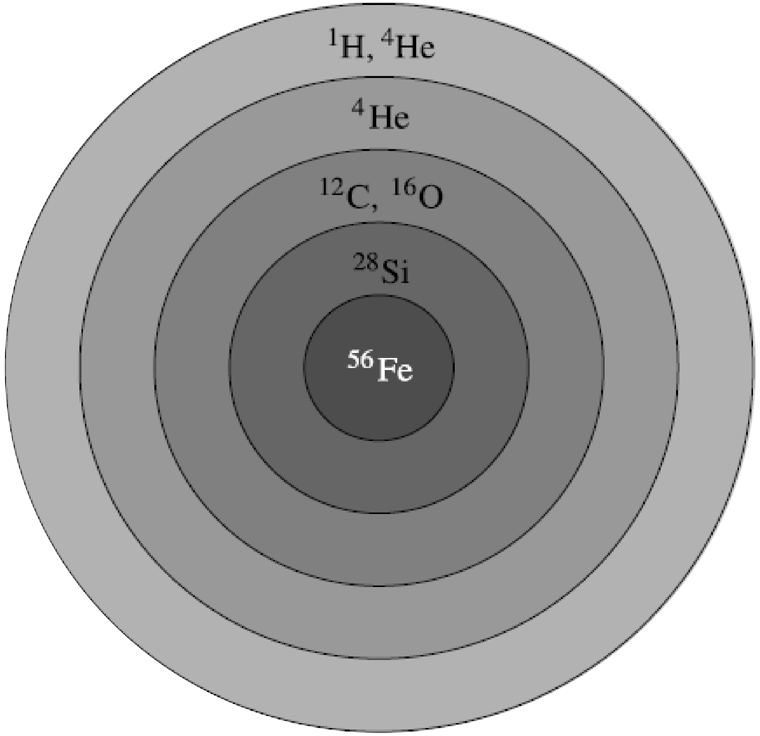
Type II Supernova (Core Collapse)

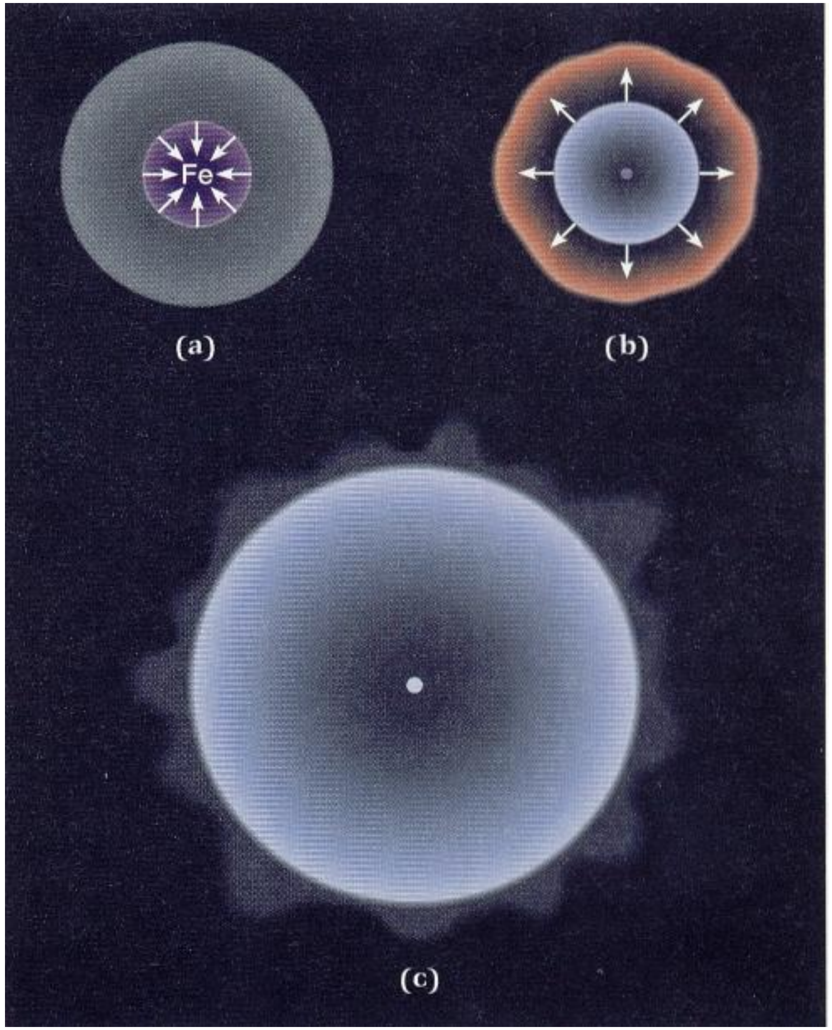
Massive stars don't become white dwarfs. When He runs out, it can continue to create heavier elements until it reaches Fe.

