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PNS parameters estimation with neutrino emission from supernovae

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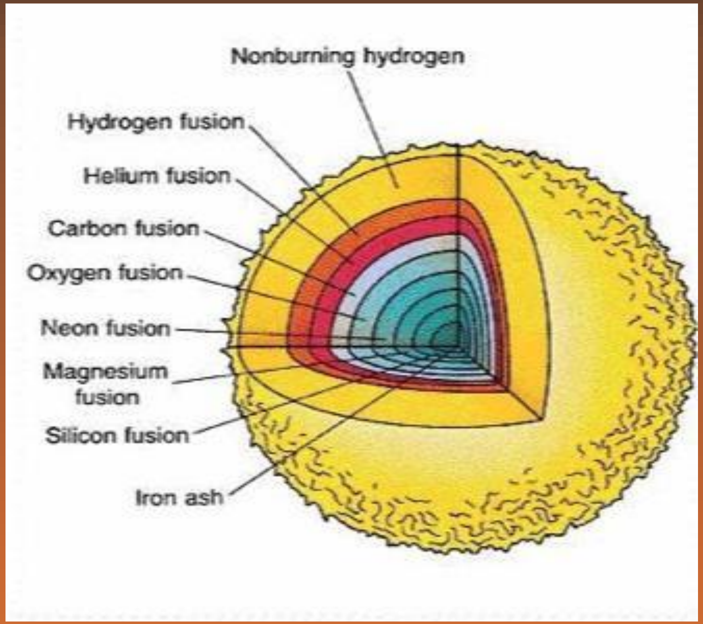
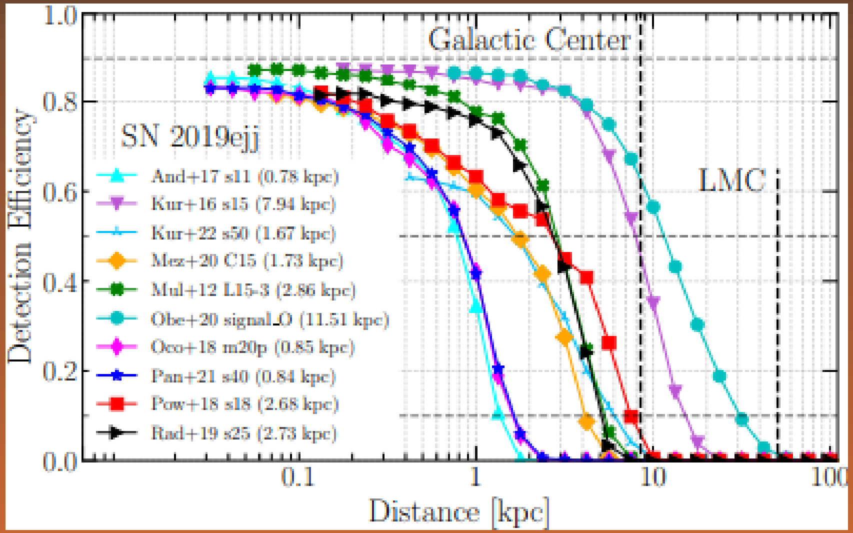
Core-Collapse Supernovae: neutrino and GW emission



CCSNe are explosive deaths of massive stars ($\geq 8\ M_\odot$)

$$\varepsilon_{NS}^{b} \cong \frac{3}{5}\frac{GM^2}{R} = (1-5)\cdot 10^{53}\, erg$$

