Using Multimessenger Synthesis to Constrain Core-Collapse Supernova Distance and Orientation

Siddharth Boyeneni, Michael Pajkos, Mark Scheel

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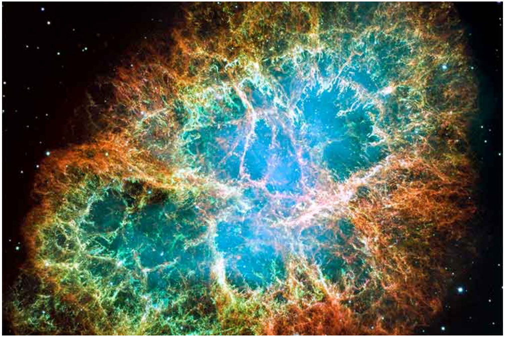
Core-Collapse Supernova (CCSN) Description

- Stars $\geq 8M_{\odot}$ can fuse elements up to ^{56}Fe
- Leads to a loss of pressure support, leading to core collapse
- Increasing central density halts infall, launches shock

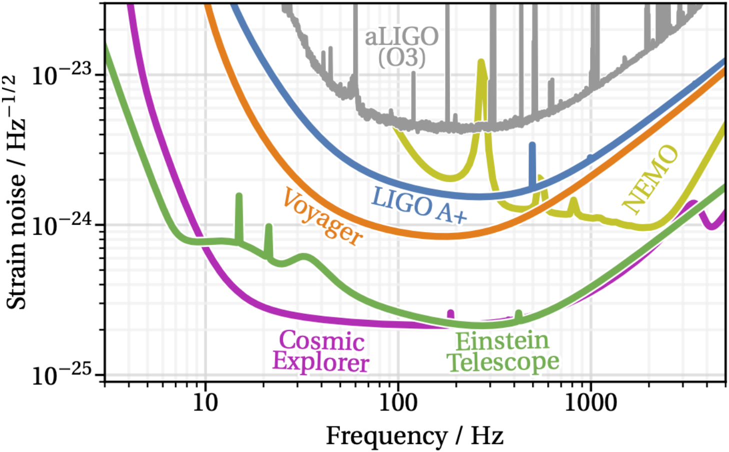


Relevance

- Oxygen on Earth was deposited via CCSNe
- The stellar rotation profile of stars is generally unknown
- CCSN are the progenitor mechanism of BH/NS

CCSN Signals

- *Neutrinos:* Release gravitational binding energy of order 10^{53} ergs
- *GWs:* Mainly emitted from protoneutron star (PNS): 100Hz - 2kHz.



Research Question

How can we constrain distance, orientation, rotation, and stellar compactness?

Definition

Supernova compactness measures stellar inner density profiles, and is defined roughly as:

$$\xi_M \propto M/R$$

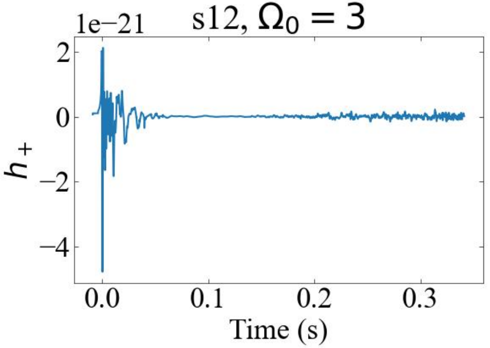
Methods/Assumptions

- 20 2D simulations via FLASH
- Applied physics-informed rotation profiles
- Simulations cover ZAMS masses of $12, 20, 40,$ and $60 M_\odot$
- Central rotation rate Ω_0: $0, 0.5, 1, 2,$ and 3 *rad*/*s*

GW Amplitude

- Quadrupole formula (slow motion, weak field)

$$h_+ \propto \frac{d^2 I_{zz}}{dt^2} \frac{sin^2\theta}{D}$$



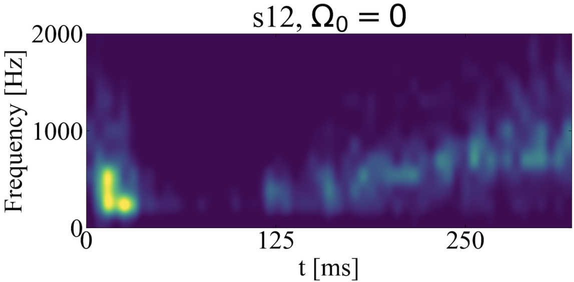
GW Frequency Properties

Two detectable properties:

- *GW bounce signal:* Initial burst from rotating CCSNe. This can be approximated as

$$\Delta h \propto \frac{\Omega_0^2}{D} \sin^2 \theta$$

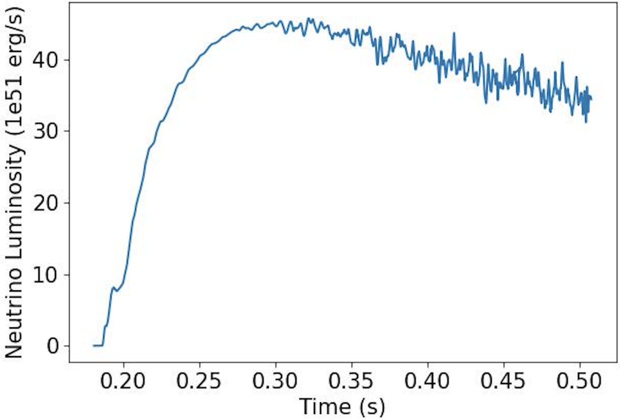
- *Peak GW frequency:* Sourced from dominant PNS mode ("ramp-up slope")



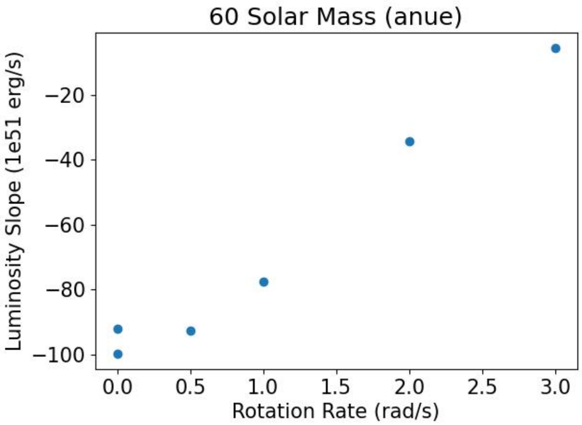
Neutrinos Slopes

Gravitational waves are not nearly enough to provide good constraints on progenitor properties. We introduce neutrinos and characterize its relations w.r.t other parameters.

Example: $12M_{\odot}, \Omega_0 = 0$



Neutrinos Cont'd

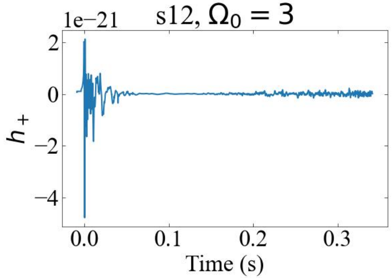


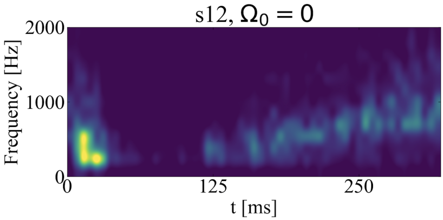
- Linear rotation relationships: peak luminosity, compactness, and luminosity slope
- SNOwGLoBES: realistic detector neutrino energies and counts

Conclusion

- We connect GW observables to CCSN physics
- Following past methodology, we obtain the following linear relationships:

$$\xi_{1.75} = 1.42\Delta h + 7.73\dot{f} - 1.30 \quad (1)$$





Conclusion Cont'd

- Connect compactness to neutrinos

$$\xi_{1.75} = (3.99)N_{tot} \times \frac{(100\text{kpc})^2}{D^2} + (-2.97)\dot{f} + (0.399) \quad (2)$$

- Connect rotation to neutrinos

$$L_{peak}^{\overline{\nu}_e} = (-14.1)\Omega_0 + (42.6)\xi_{1.75} + 48.7 \quad (3)$$

P-values $\leq 1 \times 10^{-3}$

Future Work

- *Relaxing Assumptions:* Directionally dependent neutrino luminosities.
- *Generalization:* What if we run full 3D simulations? Varying EoS?
- *Further relationships:* Correlations between electromagnetic signatures and GWs (e.g., Sedona).

Acknowledgements

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Summary

- CCSNe distance, orientation, compactness, and rotation profiles need to be constrained
- Neutrino and GW signals alone can be synthesized to constrain these four parameters