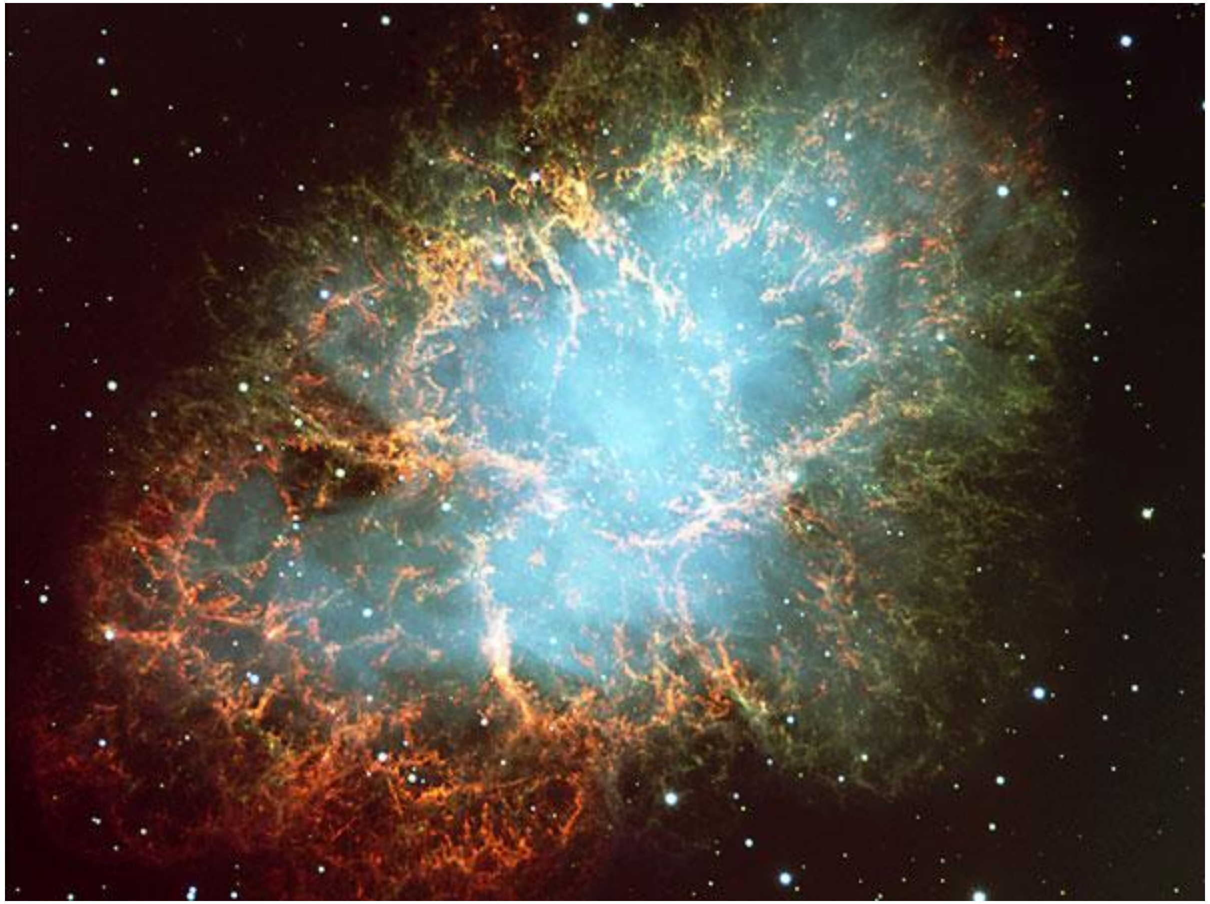
A. The Fe core contracts at speeds of 0.25 C.
B. Part of the contracting core rebounds, producing a collision.
C. The star's outer layers are ejected, generating the supernova.



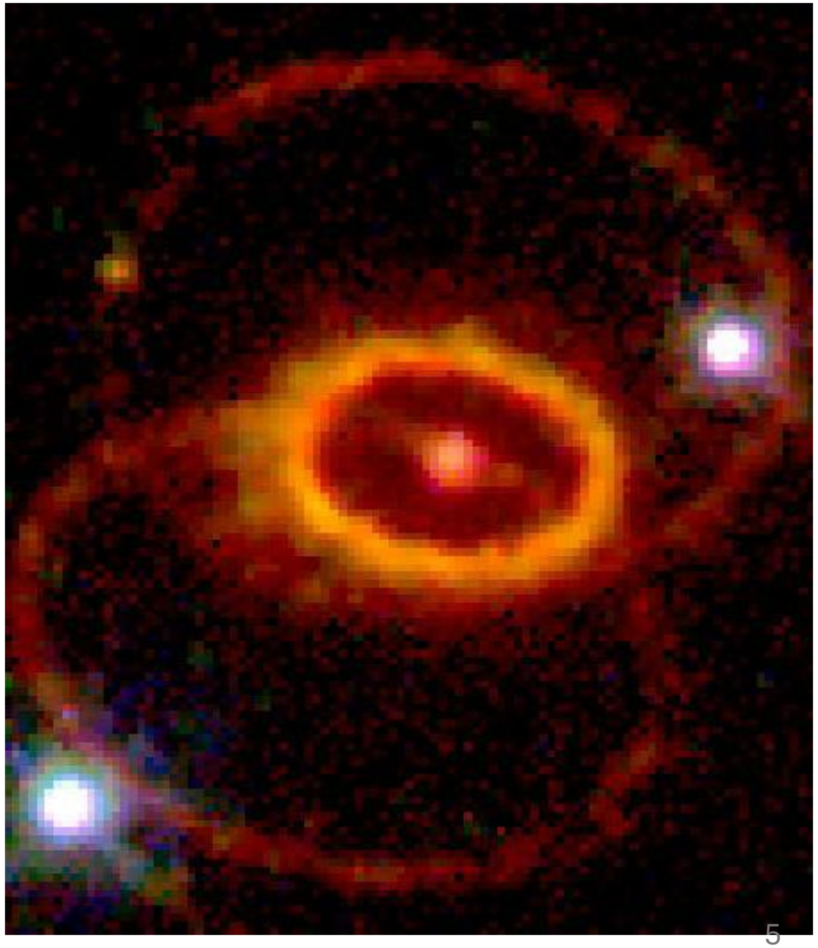
As a result of core collapse, a neutron star or a black hole can be produced.

Structure of a massive star ($30M_{\odot}$) in a late evolutionary stage. The star consists of layers with different compositions, separated by burning nuclear layers.





