Characterizing Gravitational Wave Signals from Core-Collapse Supernovae

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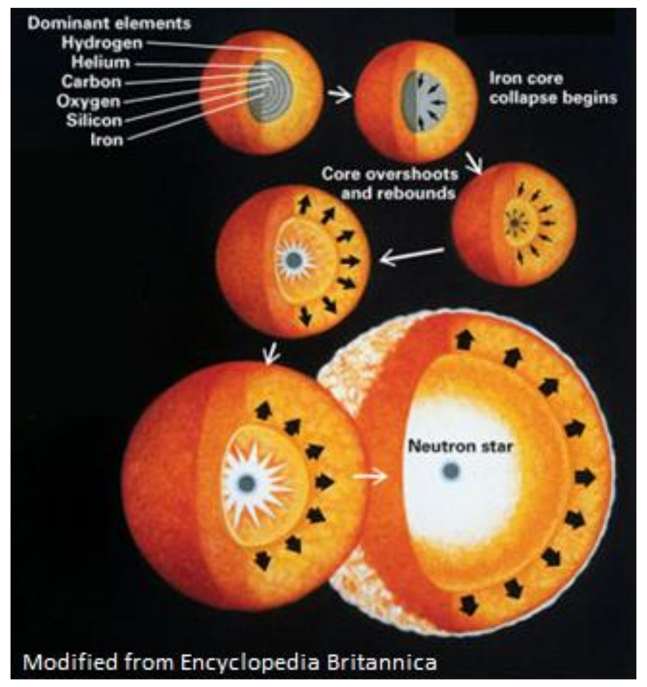
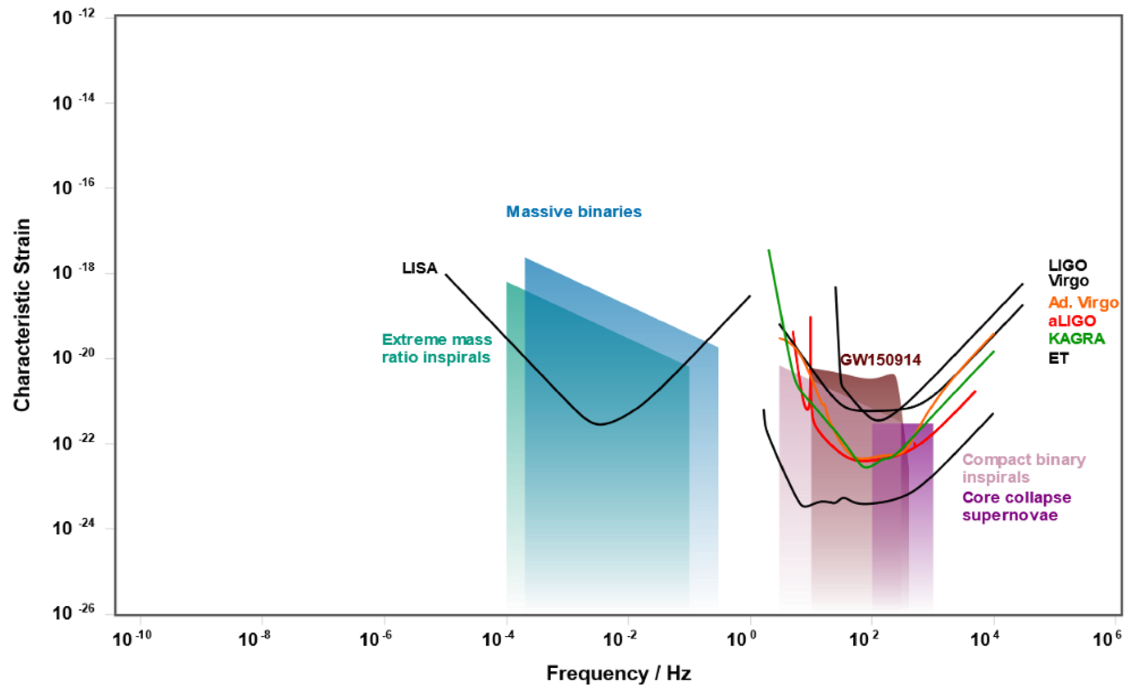
Introduction

- Core-Collapse Supernovae (CCSNe) are the explosive deaths of massive stars
- CCSNe are multi-messenger events: neutrinos, isotope abundances, light in multiple wavelengths, **gravitational waves (GWs)**
- Next-generation of GW telescopes may be able to detect CCSN GWs
- **Our Goal:** Create comprehensive multi-messenger predictions for a single set of CCSNe models





