

The Landscape of Supernovae Observations from Detailed 3D Simulations

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TEAMS 2020
Zoom, Stony Brook

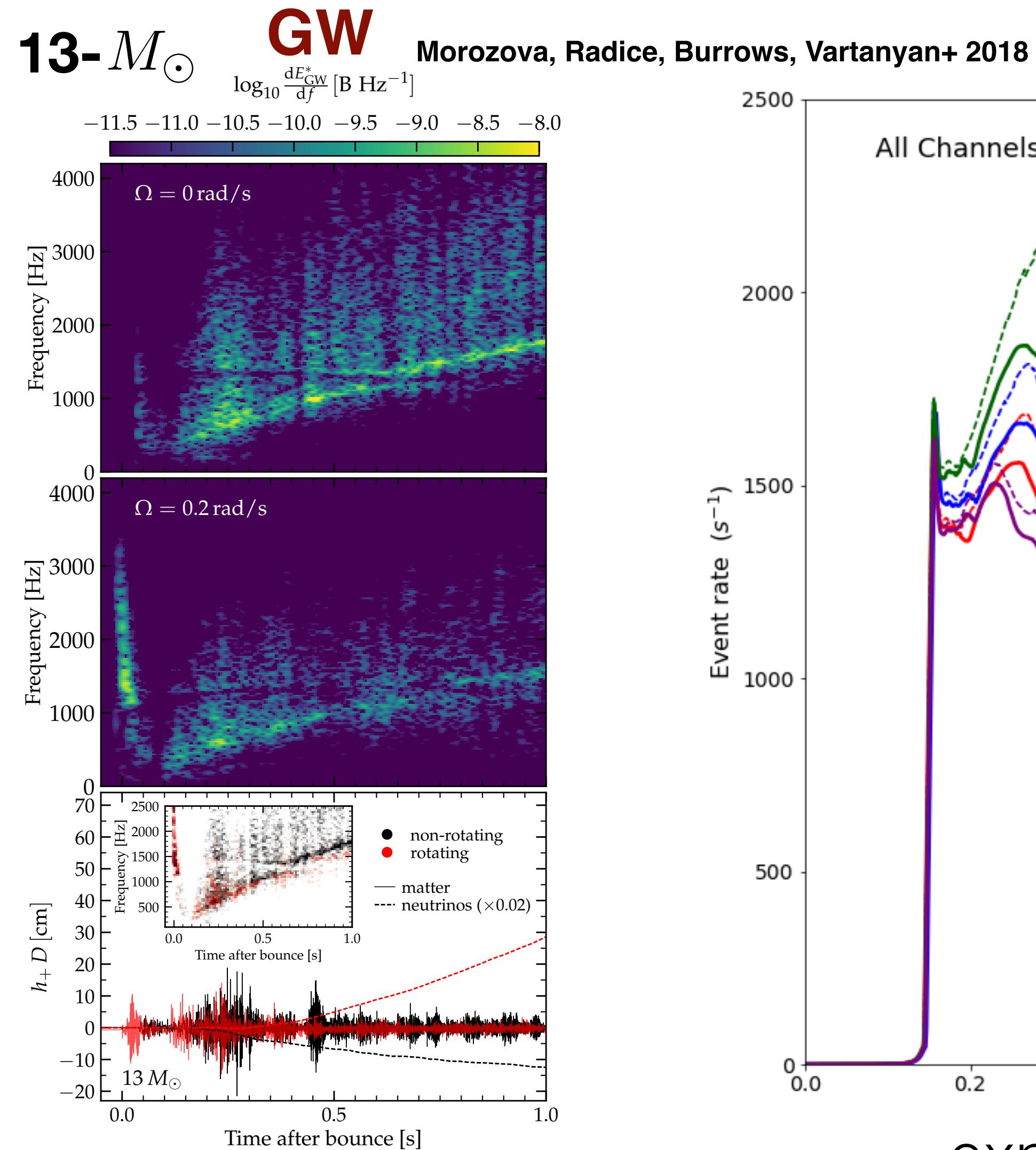
Outline

- 1. Neutrinos**
- 2. Gravitational Waves**

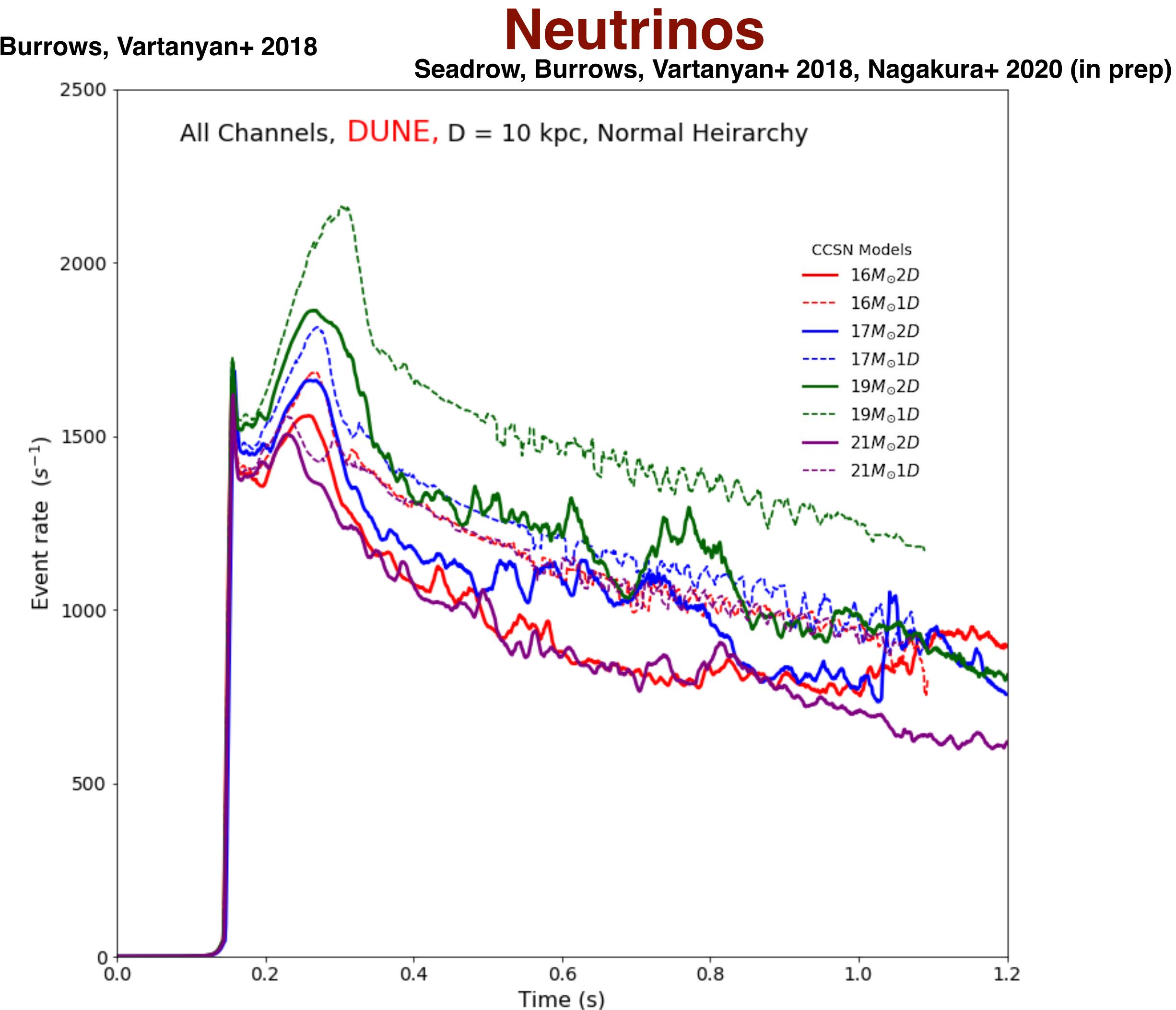
Joint detection will constrain

- Explosion mechanism**
- Large- and small-scale instabilities**
- Development and timescale of turbulence**
- PNS physics**

Overview

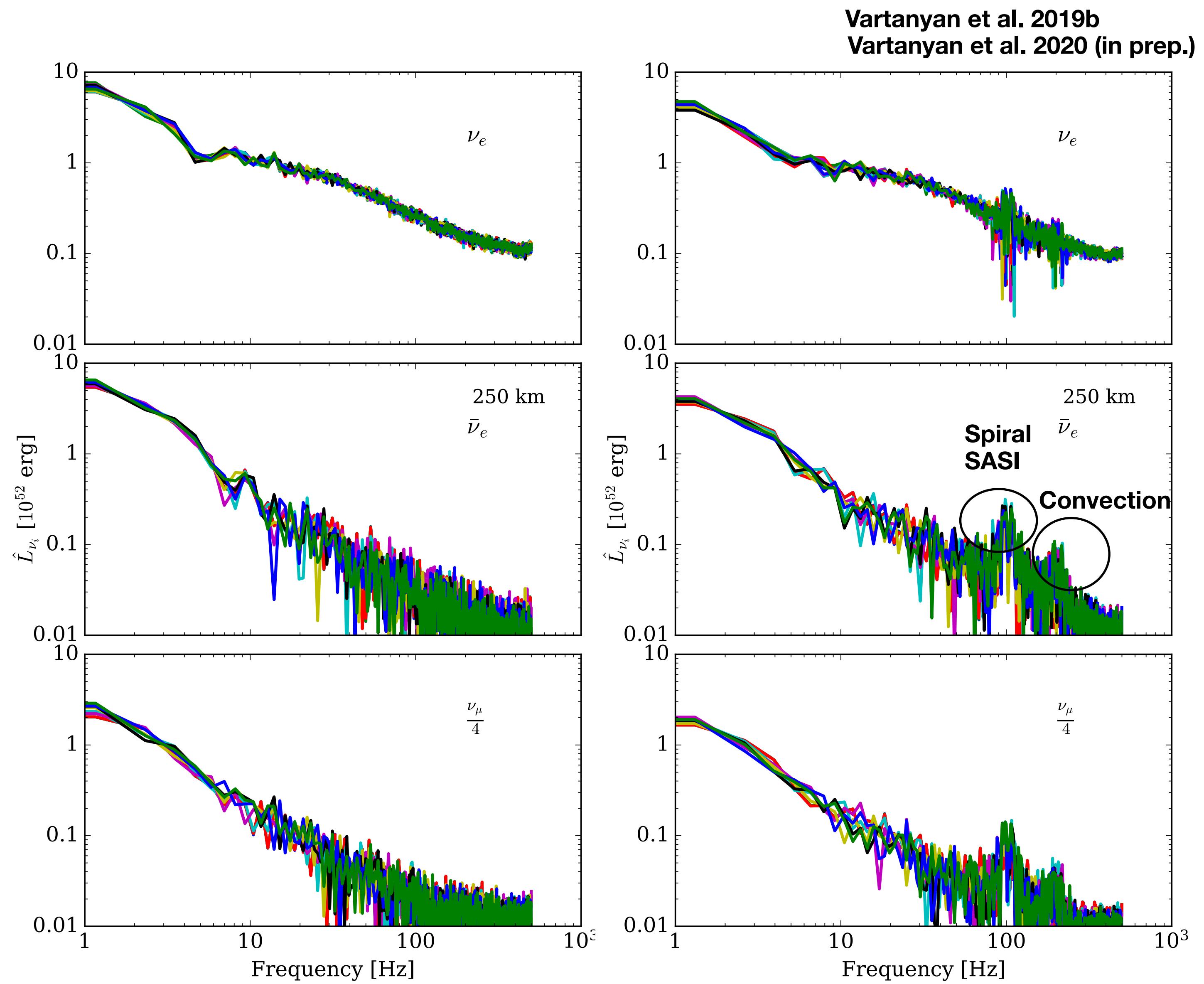
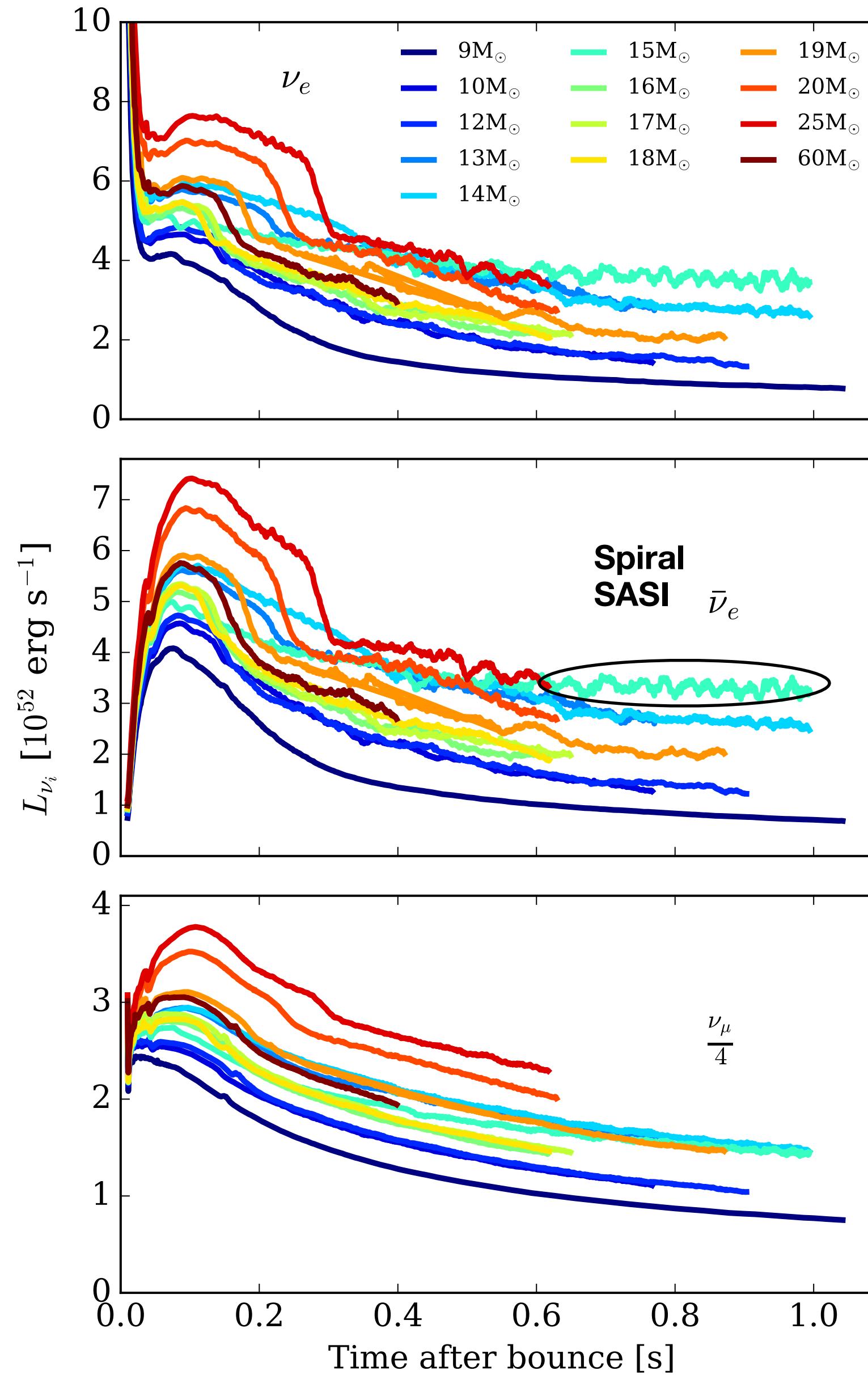