Remnant of SN1987A, which exploded in the Large Magellanic Cloud. It is the brightest SN in recent history. This image taken by the Space Telescope shows two emission rings for which we still have no clear explanation.



The Crab Nebula is the remnant of a neutron star that exploded in 1054. This image was taken by the VLT. Red is HI, while blue shows electron emission around the magnetic field in the inner region of the nebula. At the center of the nebula is a pulsar (neutron star) rotating at a rate of 30 times per second.

Type Ia Supernova

The standard theory of SNIa:

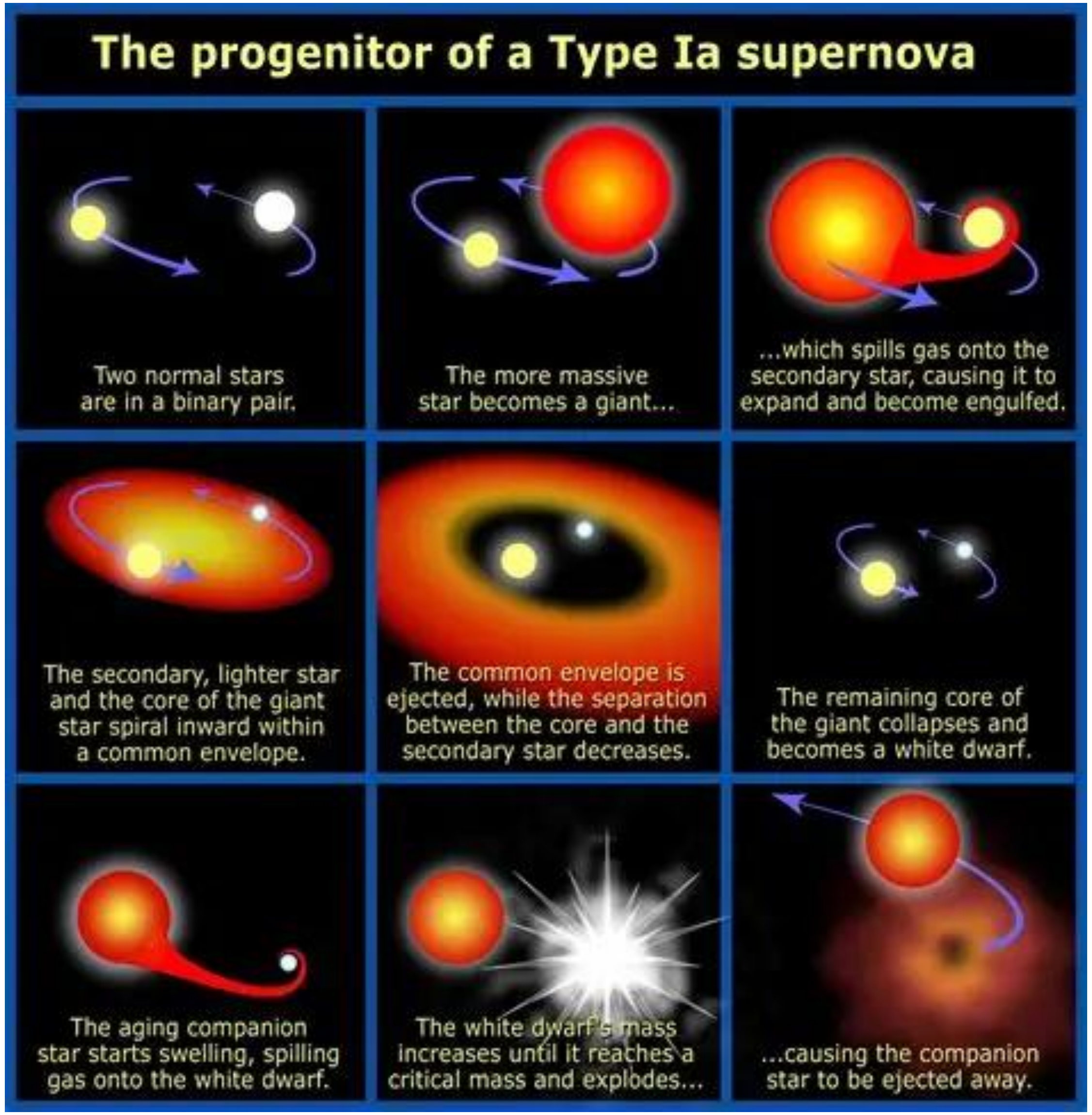
- Thermonuclear explosions of white dwarfs (WDs)
- Mass accretion of the WD
- Accretion mechanism through a companion

What is not clear:

- Binary system component
  - **I. A single degeneration:** Comprises a WD accreting material from a companion with non-degenerate material.
  - **II. 2 degenerations:** It is the fusion of two WD

Models of explosion mechanisms:

- Detonation only
- Deflagration only
- Delayed detonation transition (DDT)
- Gravitationally confined detonation (GCD)
- Reverse pulsating detonation



Neutrinos

Neutrinos are fundamental particles belonging to the group of leptons.

Características:

- Very small mass
- No charge
- Come in three flavors
- Oscillate between flavors
- Occurs in supernovae or the Sun
- Little interaction with matter

Neutrinos from SNs interact with the tank through the following interactions.

