Characterizing Core-Collapse Supernova models using neutrino signal

Royer Nicolas

IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

Subatech

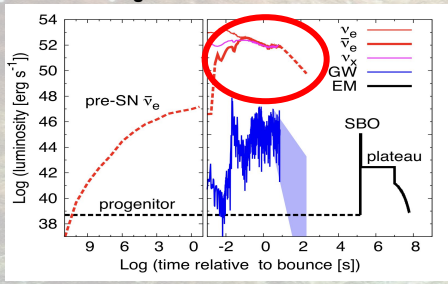
1. What is a Core-Collapse Supernova?

Brief: Explosive death of a massive star (>8 Solar Mass).
Key Stakes:
- Source of heavy elements (Fe, Au, I...).
- Births neutron stars & black holes.
- The precise explosion mechanism remains elusive.

2. Why Neutrinos?

First Messengers: Escape seconds after collapse, carrying 99% of the binding energy.
Direct Probe: Provide a real-time window into the inside of the CCSN..
Signal Contains: Information on progenitor properties, explosion dynamics, and dense matter physics.

3. The Neutrino Light Curve



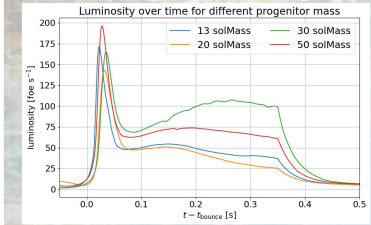
Multi-messenger luminosity from CCSN [2]

→ Collapse & Bounce (~0-10 ms): Neutron burst (ν_e spike).
→ Accretion Phase (~0-500 ms): Shock stalls, matter falls back
→ Proto-NS Cooling (seconds-minutes): Exponential decay as the neutron star cools. [1]

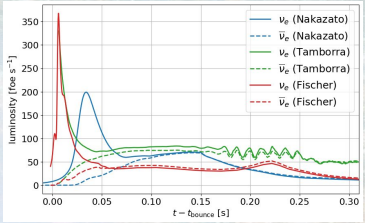
This temporal and spectral structure is the "fingerprint" of the explosion.

Goal: Link Signal Features to Physical Parameters
Can we identify telltale signs in the neutrino light curve that point to specific progenitor properties (mass, metallicity) or physics phenomenon happening during a supernova ?

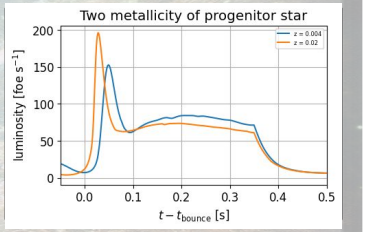
Using SNEWPy Python Library [2] → Varying parameters & compare light curve.



Different mass of progenitor star lead to specific profile and characteristics of luminosity : Height of Neutrino burst peak, Shape of plateau from accretion phase, Overall luminosity emitted during the first 500 ms.



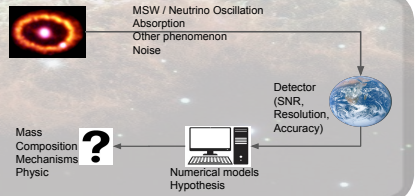
Different physical models and different physic hypothesis lead to specific and recognizable light curves !
Possible to infer physical properties and phenomenon happening during the explosion.



Different composition of progenitor star can give information about nature of progenitor stars as well as products of supernova !

Significance

- Possibility to infer properties and physics from *recognised key features*.
- Unlike some "black-box" AI/ML methods, this approach builds physical intuition. We *understand why* a feature changes with a parameter.
- *Prepares* the interpretation of the next observation and compare models [3].



References

[1] Victor Lebrin, https://theses.hal.science/tel-04098003v1
[2] K. Nakamura et al., MNRAS 461, 3, 21 (2016)
[3] SNEWS SNEWPy, https://github.com/SNEWS2/snewpy/tree/main
[4] Supernova Model Discrimination with Hyper-Kamiokande, DOI 10.3847/1538-4357/abf7c4

Acknowledgement

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