GW within aLIGO's
bandpass & threshold



explosions have distinct
GW & neutrino signals

1) Luminosity as a Looking Glass

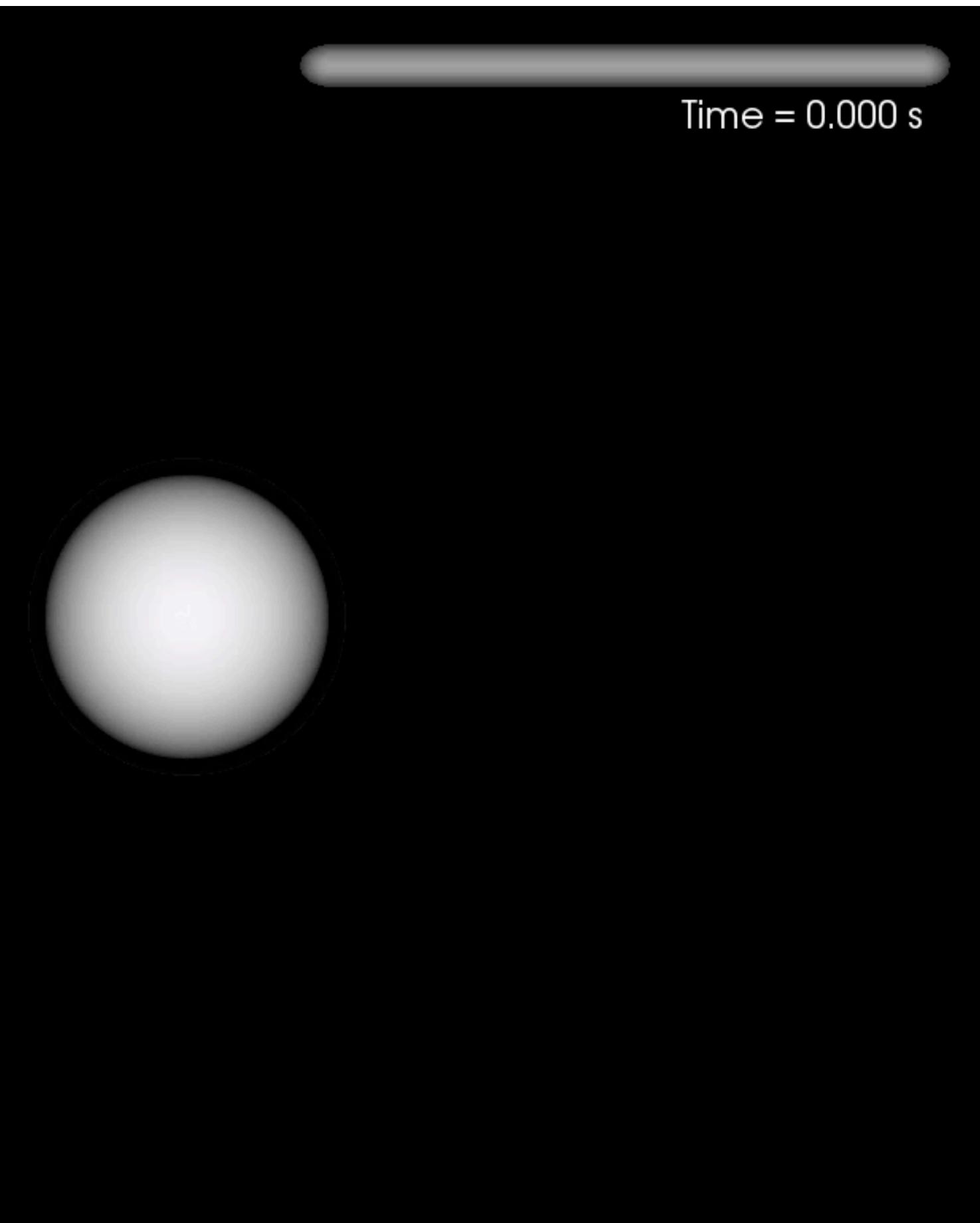


Only non-exploding models develop the SASI

Vartanyan et al. 2019b
Vartanyan et al. 2020 (in prep.)

