Gravitational Waves From Core Collapse Supernovae

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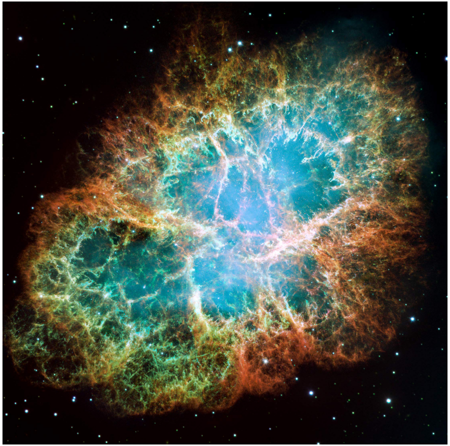
Core collapse

- Massive stars
- Shell burning
- Iron core collapse
- Repulsive nucleon interactions
- Core bounce

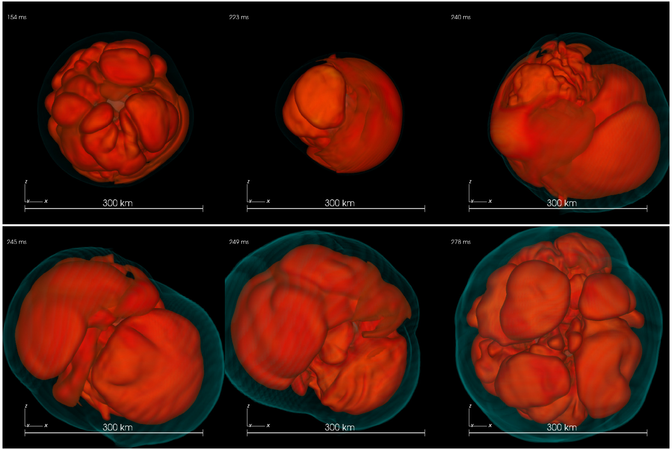
Image Credit: NASA, ESA, J. Hester



Post bounce

- Stalled accretion shock
  - Hot bubble convection
  - Large scale shock deformation (SASI)
- Shock revival
  - Neutrino heating
  - Supported by SASI activity

Image credit:
F.Hanke et al 2013



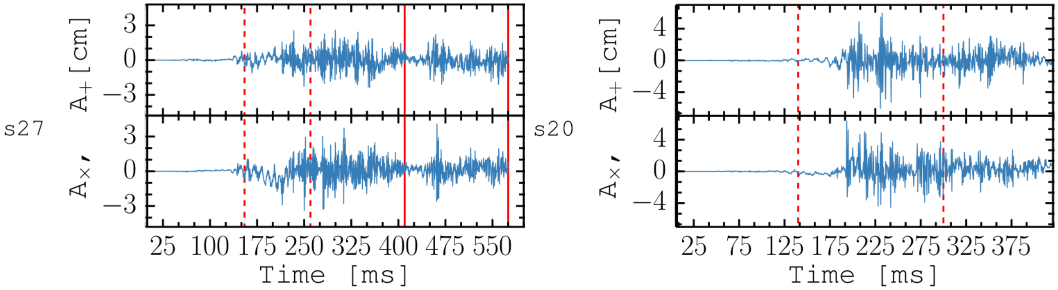
Numerical models

Progenitors:
$11.2 M_\odot$, $20 M_\odot$ and $27 M_\odot$
(Woosley et al 2002 & 2007)