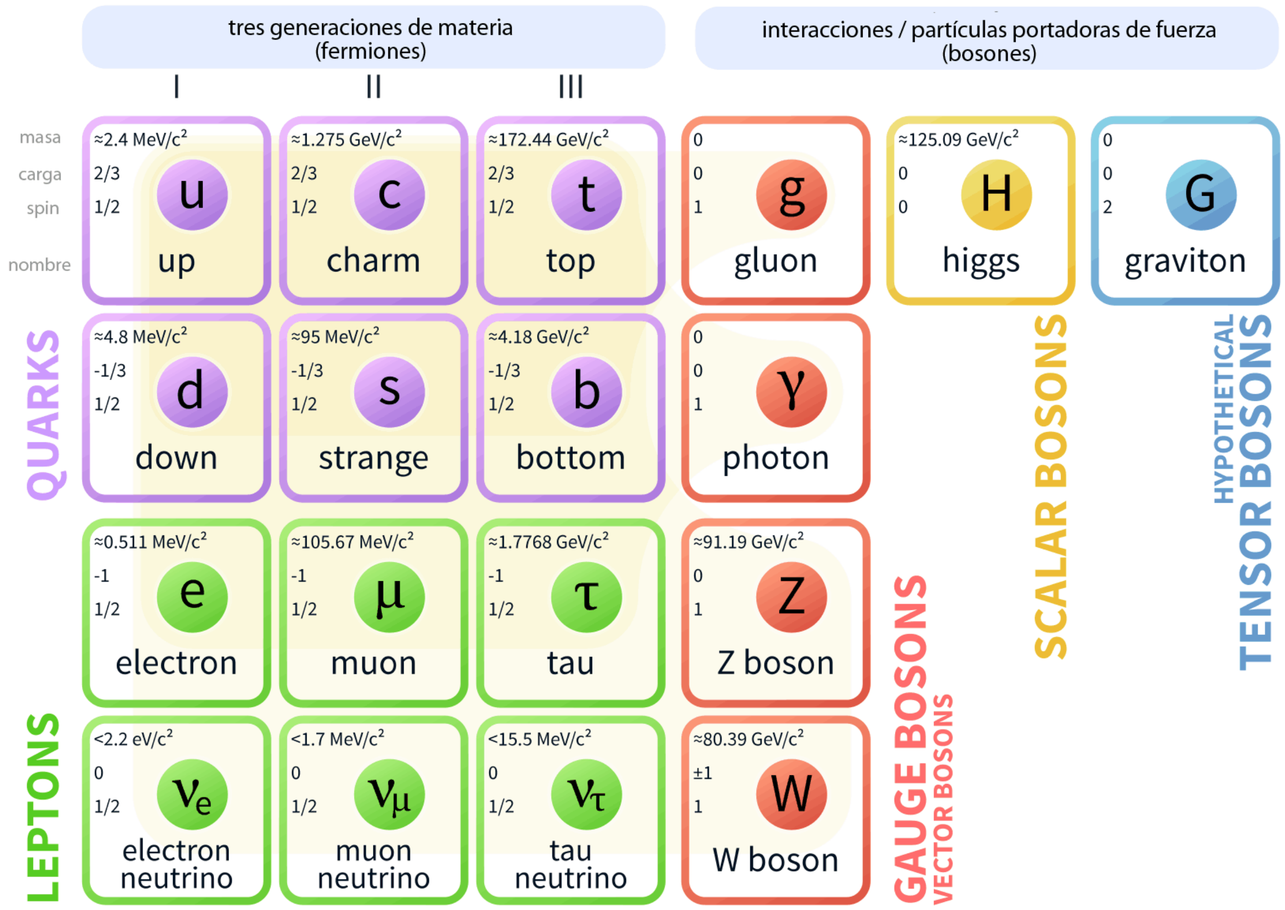
$^{16}O + \bar{\nu}_e \rightarrow X + e^+$ **Inverse Beta Decay**