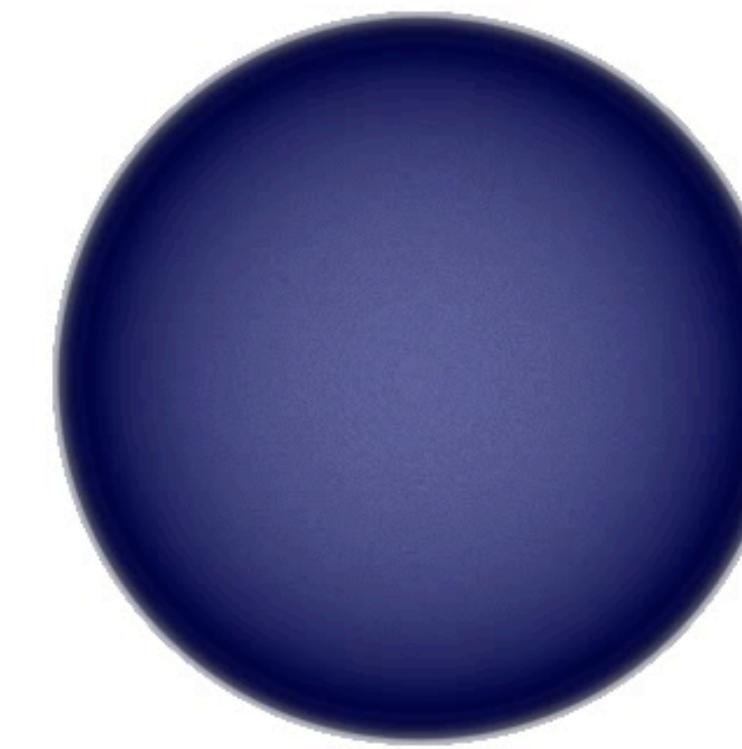
SASI: Only in Failed Explosions

16- M_{\odot}



13- M_{\odot}

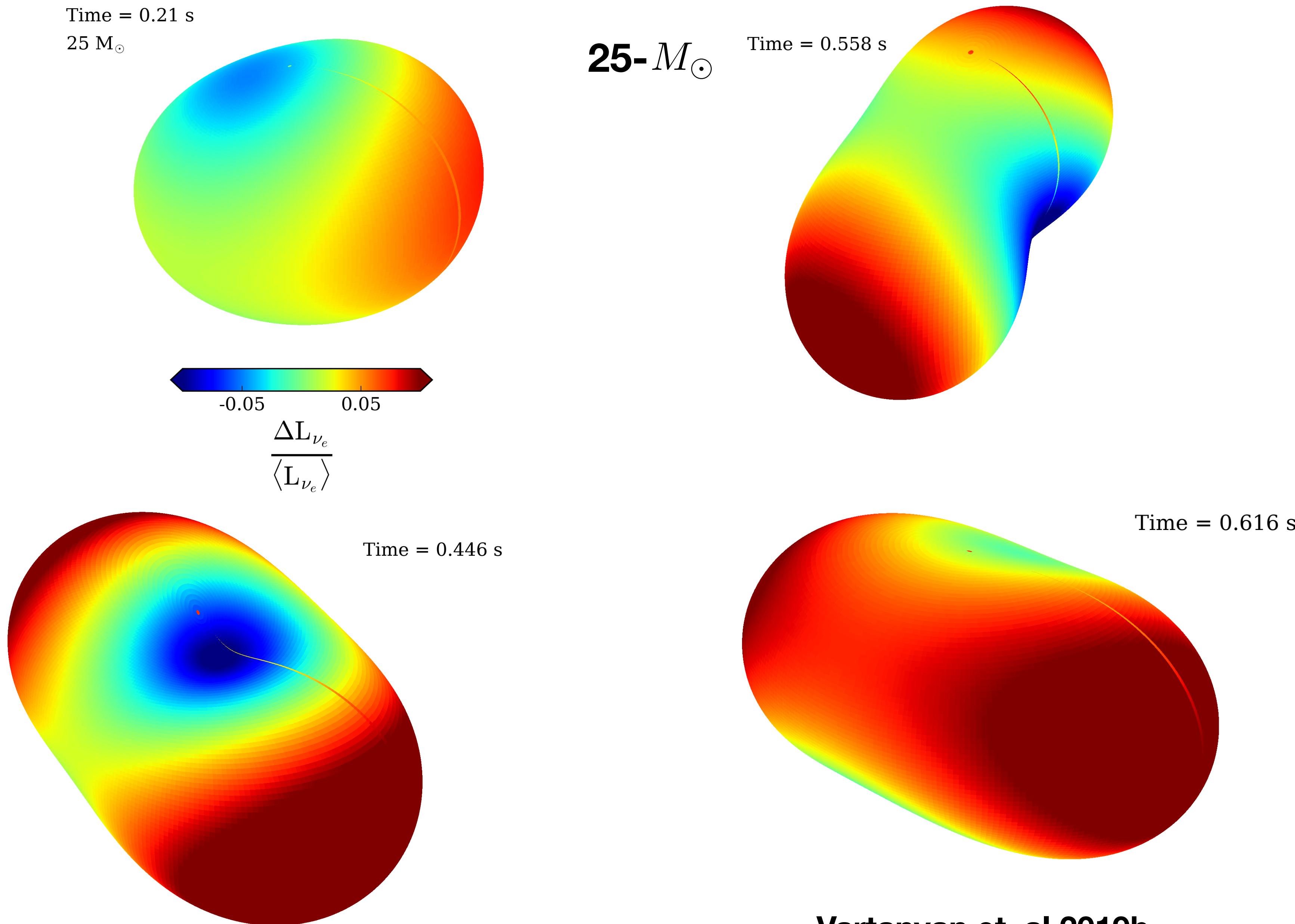
$t = 0.010 \text{ s}$



Vartanyan et al. 2019a

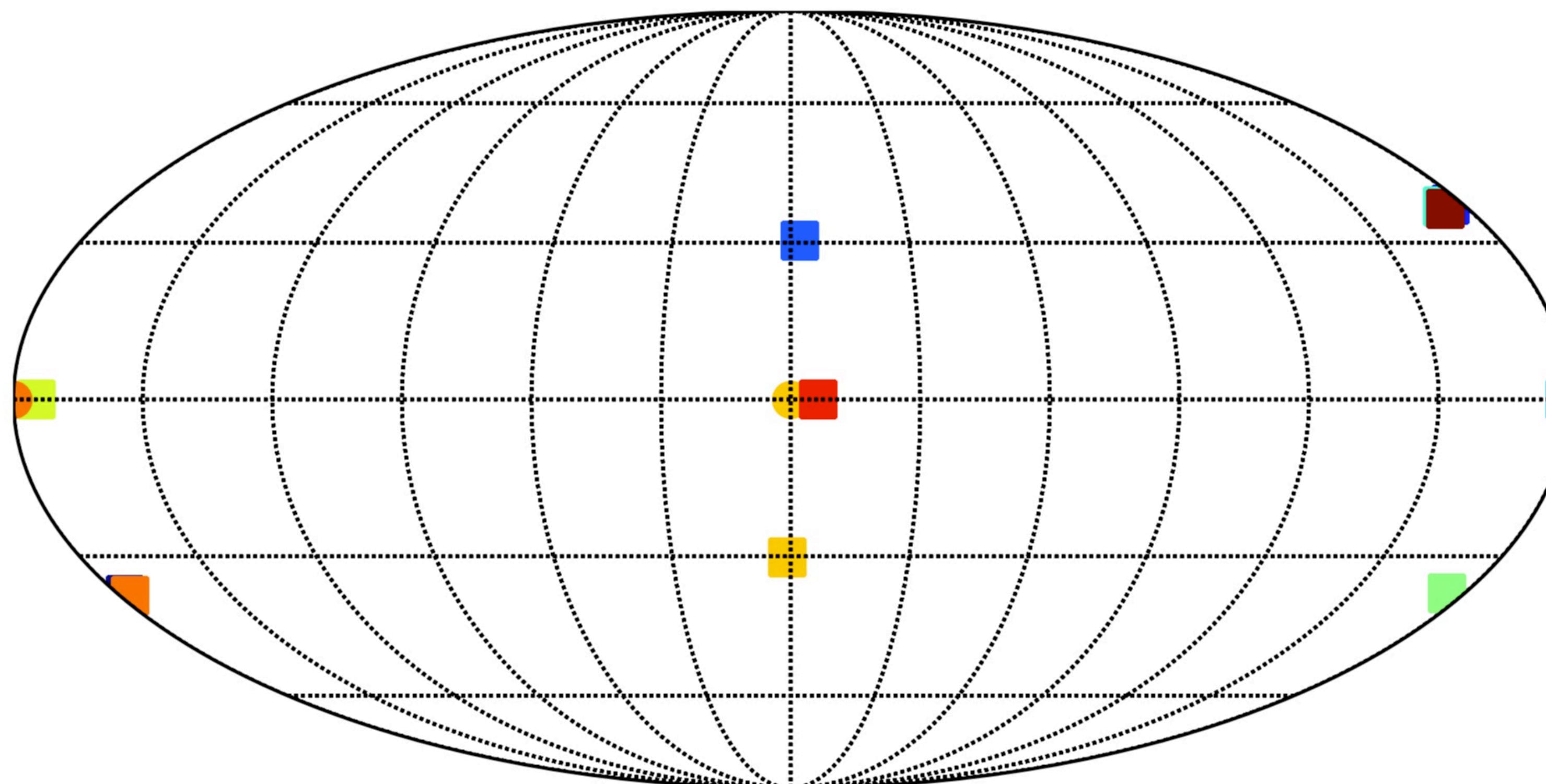
Burrows et al. 2019 a,b

L_{ν_e} Viewing Angle Variation



Circle: LESA

Square: Y_e

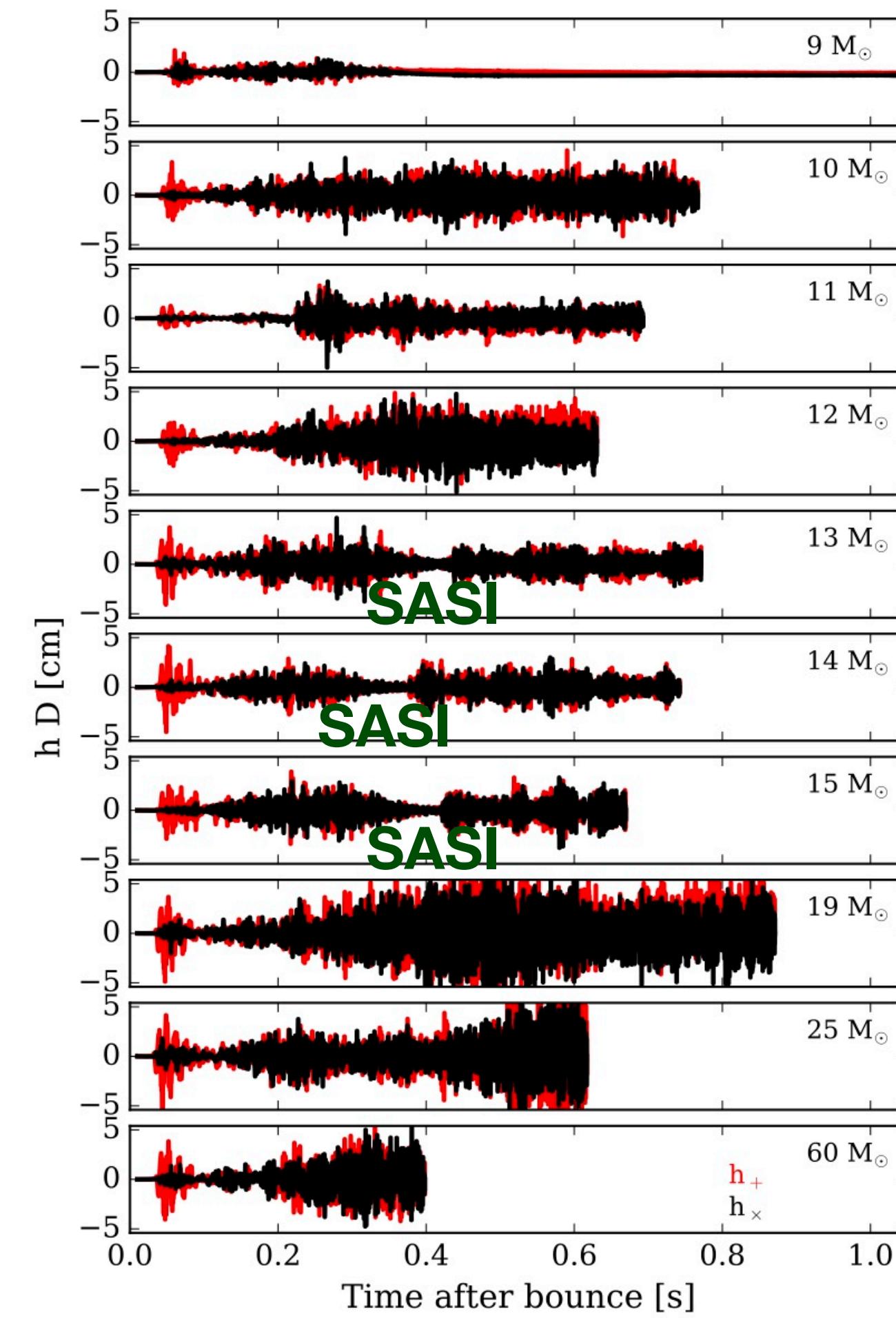


0.000 s

[Dark Blue Square]	$9 M_{\odot}$	[Cyan Square]	$13 M_{\odot}$	[Orange Square]	$19 M_{\odot}$
[Blue Square]	$10 M_{\odot}$	[Light Green Square]	$14 M_{\odot}$	[Red Square]	$25 M_{\odot}$
[Light Blue Square]	$11 M_{\odot}$	[Yellow Green Square]	$15 M_{\odot}$	[Dark Red Square]	$60 M_{\odot}$
[Light Blue Square]	$12 M_{\odot}$	[Yellow Square]	$16 M_{\odot}$		