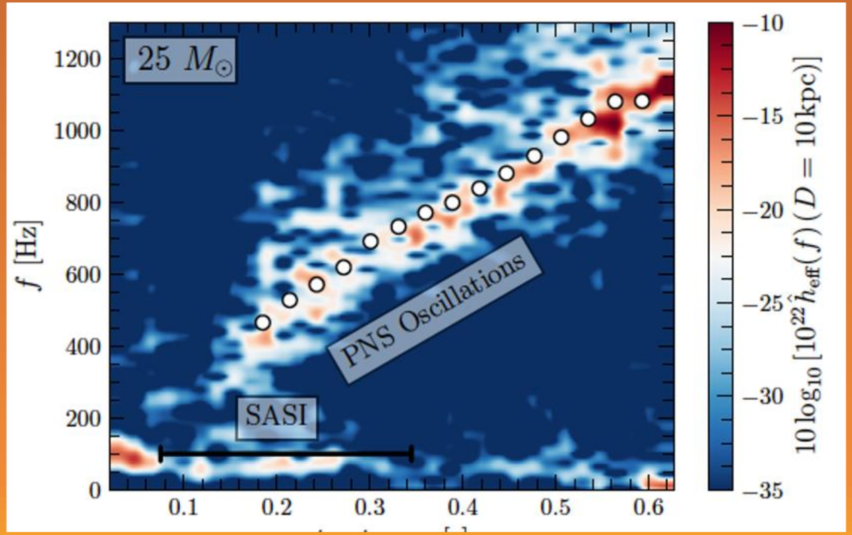
$$\varepsilon_{\nu} \approx 99\% \cdot \varepsilon^{b}$$
$$\varepsilon_{kin} \approx 1\% \cdot \varepsilon^{b}$$
$$\varepsilon_{\gamma} \sim 0.01\% \cdot \varepsilon^{b}$$
$$\varepsilon_{GW} \leq 0.0001\% \cdot \varepsilon^{b}$$



Szczepanczyk et al, Phys. Rev. D 110, 042007 (2024)

GW detection is very difficult and the horizon is small. → exploit neutrino information!

GW produced by PNS oscillations are particularly interesting and linked to functions of M/R^n



Abdikamalov, Pagliaroli, and Radice, arXiv:2010.04356

Core-Collapse Supernovae emission

Neutrino emission can be summarized according to our current understanding into (*Pagliaroli et al., Astropart.Phys. 31 (2009) 163-176*):

- **Accretion phase** ($t < 1s$): $\nu_e, \bar{\nu}_e$ produced by (*neutrino-driven explosion*):

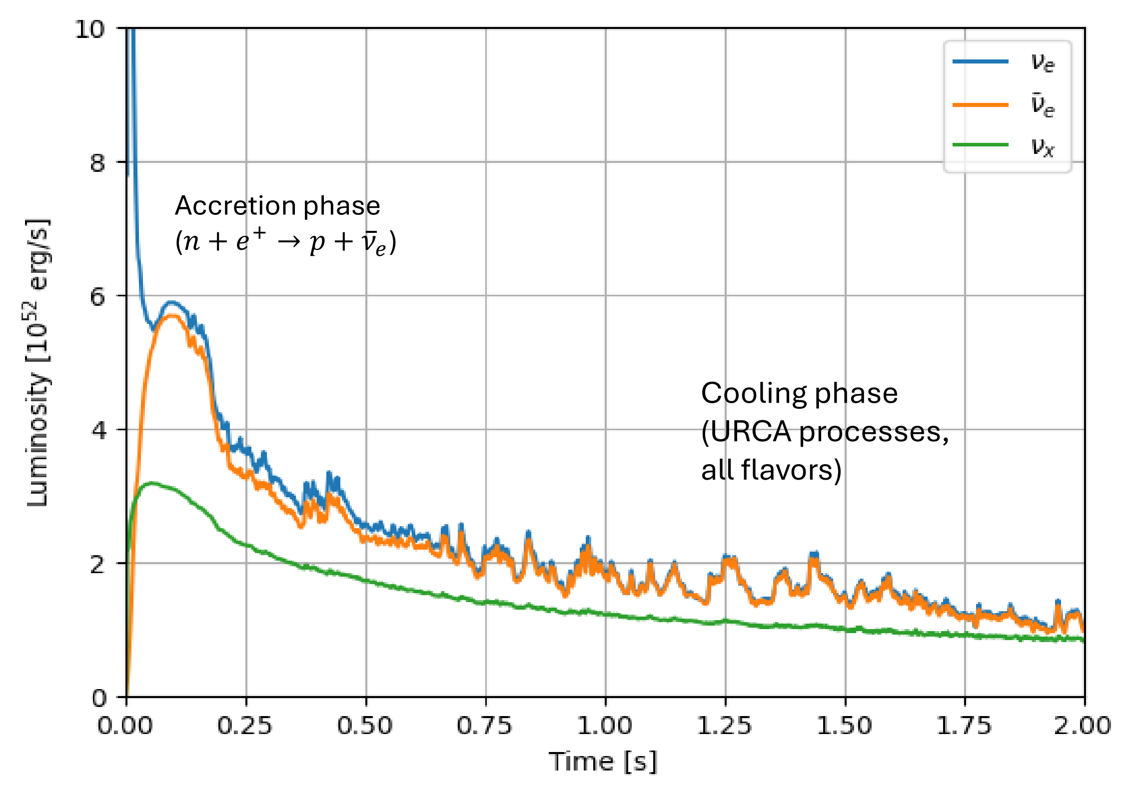
  $n + e^+ \leftrightarrow p + \bar{\nu}_e$ $\qquad$ $p + e^- \leftrightarrow n + \nu_e$