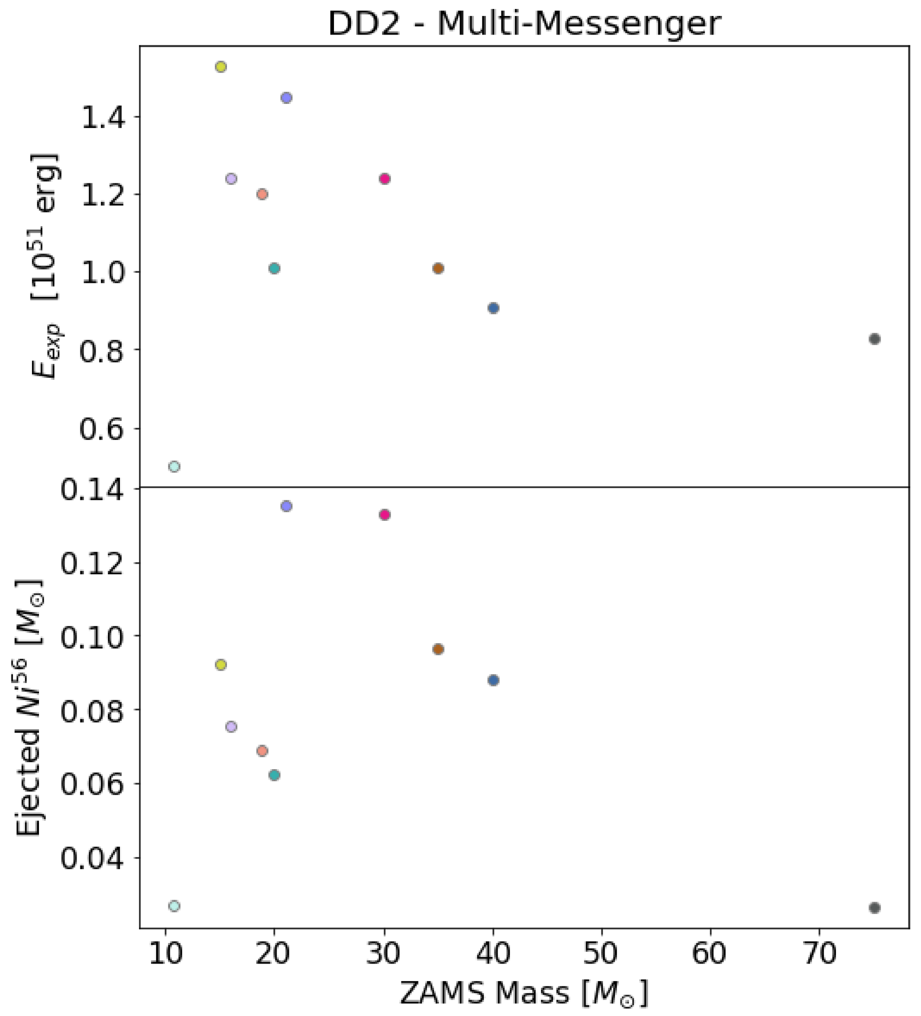
Left: *Expected frequency and strain ranges of current and second-generation GW telescopes*[6]