2) Gravitational Waves

Matter

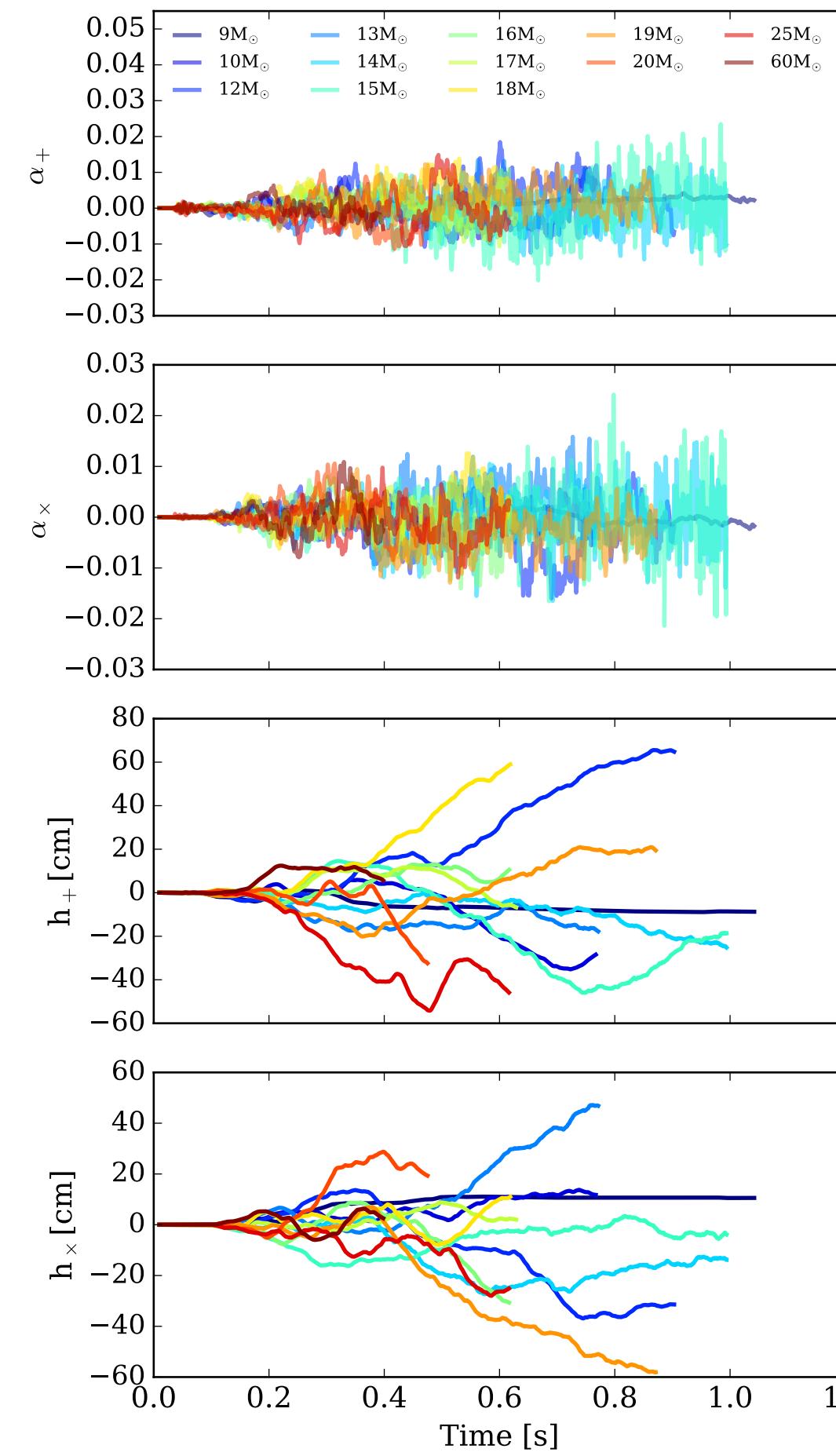


Neutrino anisotropy and strain

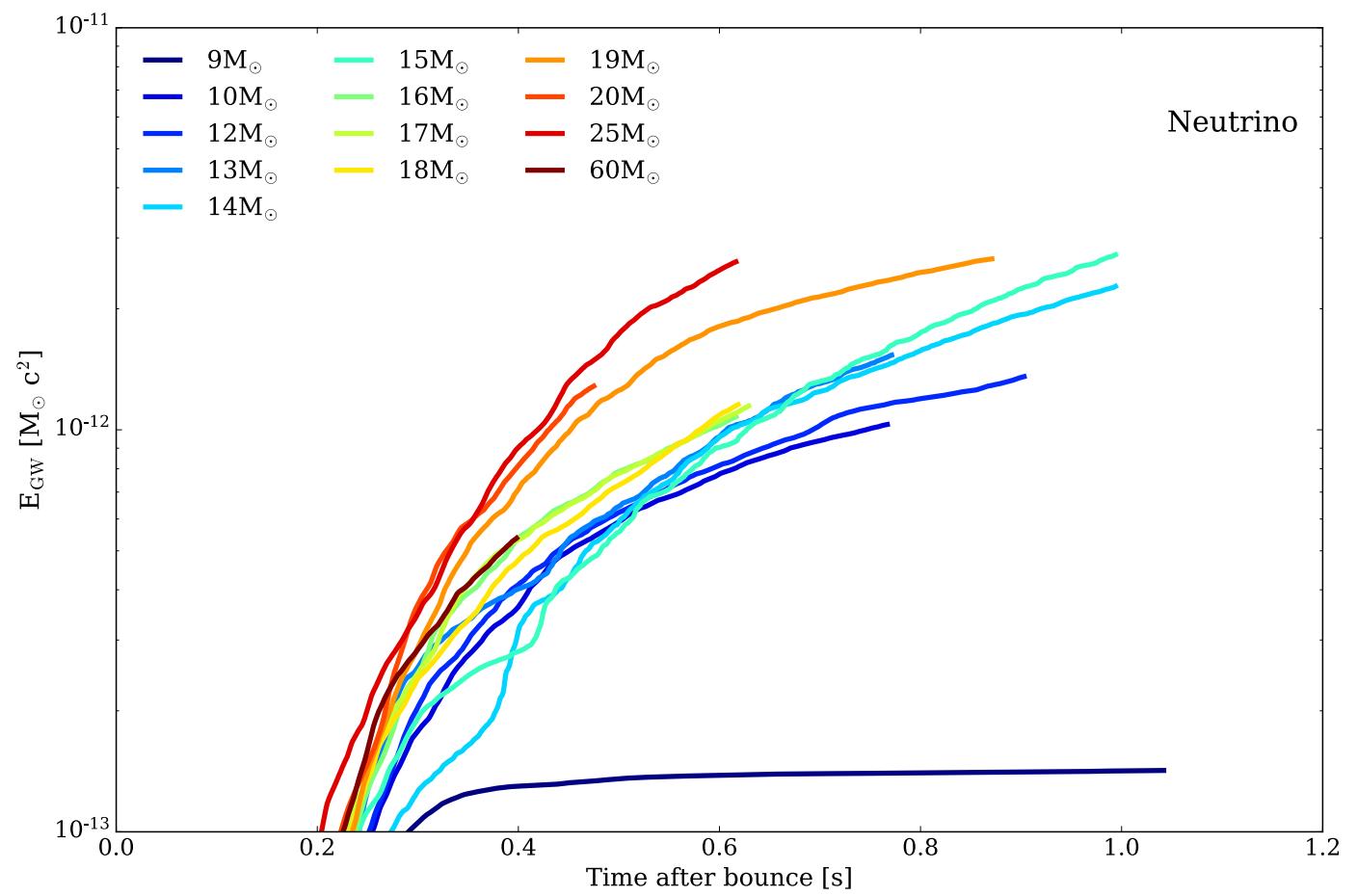
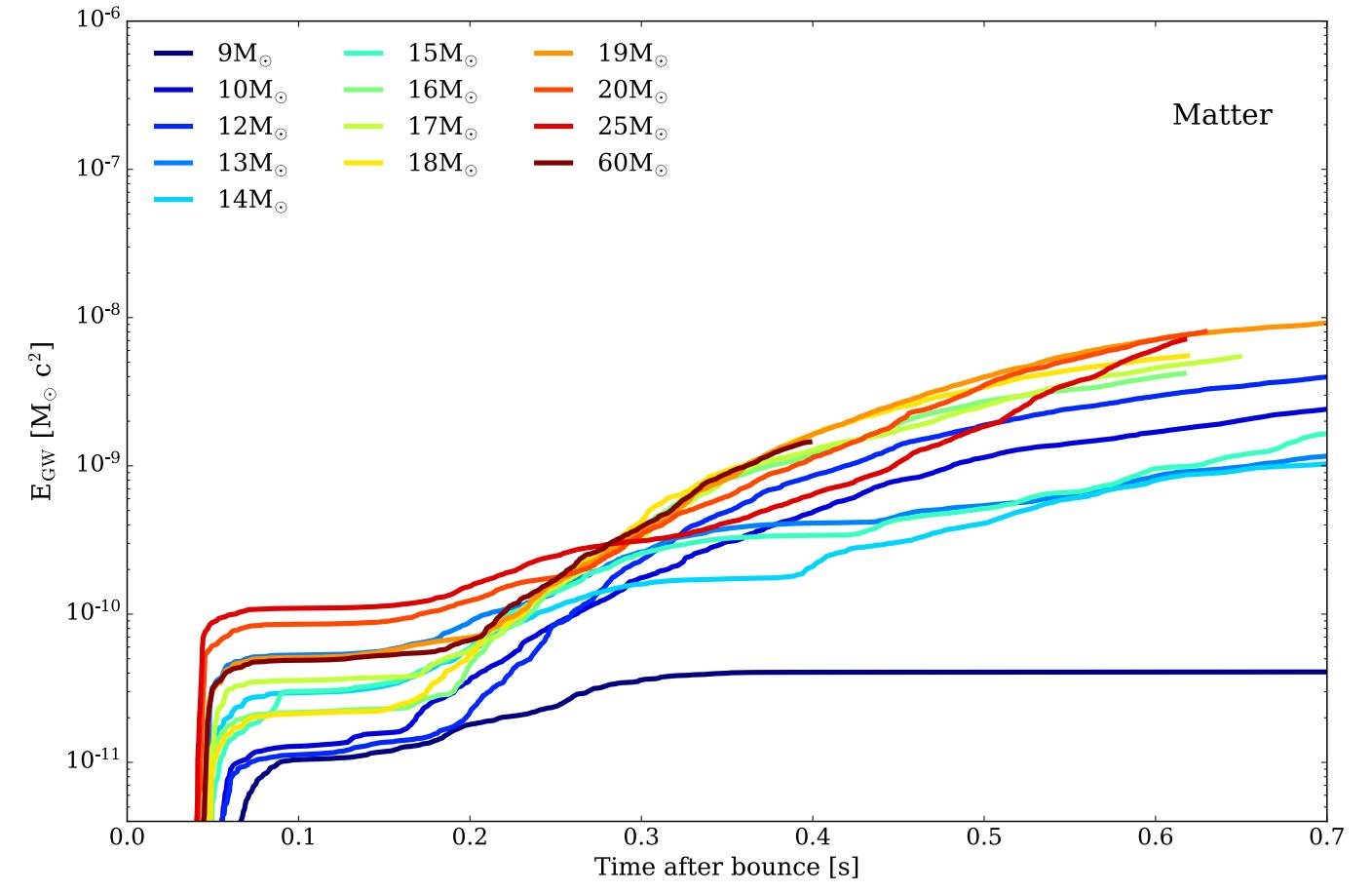
$$\alpha_S(t, \alpha, \beta) = \frac{1}{\Lambda(t)} \int_{4\pi} d\Omega' W_S(\Omega', \alpha, \beta) \frac{d\Lambda}{d\Omega'}(\Omega', t)$$

$$h_S(t, \alpha, \beta) = \frac{2G}{c^4 R} \int_0^t dt' \Lambda(t') \alpha_S(t', \alpha, \beta)$$

Neutrinos



Radice et al. 2019



Vartanyan et al. 2019 (in prep.)