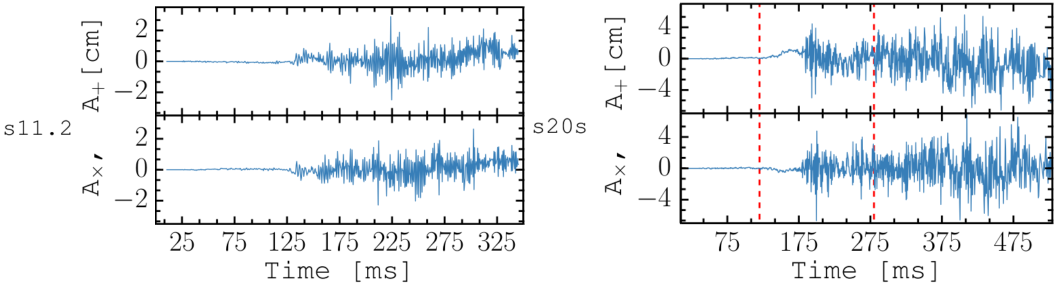
Numerical simulations

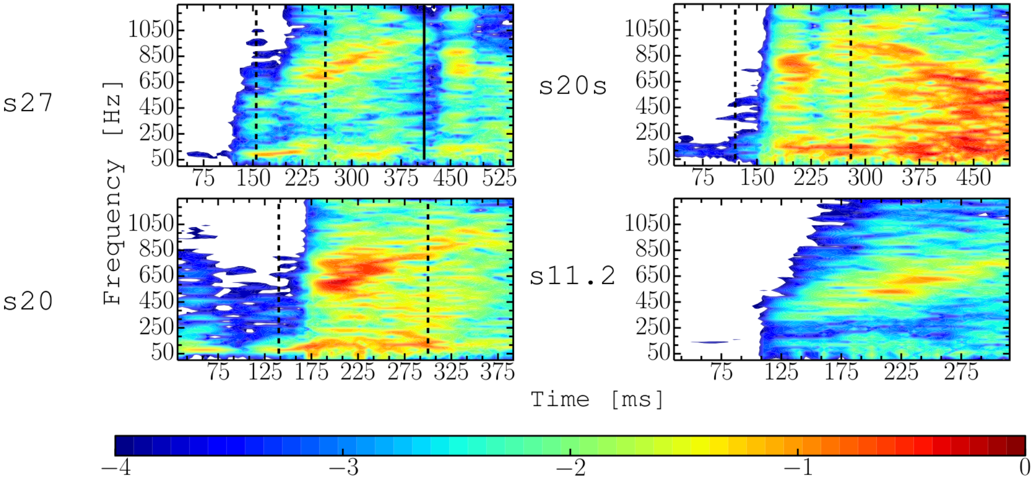
- Three non-exploding models: s11.2, s20, s27 (Hanke et al 2013)
- One successful explosion: s20s (Melson et al 2015)
  - Strange quark contributions to the nucleon spin

Wave forms


s27
A_+ [cm]
$A_\times$
3
0
−3
25 100 175 250 325 400 475 550
Time [ms]
s20
4
0
−4
25 75 125 175 225 275 325 375
Time [ms]

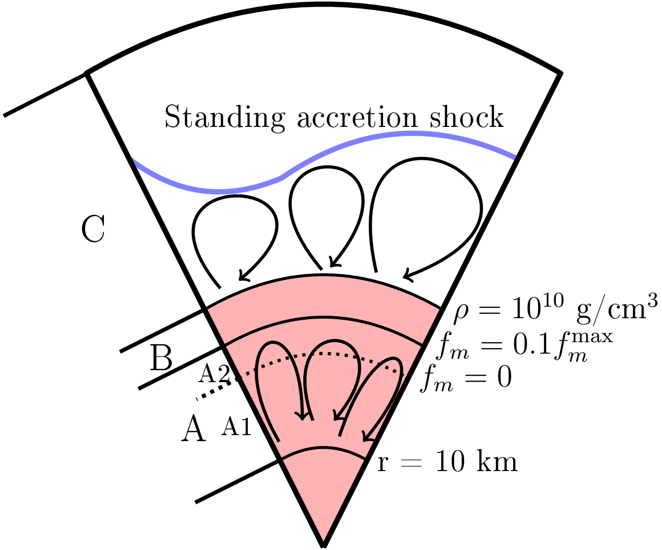
Wave forms




s27
s20s
s20
s11.2
Frequency [Hz]
Time [ms]
1050
850
650
450
250
50
75
150
225
300
375
450
525
125
175
275
325
−4
−3
−2
−1
0

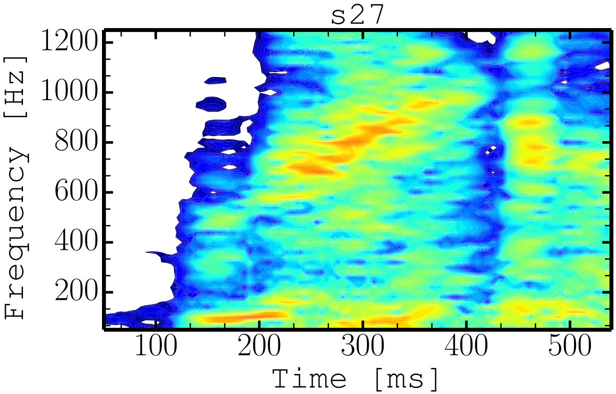
Signal origin

- SASI
- PNS accretion
- PNS convection



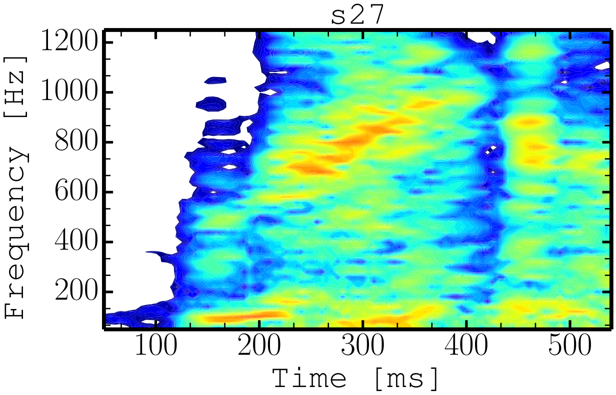
Low frequency signal

- Large scale shock deformation (SASI)
  - Only seen in models with strong SASI activity
  - Frequency overlap with the SASI
- Asymmetric mass distribution in the post-shock volume
- Interaction with the PNS