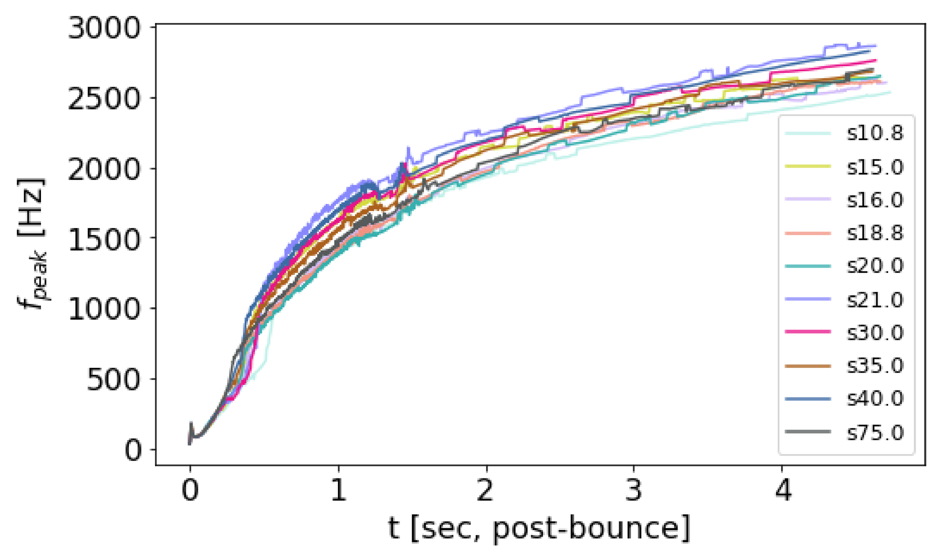
Methodology

- Gravitational Wave calculations
  - Only find eigenfrequencies, but not amplitudes from our models
  - $l = 2$ Spherical harmonic mode for quadrupole oscillations
  - Need: radius, pressure, specific internal energy, adiabatic index, and lapse function in each cell as a function of time
  - From Morozova et al. 2018[1]
- Supernova models
  - Spherically symmetric models calculated with AGILE-IDSA
    - Computational domain includes up to Helium shell
    - GR Hydrodynamics
    - Neutrino transport: IDSA (electron flavors) and spectral leakage (heavy flavors)
    - Nuclear Equation-of-State (EOS): DD2 and SFHo
    - Explosions obtained using the PUSH method[2,3]
  - Stellar Models
    - Solar metallicity, with a range of ZAMS masses and compactness[4]
    - Naming convention: s for solar metallicity, ##.# for ZAMS mass

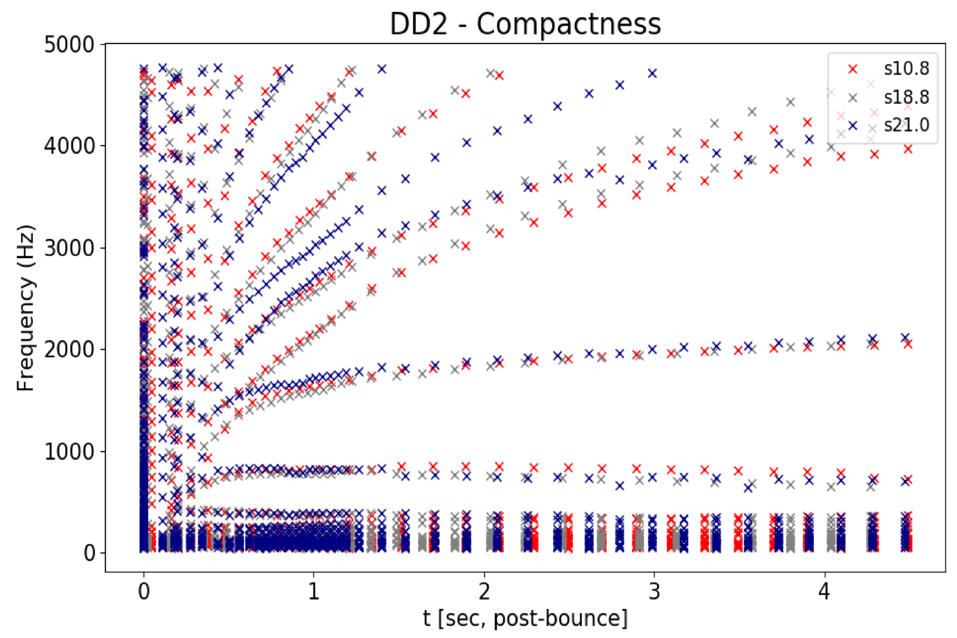
Multi-Messenger Predictions

- Multi-messenger predictions for 10 models with DD2 EOS
- Ni and explosion energies from Ebinger et al. 2019[3]
- Possible correlation between high E_{exp}, Ni mass, and f_{peak}
- Correlation of order of f_{peak} values at most times and compactness
  - Both f_{peak} and compactness are dependent on/proportional to PNS mass and radius
- f_{peak} Calculations from Morozova et al. 2018[1] and Müller et al. 2013[7]
  - Morozova et al. found that it closely matched the f-mode and highest amplitude of the gravitational wave signal