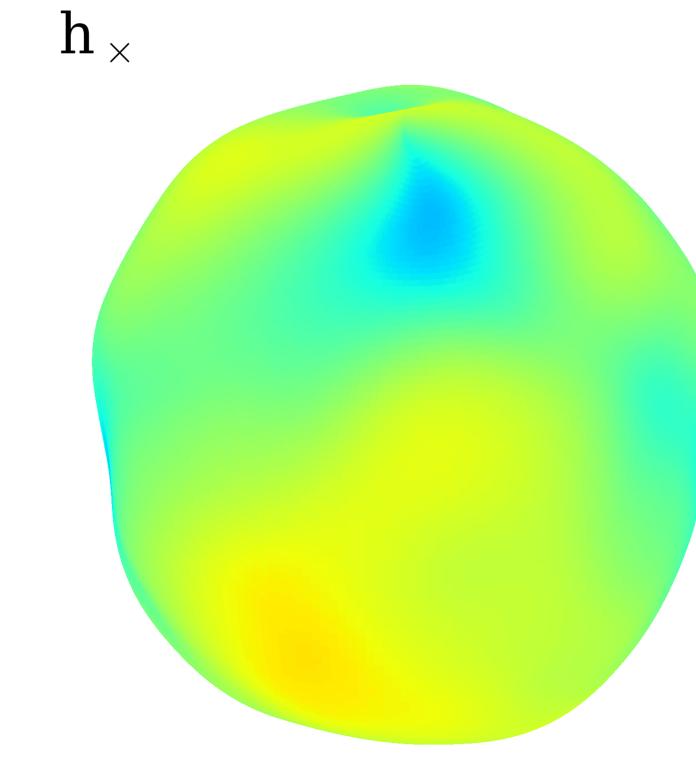
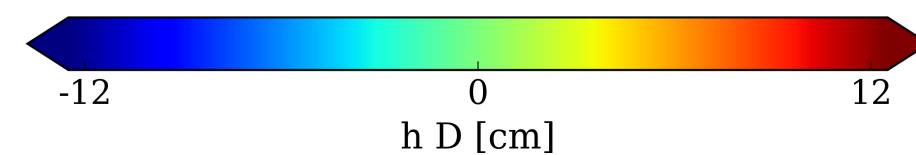
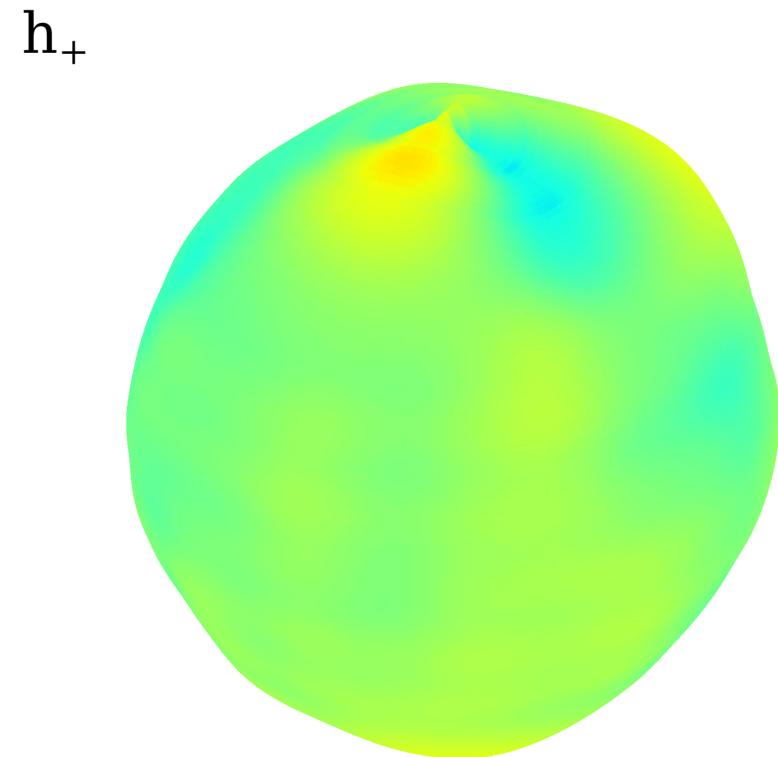
a) Neutrino GWs are ~2 OOM higher in strain than matter GWs, but contribute <1% of GW energy due to lower frequencies

b) GW ramp time = proxy for turbulence to develop

GW Viewing Angle Variation

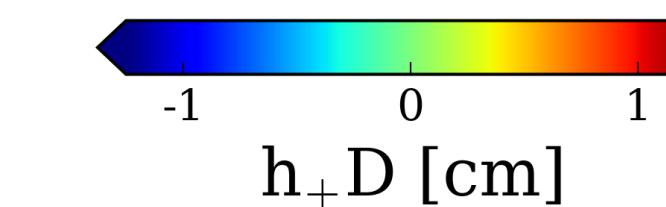
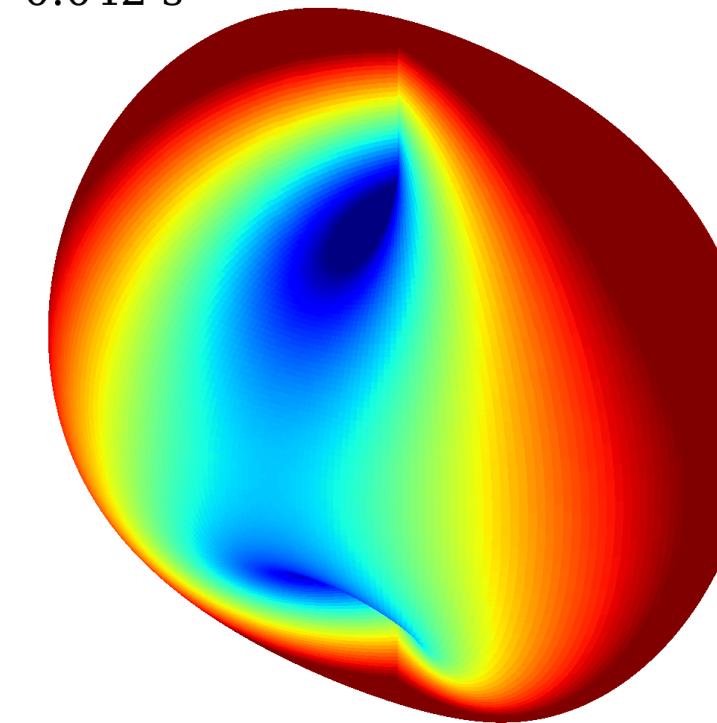
Neutrinos

Time = 0.153 s
 $19M_{\odot}$

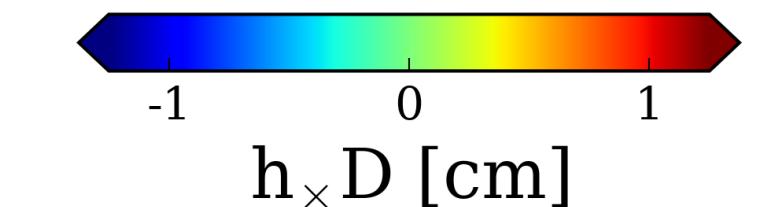
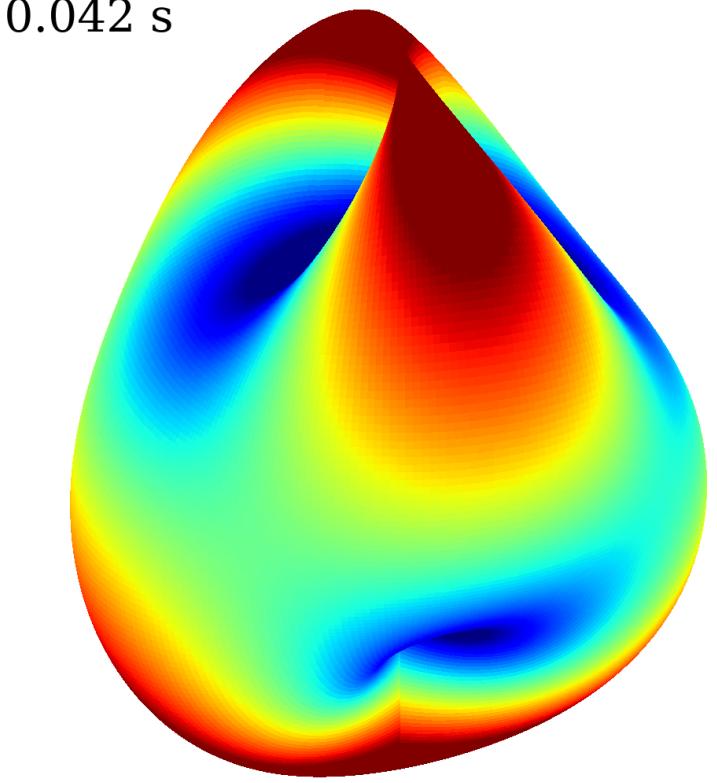


Matter

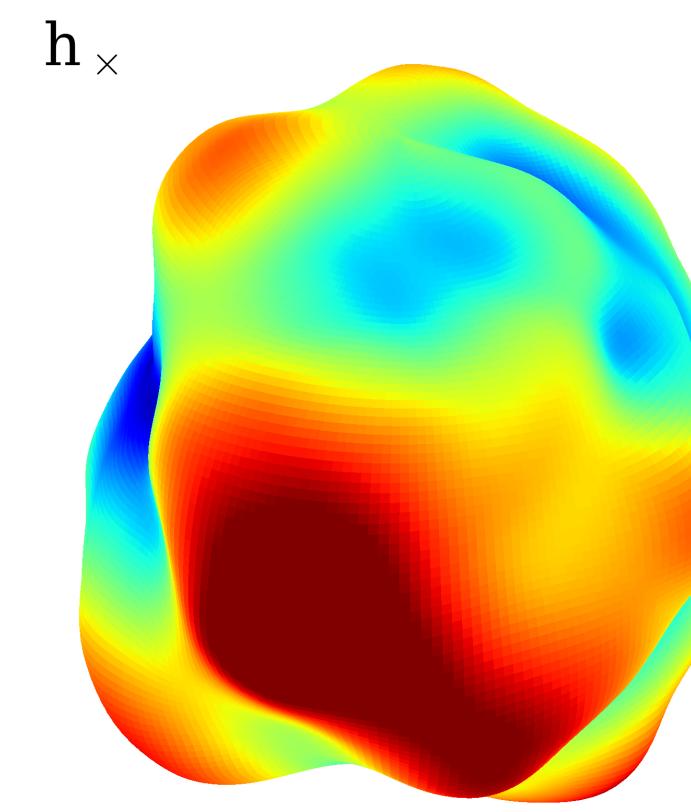
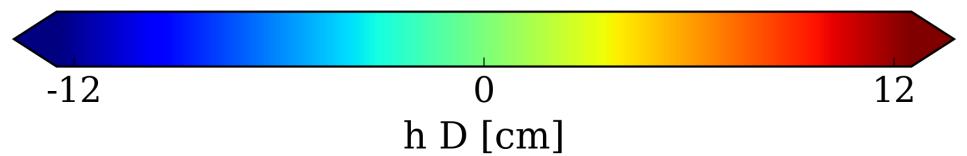
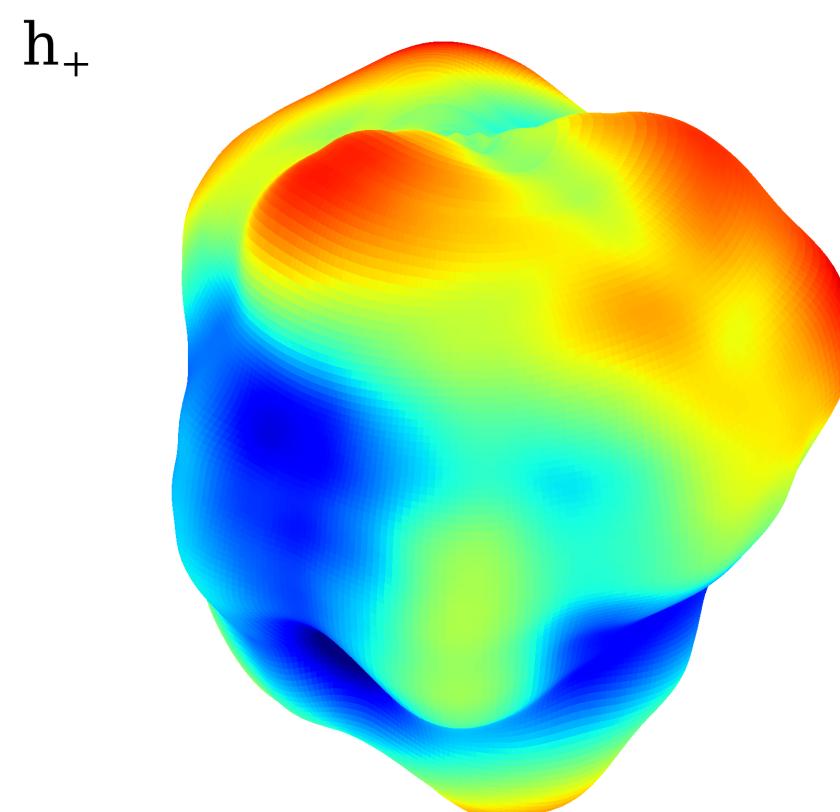
Time = 0.042 s