$^{16}O + \nu_e \rightarrow X + e^-$ **Electronic Scattering**

$\nu + e^- \rightarrow \nu + e^-$

$\bar{\nu}_e + p \rightarrow n + e^+$ **Charge Current**

Modelo estándar de partículas elementales y gravedad



Fundamental particles of the Standard Model

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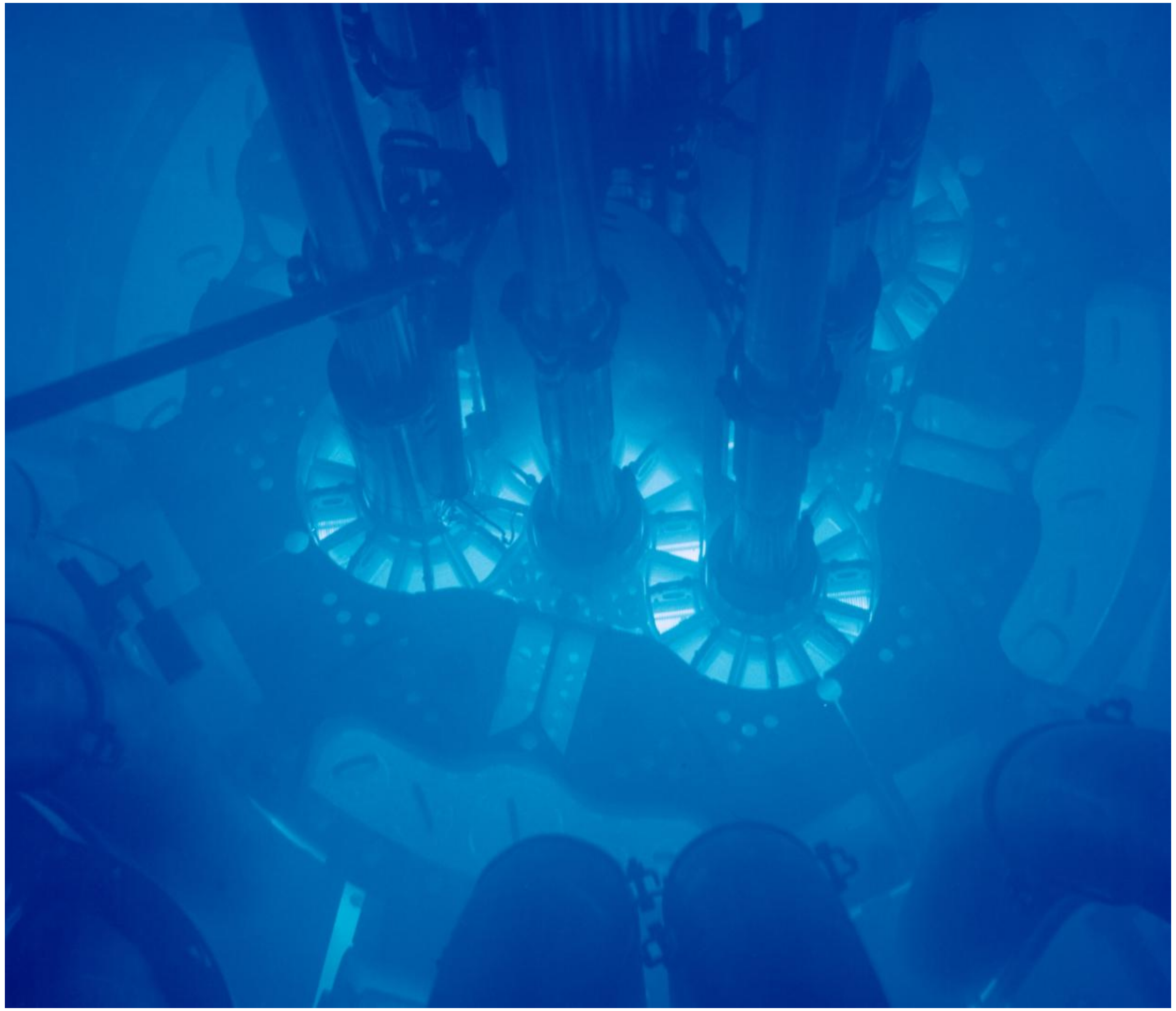
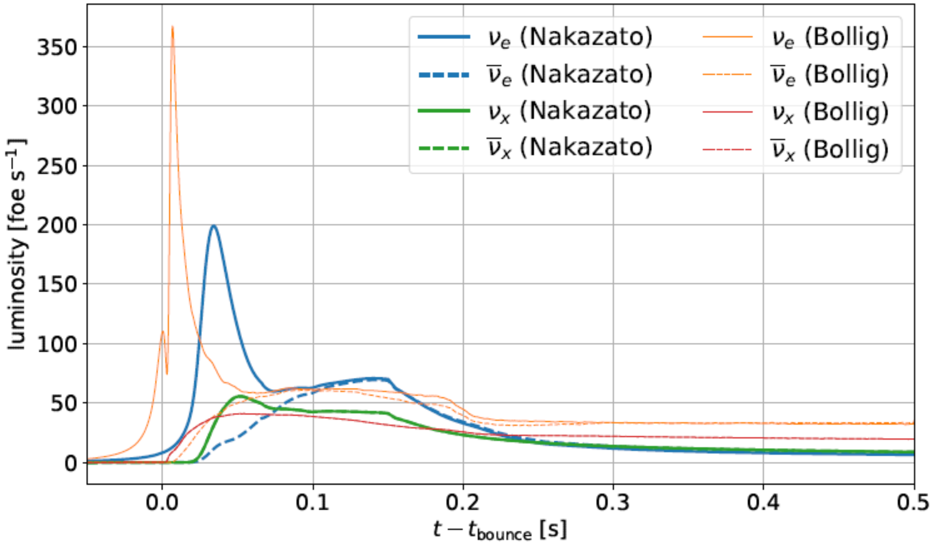


Cherenkov radiation glowing in the core of the Idaho National Laboratory's Advanced Test Reactor

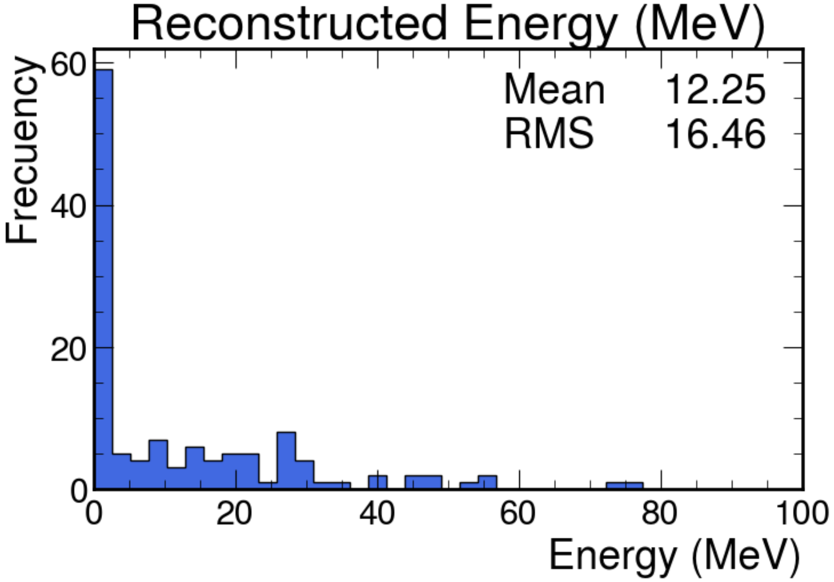
Software toolchain

This is the chain of programs used to analyze the neutrino signals emitted by SN in the Hyper-K

Sntools/SNEWPY	Event generation through MonteCarlo
WCSim	Full tank simulation
BONSAI-FLOWER	Vertex and energy reconstruction
Python	Data Analysis



The figure shows the luminosity in different flavors as a function of time on the Y axis, and the bounce time in seconds on the X axis of the Nakazato and Bollig models (Amanda L. et al. 2021).