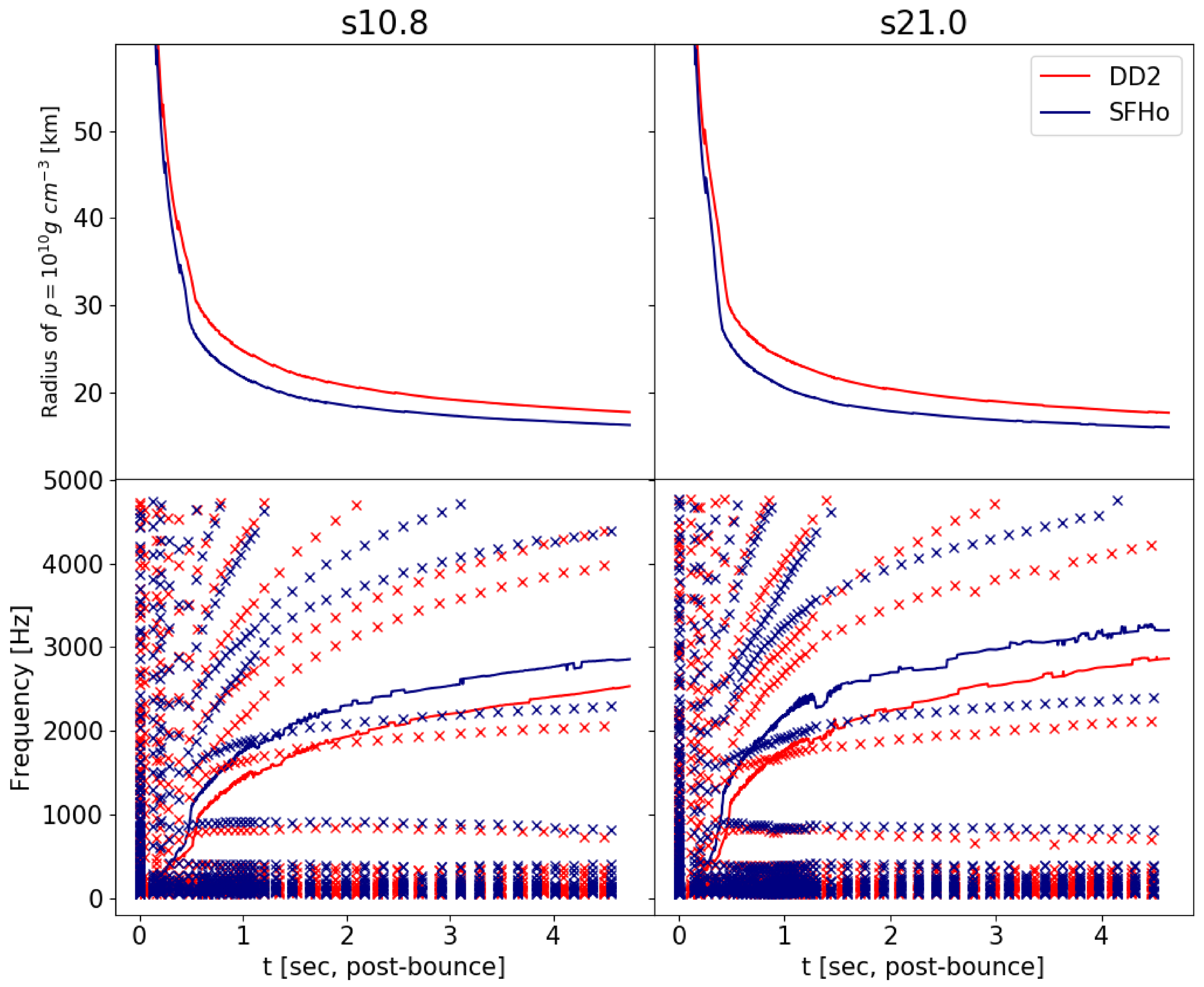


Influence of Compactness



- $\xi_M = \frac{M/1\,M_{\odot}}{R(M_{bary}=M)/1000\,km}$ from O'Connor and Ott 2011[5]
- $\xi_{2.0}$ values
  - s10.8: 0.009
  - s18.8: 0.249
  - s21.0: 0.460
- s21.0 initially follows others, but flattens out sooner
- At ~2.5s, s21.0 lines up with others that started as different mode

Influence of **Equation-of-State**



Top: Free boundary radius, an estimate of PNS radius

Bottom: f_{peak} graphed with solid line

- Slightly sharper changes in eigenfrequencies in SFHo → may be the result of "softer" EOS
- Some difference in p-mode frequencies; need node numbers for more detailed analysis
- f_{peak} Does not exactly match estimated f-mode

Conclusions & Future Work

- f_{peak} Discrepancy could mean:
  - Different f-mode in our models?
  - Different location of highest amplitude frequency in our models?
- Calculation of node numbers for each mode
- Test with more models and EOSs for a more systematic analysis
- Incorporate into **comprehensive multi-messenger predictions!**

Acknowledgments

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References

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