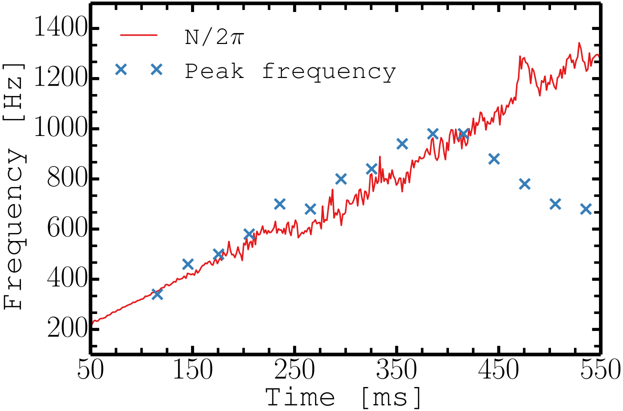
High frequency signal

- Present in all models
- Consistent with the theoretical frequency of buoyancy driven effects



High frequency signal

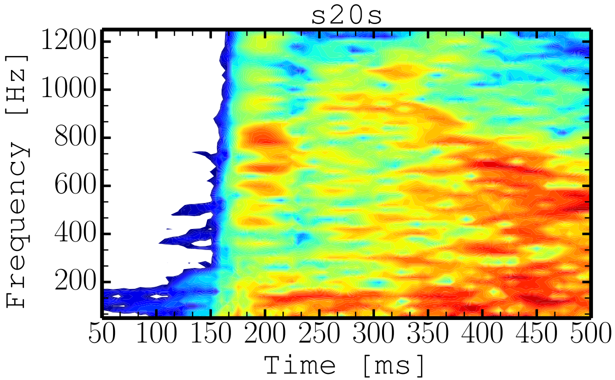
- Present in all models
- Consistent with the theoretical frequency of buoyancy driven effects
- Convection inside the proto-neutron star



$$f_N = N/2\pi = \frac{1}{2\pi}\sqrt{\frac{1}{\rho}\frac{\partial\Phi}{\partial r}\left[\frac{1}{c_s^2}\frac{\partial P}{\partial r} - \frac{\partial\rho}{\partial r}\right]}$$

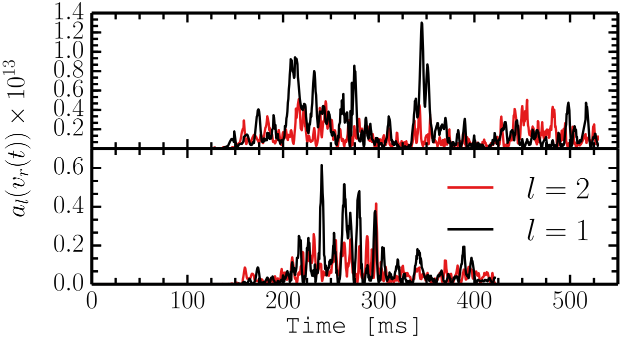
Exploding model

- Similar to non-exploding models before onset of shock expansion
- Increased gravitational wave emission



Exploding model

- Geometry of the convectively unstable region with in the PNS
- Shifts to a $l = 2$ dominated state



$$\sum_{m=-l,l} |a_l^m(t)|^2 \quad (l = 1, 2), \tag{1}$$

$$a_l^m(t_n) = \frac{(-1)^{|m|}}{\sqrt{4\pi(2l+1)}} \int v_r(\theta, \phi, t) Y_l^m \mathrm{d}\Omega. \tag{2}$$

Detection prospects

- Optimal orientate detector signal-to-noise ratio
    - Ratio of power in the low and high frequency band
- Advance LIGO (D $\sim$ 1 kpc)
- Einstein Telescope (D $\sim$ 10 kpc)

Conclusions

- Core collapse supernovae are a promising source for gravitational waves and more importantly gravitational waves can provide insight into the collapse scenario
- SASI activity leads to strong emission below 250 Hz
- PNS convection exites high frequency waves
- Good detection possibilities in future detectors

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