Energy reconstruction with FLOWER
(Sergio,2024)

Supernova simulation

Event generation

We generate the events through sntools, using the models given in the SNEWPY repository, we generate a sample of 1000 data sets that for each iteration has approximately 100 events.

Complete tank simulation

The complete simulation of the detector was done using WCSim, adding the NUANCE files from sntools and generating the Hyper-K geometry, the simulation will generate the response of the photomultipliers (PMTs) to the Cherenkov light of the interactions inside the tank.

Energy reconstruction

The final step will be the reconstruction of the vertices, as well as the position and energy of the outgoing lepton. We used a configuration of 40,000 box-and-line photomultipliers, resulting in 40% photocoverage on the Hyper-K detector.

Model	Type	d_{100}
Warren	CCSN	148 kpc
Kuroda		135 kpc
Nakazato		158 kpc
Tamborra		134 kpc
DDT	Ia	4 kpc

We use these models with a neutrino flavor transformation.

- TwoFlavorDecoherence NMO

Data analysis

Data reduction

These cuts are intended to eliminate the low-energy background from accidental dark noise coincidences, as well as radioactive decays in the detector.

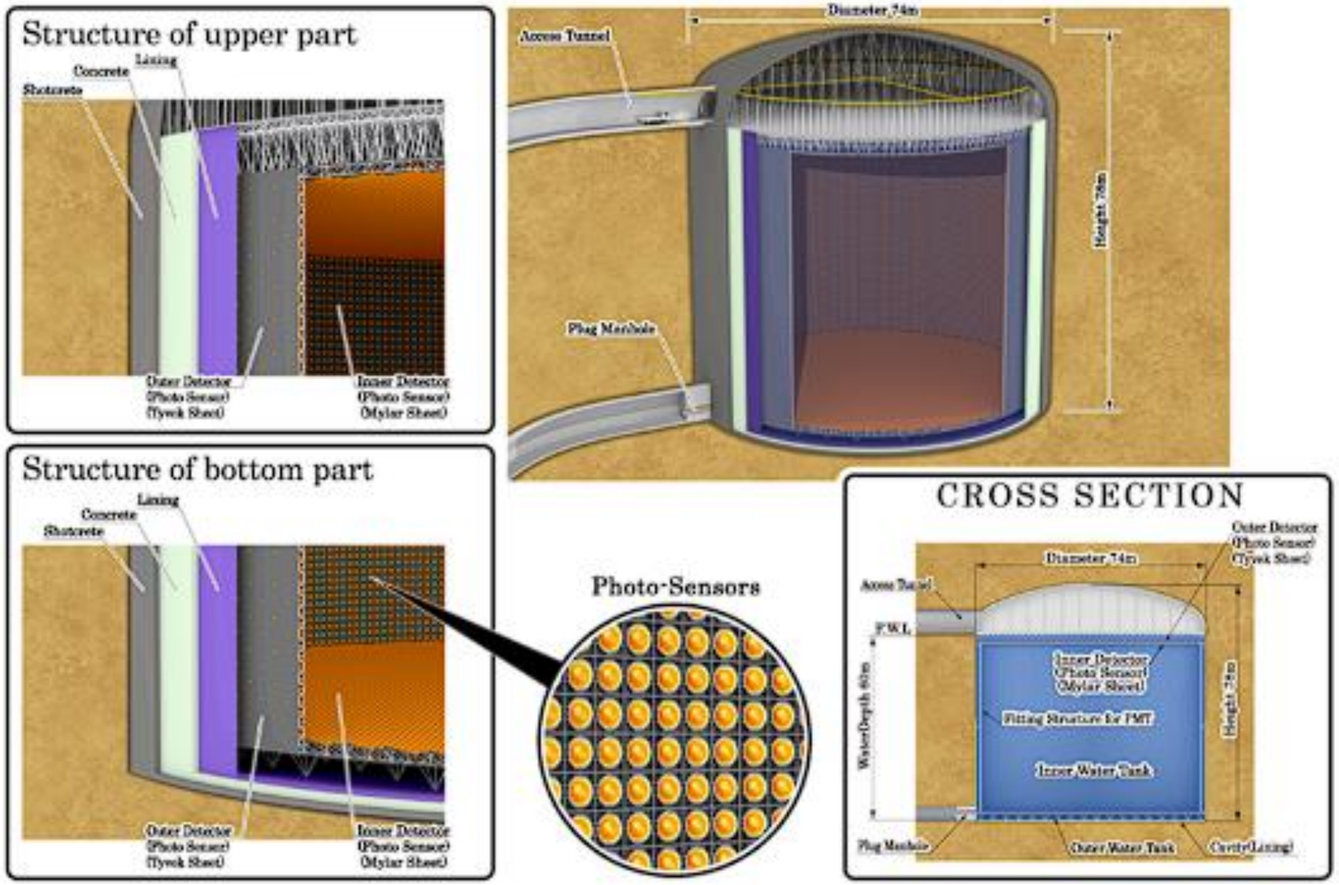
- Energies below 5 MeV will be excluded.
- Vertices located less than 1.5 meters away will be excluded.

Statistical treatment

The log likelihood function was applied to the remaining reconstructed data after truncation to assess how well the data set matches each of the supernova models.

$$L = In\,\mathcal{L} = \sum_{i=1}^{N_{obs}} In\,N_i$$

where the index i runs through the remaining N_{obs} events in the dataset and N_i is the number of events predicted by a given supernova model.