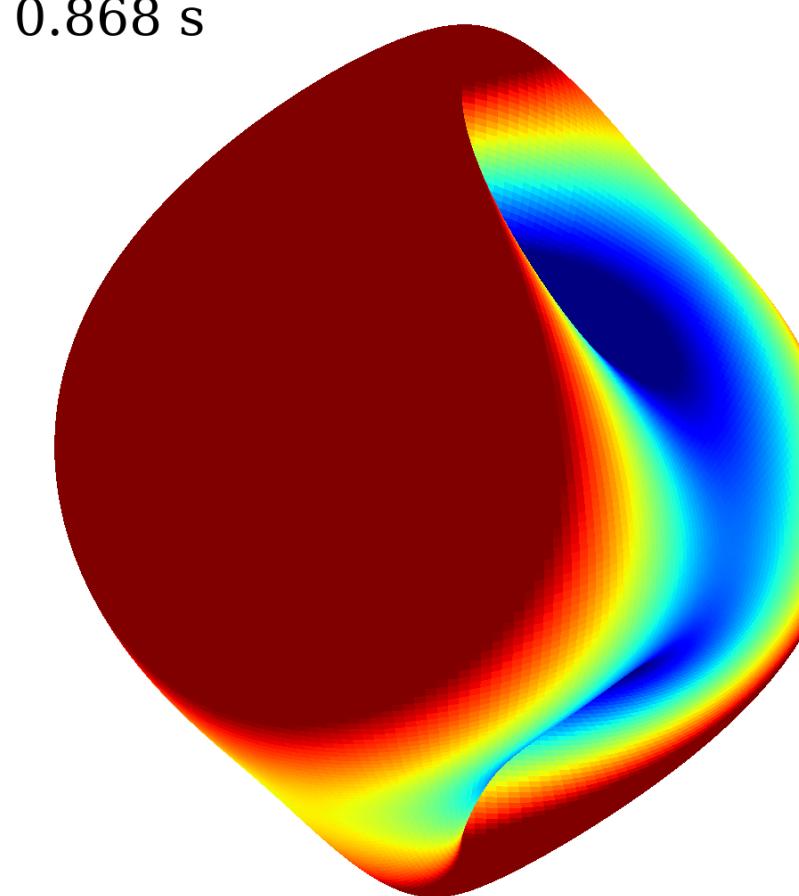
Time = 0.042 s



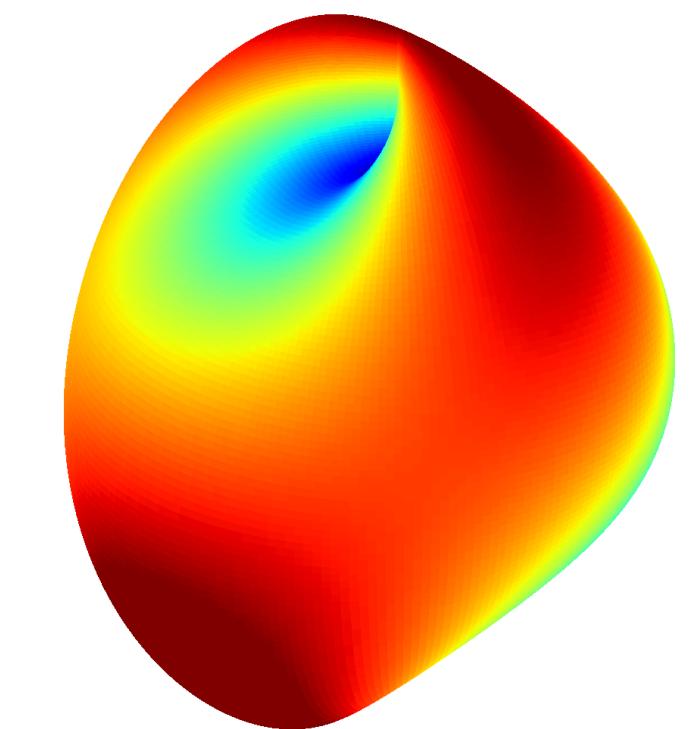
Time = 0.249 s
 $19M_{\odot}$



Time = 0.868 s



Time = 0.55 s



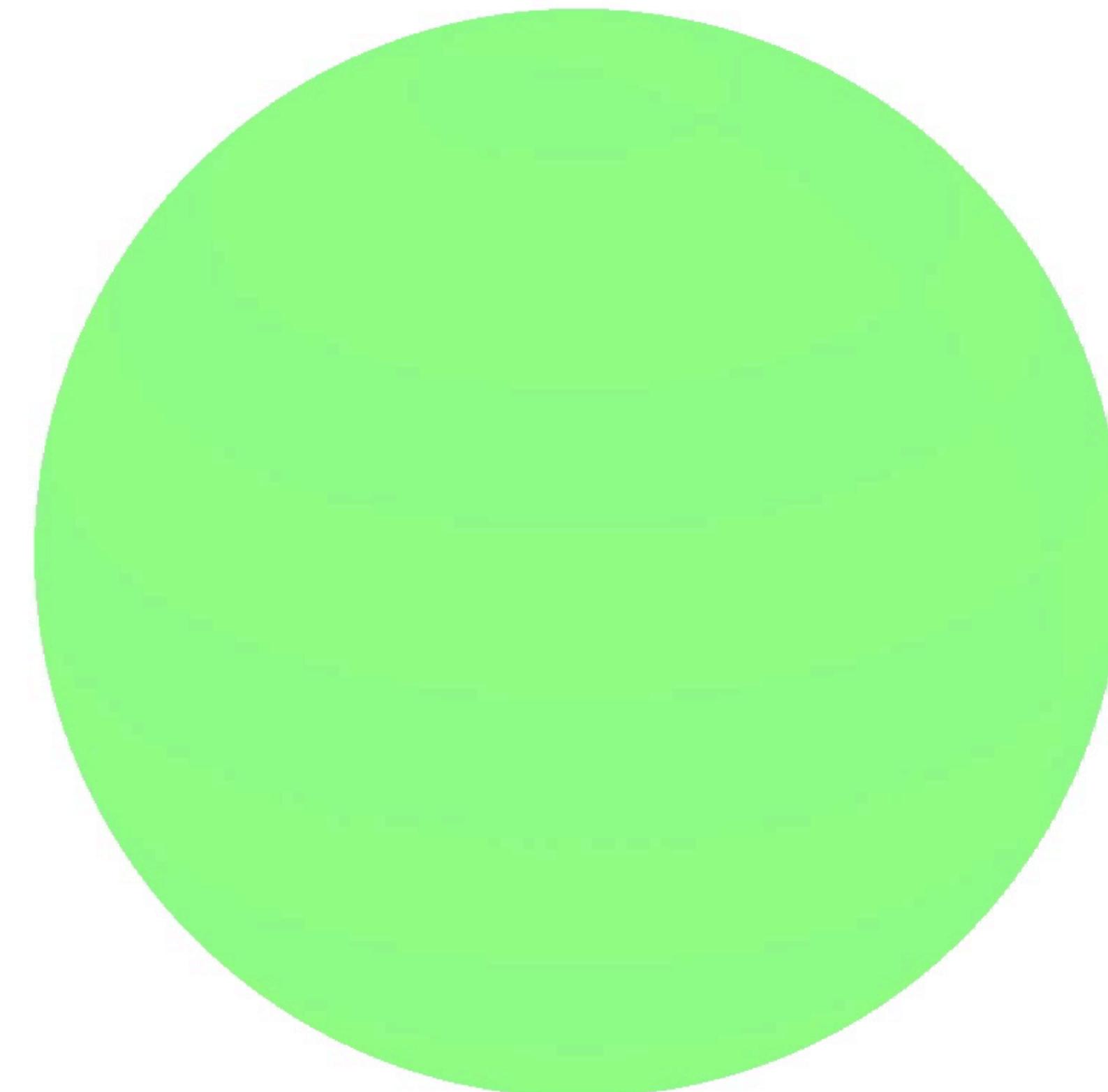
Vartanyan et al. 2019b

Vartanyan et al. 2020 (in prep.)