  $$\Phi^0_A(E_\nu, t^{em}) \propto N_n(t^{em})\, \sigma_{e^+n}(E_{e^+})\, \frac{E^2_{e^+}}{1+e^{\left(\frac{E_{e^+}}{T_A(t^{em})}\right)}}$$

- A second, long lasting **cooling** phase, which carries 80-90% of total energy through neutrinos of all flavors:

  $$\Phi^0_C(E_\nu, t^{em}) \propto R^2_{PNS}\, \frac{E^2_\nu}{1+e^{\left(\frac{E_\nu}{T_C(t^{em})}\right)}}$$

Neutronization peak
$(p + e^- \rightarrow n + \nu_e)$



Simulation from Vartanyan, Burrows, *Mon.Not.Roy.Astron.Soc.* 526 (2023) 4, 5900-5910

Alternative cooling model

- A step forward in the analysis can be done using a novel approach for the luminosity of the cooling phase proposed in *Lucente et al., Phys.Rev.D 110 (2024) 6, 6*.
- It considers an enhanced neutrino transport inside the PNS caused by convection, through:

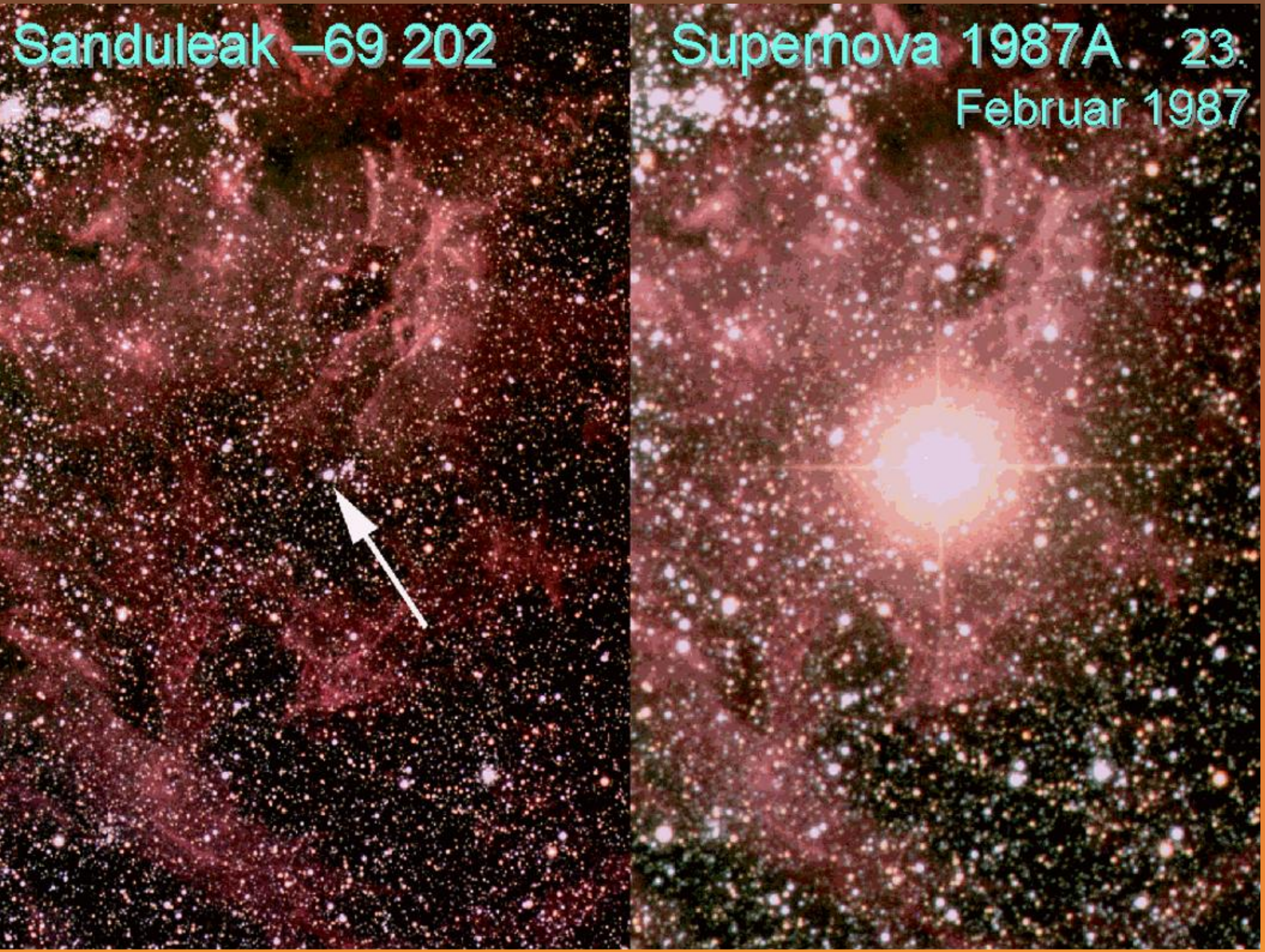
$$L_{\nu_x}(t) = Ct^{-\alpha}e^{-(t/\tau)^n}$$