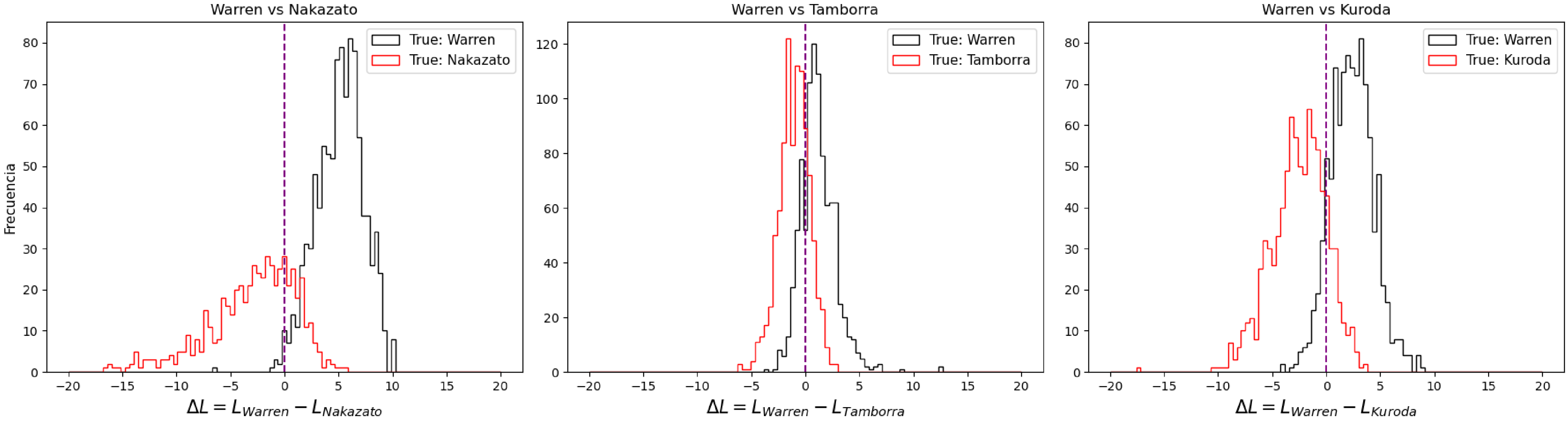


Schematic view for the configuration of single cylindrical tank instrumented with high density (40% photocoverage) PMTs. It is referred as 1TankHD in this report.

Results

The log-likelihood function was applied to the remaining reconstructed data after the reduction to assess how well the data set matches each of the supernova models.

These results compare the Type II supernova models; each model was compared separately.



The figure shows the delta log-likelihood comparisons to evaluate the effectiveness of Hyper-K in differentiating between models. (Sergio, 2024), as can be seen, a portion of the distributions overlap, so the models in that section cannot be differentiated.

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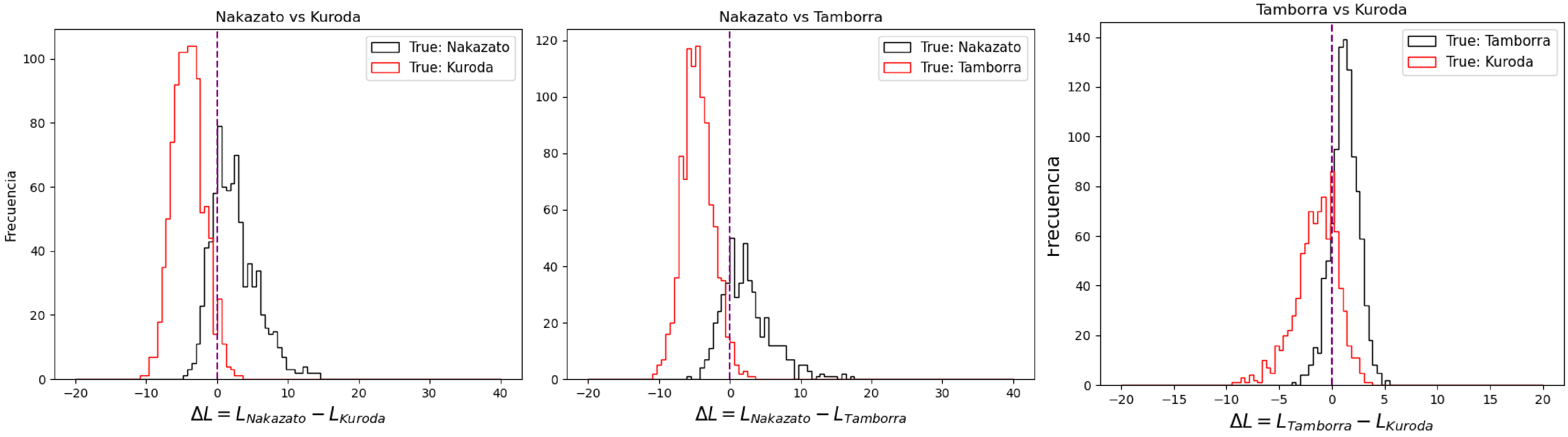

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Results

This table shows a confusion matrix, in which all models were compared simultaneously with each other, to see if they are identified as themselves or as another model.