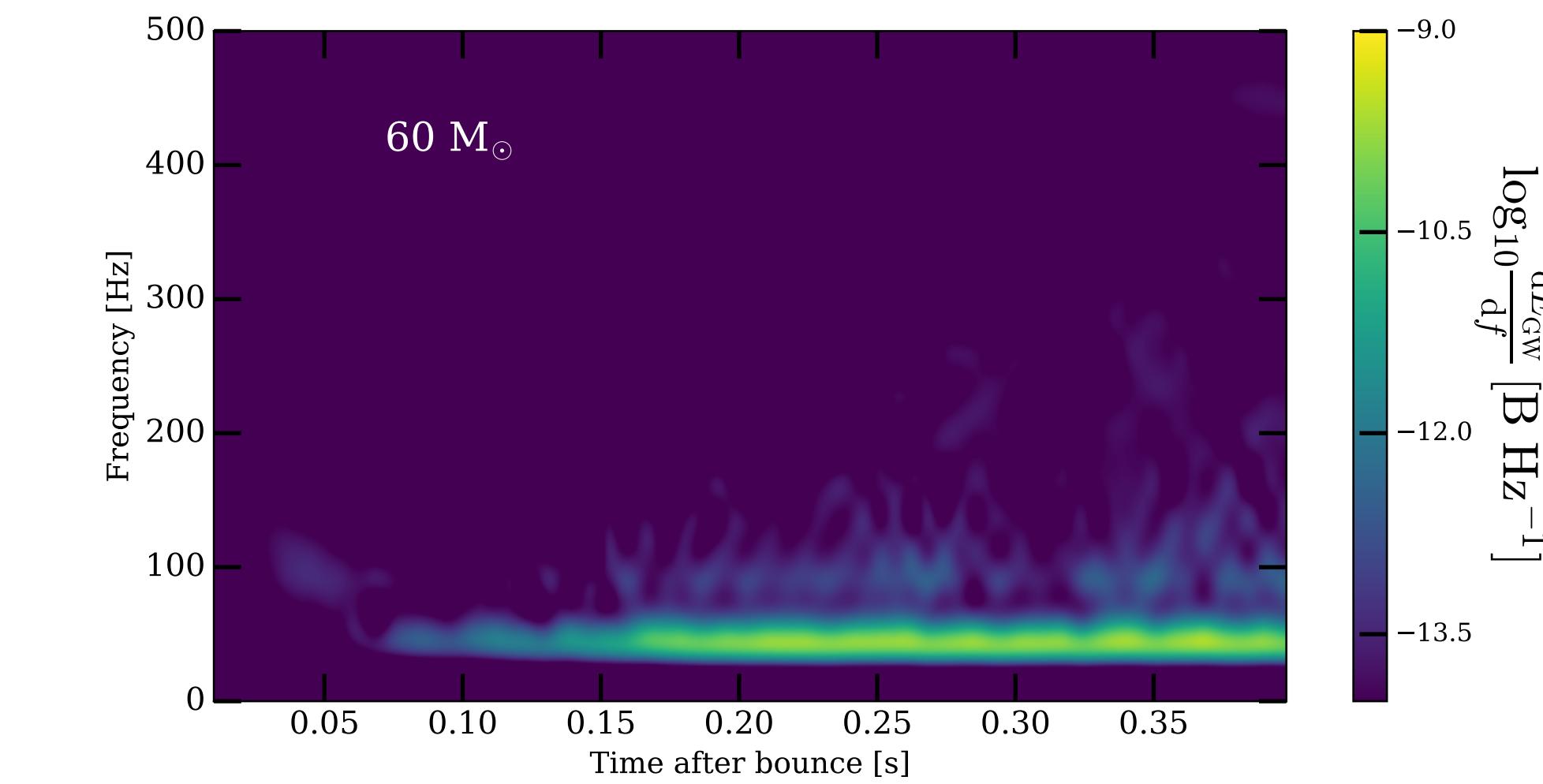
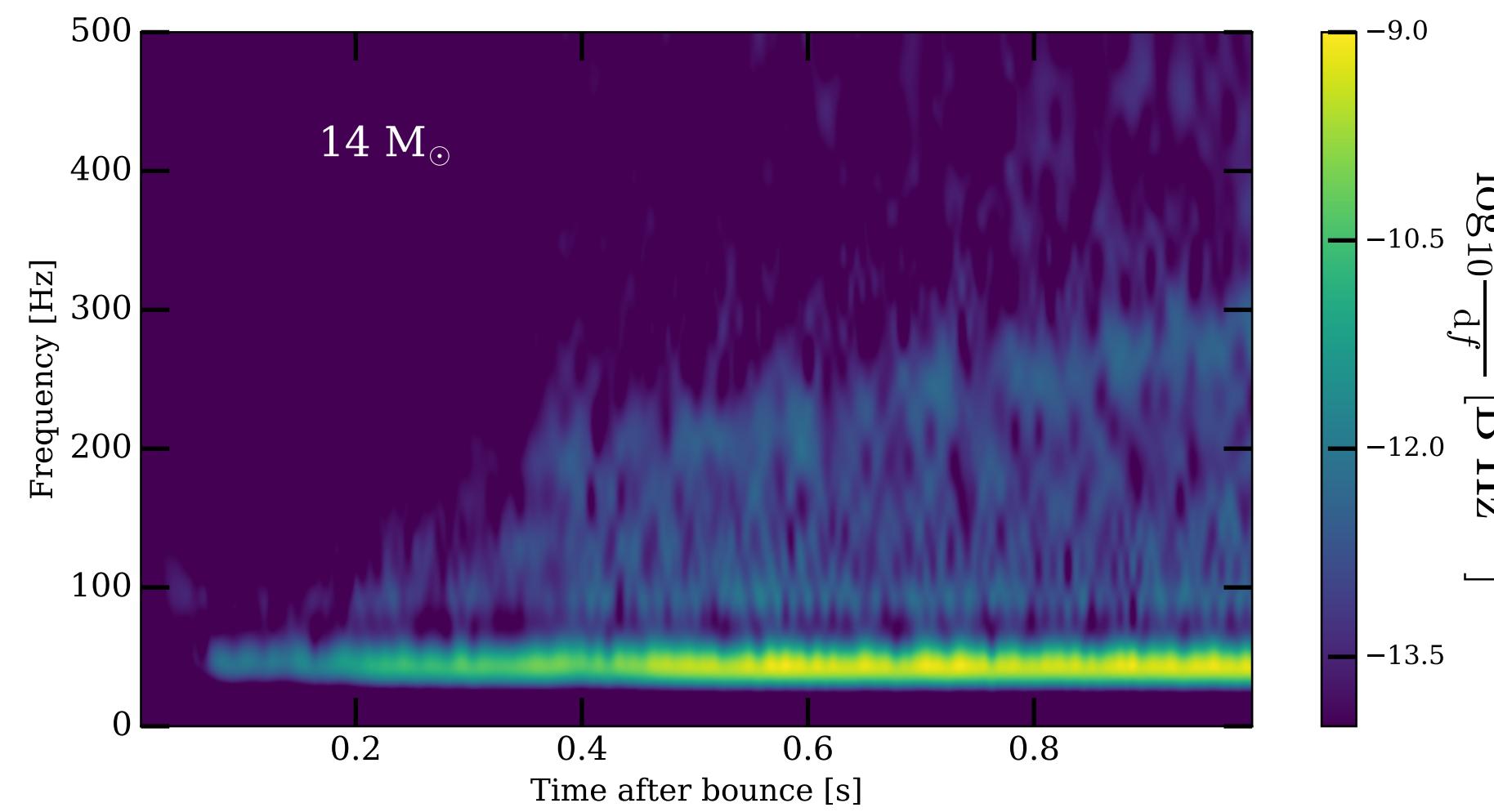
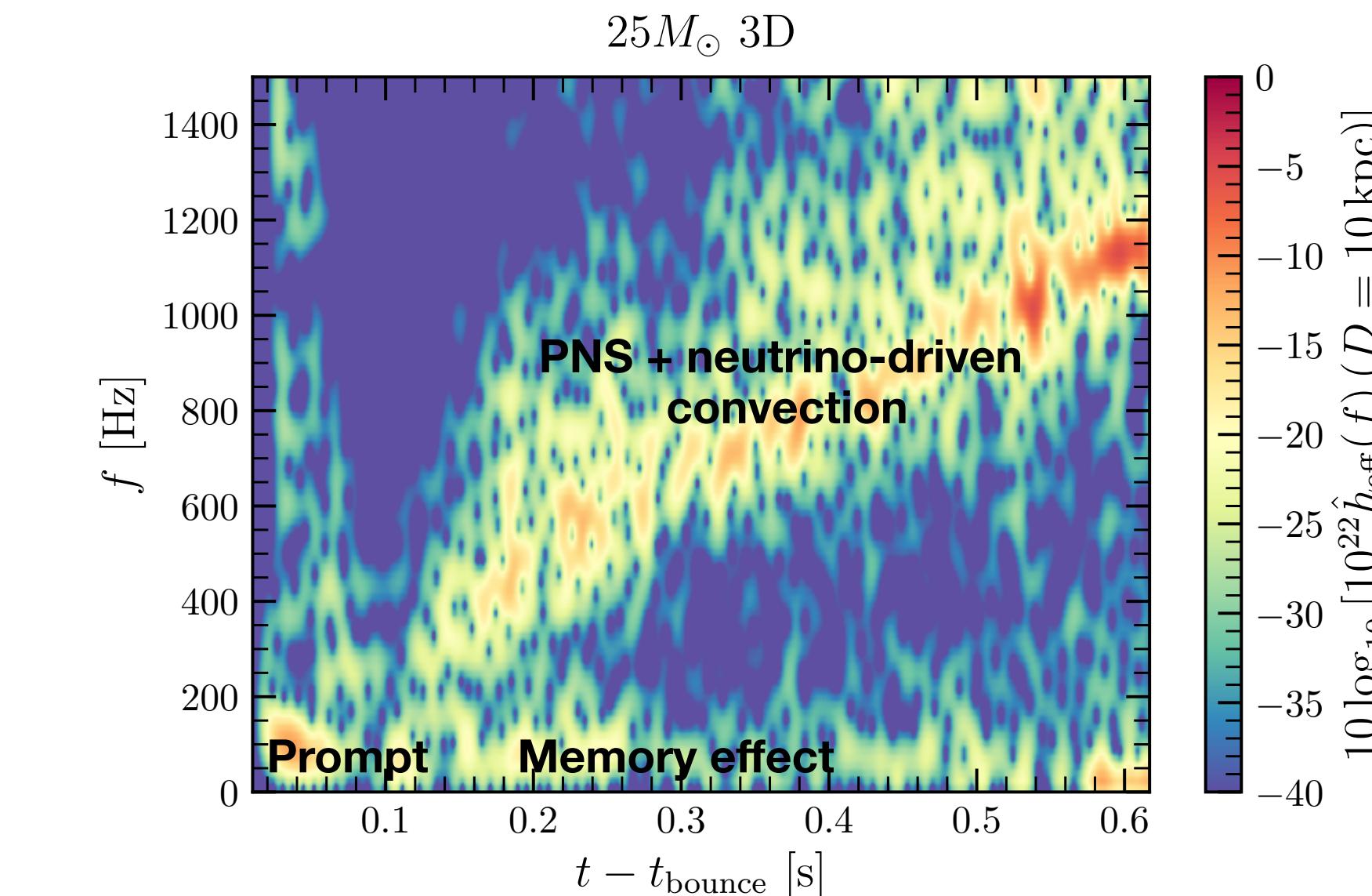
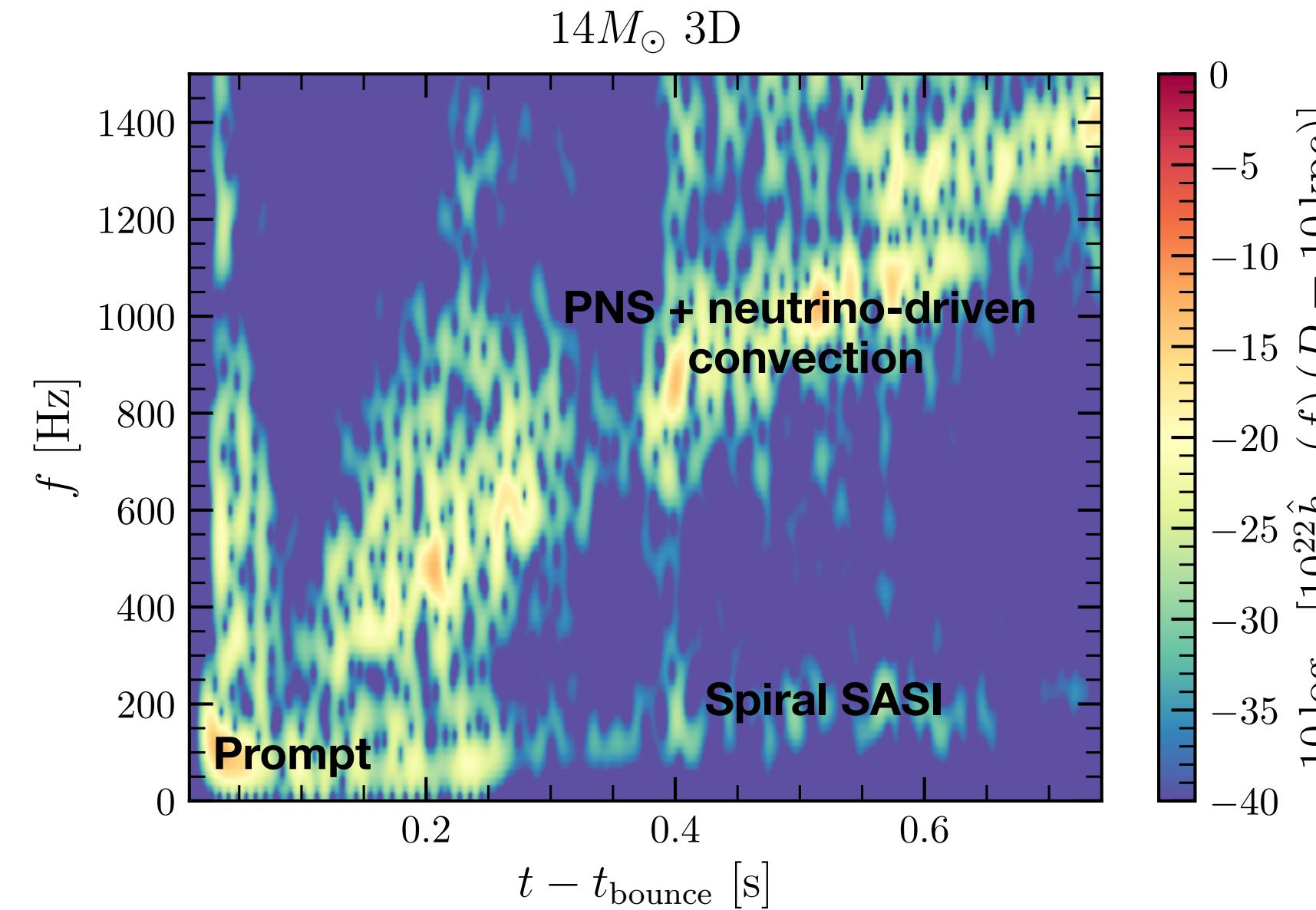
Neutrino Anisotropy Contribution to GW: High Strain, Low Frequency