- This approach is valid for times > 1s post bounce, leading to an arbitrary cut of the dataset. Solutions to this could be:
  - Adding the accretion component and perform a combined fit (assuming NH)
  - Adding a 'rising' term in case of IH, when no accretion is present:

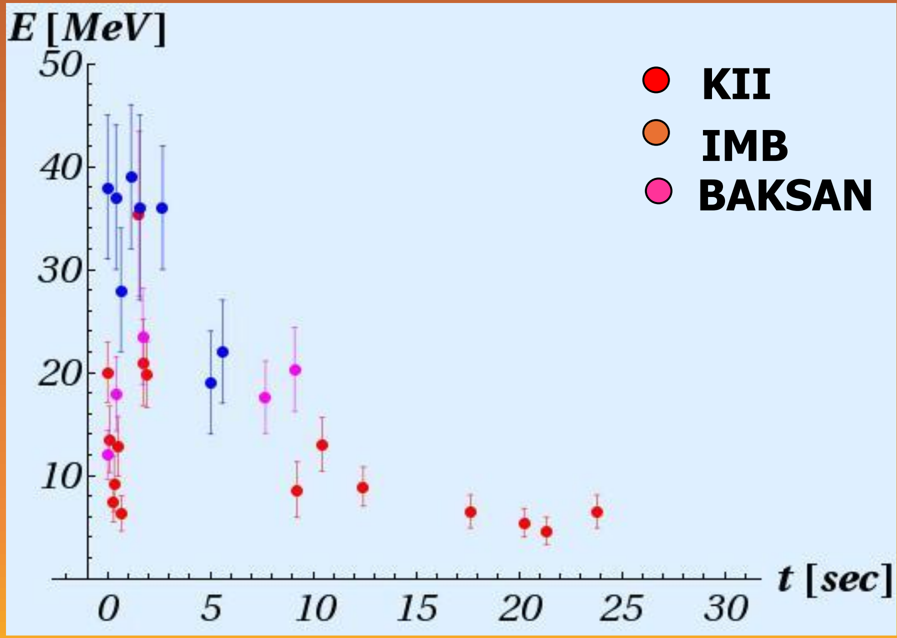
$$L_{\nu_x}(t) = (1 - e^{-t/t_{rising}})Ct^{-\alpha}e^{-(t/\tau)^n}$$

This functional form was tested and successfully fits ν_x emission from 2D simulations

SN1987a



- We tested the 'standard' accretion+cooling model on SN1987a data
- Aim to test the model from Lucente et al too (ongoing)



Summary

- We want to refine our data analysis techniques to extract the maximum information from a future galactic SN explosion, especially focusing on PNS parameters
- This can lead to a powerful joint neutrino-GW detection, which would be able to constrain both mass and radius of the PNS

The next steps to be implemented involve:

- Extensively analyze the new cooling model adding the accretion component
- Understand what constraints can be put on the radius of the PNS, both with SN1987a data and simulation future detections