True Models	Nakazato	Warren	Kuroda	Tamborra
Nakazato	**770**	5	42	16
Warren	80	**744**	88	209
Kuroda	102	65	**708**	137
Tamborra	48	186	162	**638**

The table shows the number of models that were identified individually or as other models. (Sergio, 2024)

Results

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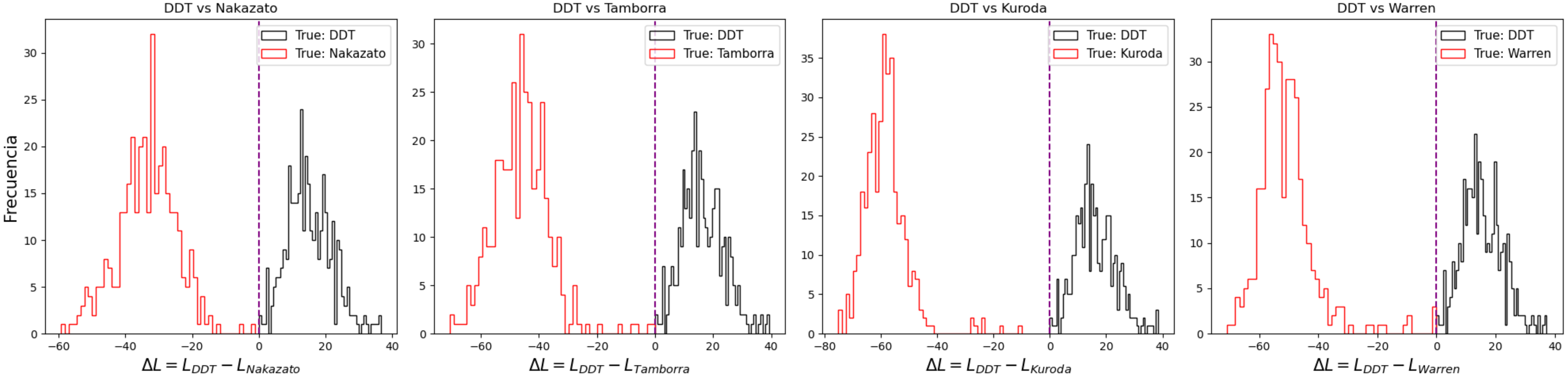
These results comprise the Type Ia supernova models, each model was compared separately whit the supernova type II models.



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Results

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True Models	DDT	Nakazato	Warren	Kuroda	Tamborra
DDT	**358**	0	1	0	1
Nakazato	0	**267**	2	9	3
Warren	0	33	**236**	41	102
Kuroda	0	45	38	**247**	67
Tamborra	0	13	81	61	**185**

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Next step…

- Obtaining larger data samples on Type Ia supernovae for better comparison
- Applying a dark matter model that implements the ordinary matter-DM interaction
- Studying the mechanisms of pre-supernovae

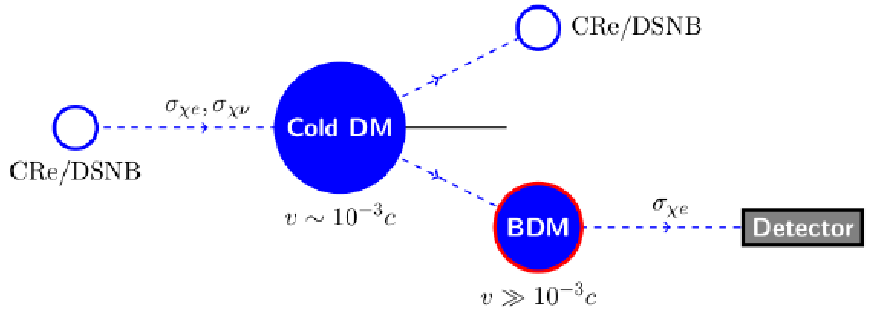

FIG. 1. Schematic diagram for production of boosted dark matter (BDM) due to scattering with CR electrons (CRe) and DSNB neutrinos, and their subsequent detection at the detectors.

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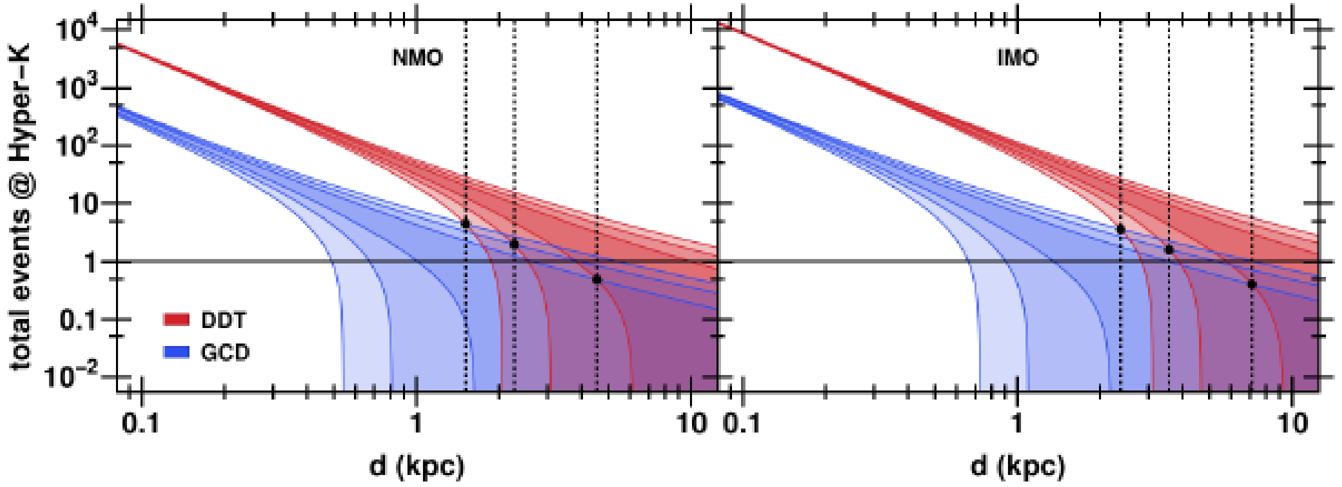

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