Time = 0.01 s

60 M_⊙



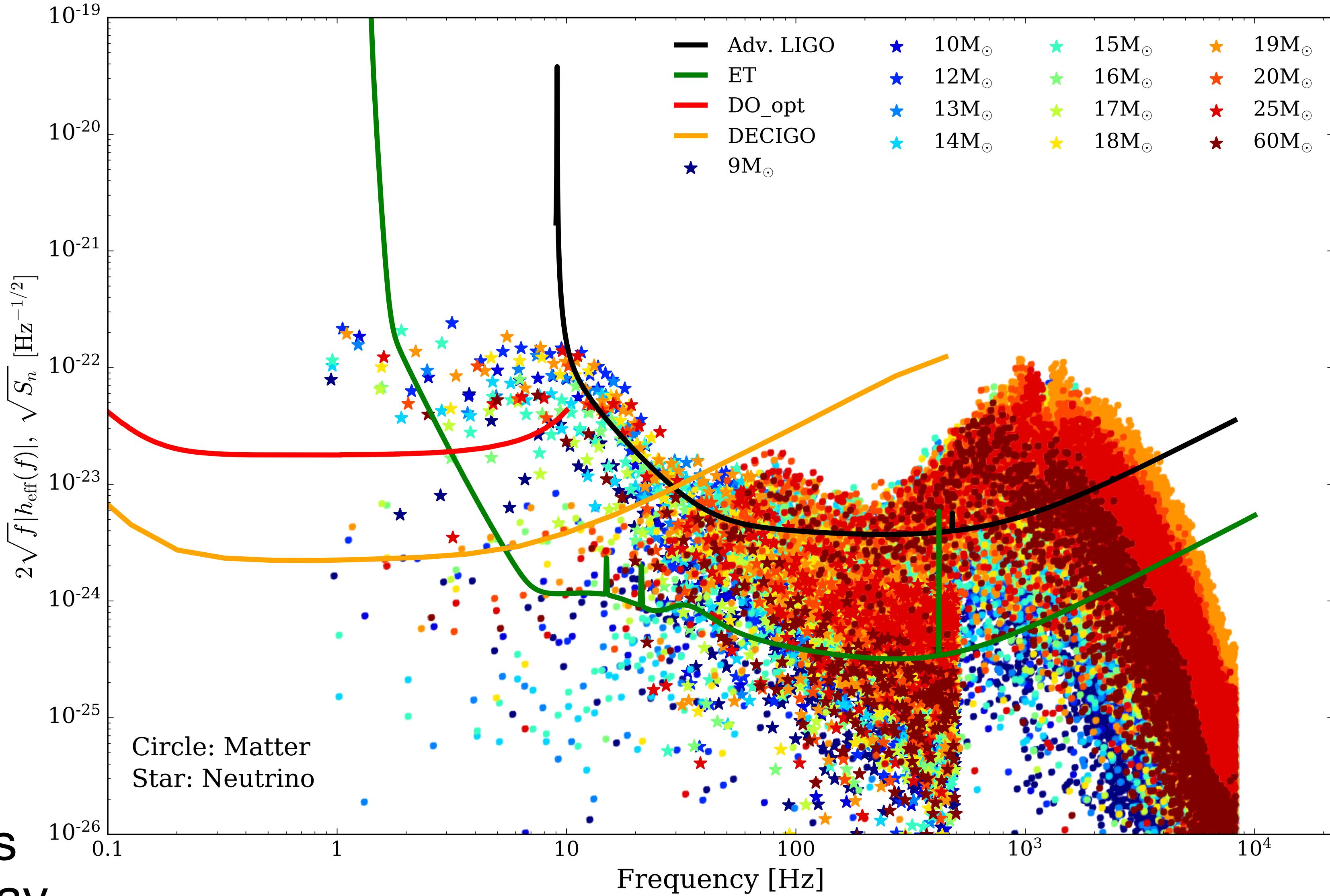
All Silent on the Neutrino Front



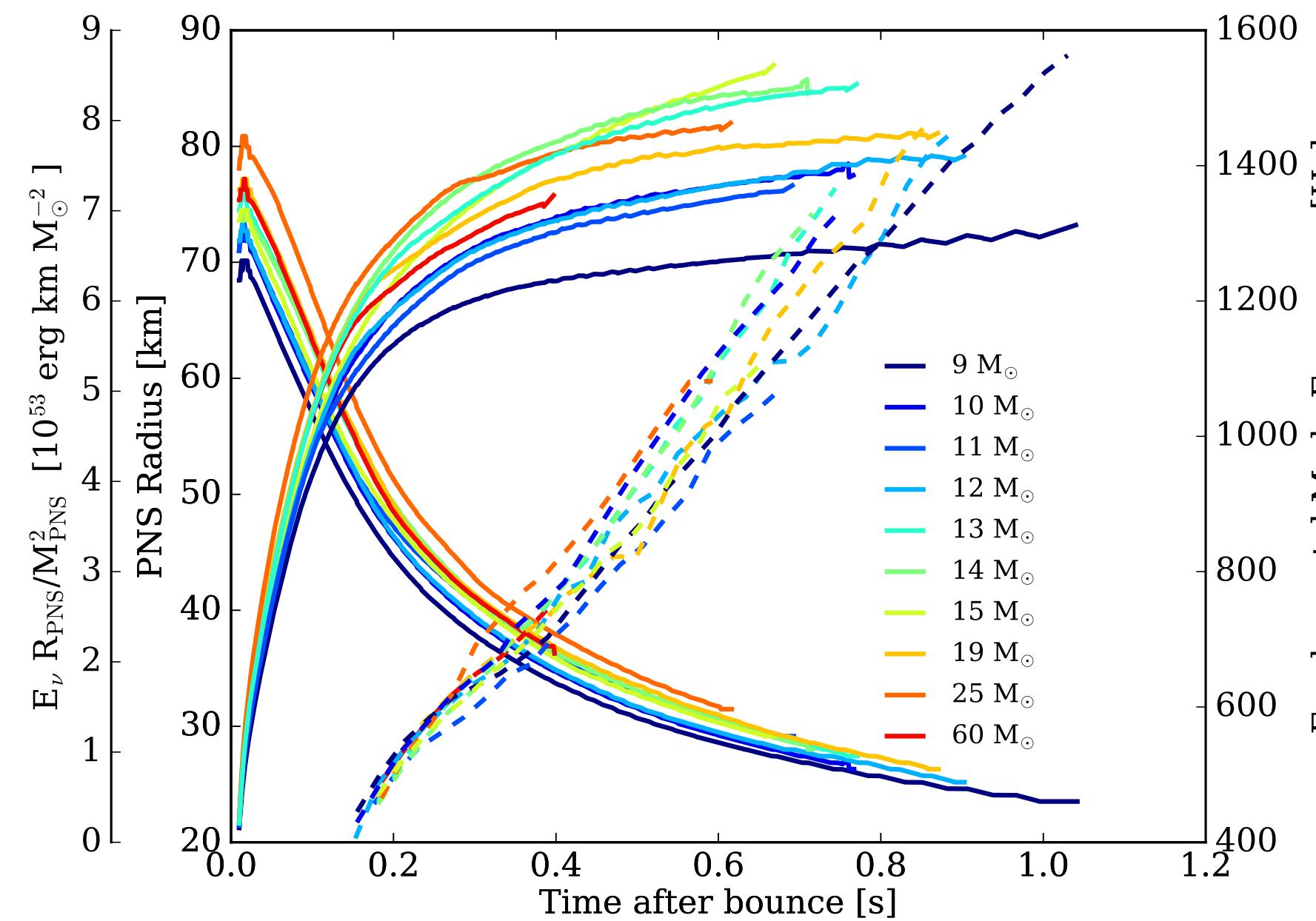
Near-Future Detection Prospects for Galactic Events

Amplitude spectral density plots constrain inherent noise of detectors and set detection thresholds

ET, DECIGO, & a-LIGO will detect matter + neutrino GWs spanning 4 OOM for a broad suite of stellar masses for CCSNe within the Milky Way



Neutrinos, Gravitational Waves & Core Dynamics

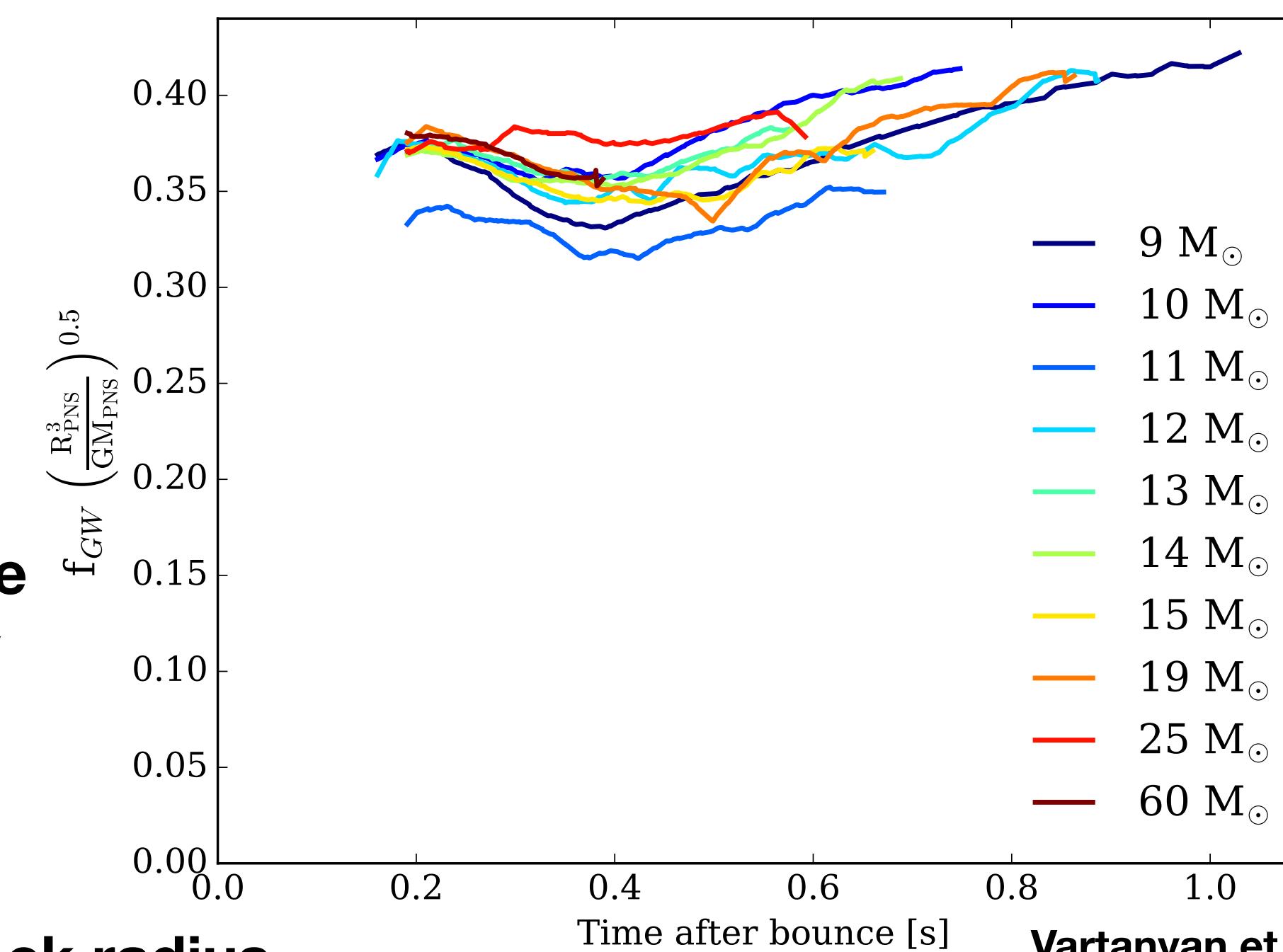


**2) Fundamental Mode
probes core density**

**GW & Luminosity probe accretion rate;
Luminosity evolution also correlates with shock radius**

1) Gravitational Waves

PNS Radius



Vartanyan et al. 2019b