Monopolar gravitational wave signal from the collapse of a stellar core to a neutron star

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Tensor-scalar theories are physically well-motivated alternatives theories of gravity (string theory, higher order Lagrangian)

weak equivalence principle + “graceful exit” from inflation

spin-2 field $g_{\mu\nu}$ and one (or more) spin-0 $\varphi$,

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu} + 2\partial_\mu \varphi \partial_\nu \varphi - g_{\mu\nu} g^{\rho\sigma} \partial_\rho \varphi \partial_\sigma \varphi$$

+ “wave” equation : $\Box_g \varphi = -4\pi G \alpha(\varphi) T$

in our model $\alpha(\varphi) = \alpha_0 + \beta_0 (\varphi - \varphi_0)$
Model

Spherical symmetry and Radial Gauge Polar Slicing

Collapse of a degenerate stellar core in which the degenerate electrons can no longer support gravity

Simplified model: perfect fluid and \( p = (\gamma - 1)\rho \epsilon \) with

\[
\gamma = \gamma_{\text{min}} + S(\log(\rho) - \log(\rho_{\text{bounce}}))
\]
Gravitational Radiation

$\Box(\varphi - \varphi_0) = 0$, so $h_s(t) \simeq \frac{2}{d} (R(\varphi(R) - \varphi_0))$

$\alpha_0 = -0.01, \beta_0 = -4,$

$\rho_{\text{bounce}} = 1.5 \rho_{\text{nuc}}, S = 1$

$\rho_{\text{bounce}} = 15 \rho_{\text{nuc}}, S = 5$

$M_g = 1.2M_\odot, N_{\text{min}} = 0.7,$

$E_{\text{rad}} = 2.3 \times 10^{-3}$ FOE

$M_g = 1.1M_\odot, N_{\text{min}} = 0.4,$

$E_{\text{rad}} = 5.8 \times 10^{-2}$ FOE
Combined code

High Resolution Shock Capturing schemes $\rightarrow$ Hydrodynamics

$+$

Spectral Methods $\rightarrow$ smooth fields (only scalar field)

$\Rightarrow$ 2 numerical grids:

Spectral $\rightarrow$ HRSC one: summation of the truncated series of Chebyshev polynomials

HRSC $\rightarrow$ Spectral one: smooth interpolation (minimizing the second derivative)
● Each part tested separately
● Whole code able to recover:

- GR results with $\varphi = \varphi_0$ and $\alpha(\varphi) \equiv 0$
- “dust collapse” of (Shibata et al 1994) and (Scheel et al 1995) with $p = 0$
- collapse to a black hole of (Novak 1998), starting from a neutron star
oscillations linked with the appearance of
“spontaneous scalarization”

Novak, Phys. Rev. D 58
Conclusions

- Interesting type of code for the future (2D and 3D)
- allowed for simulation of spherical collapse in tensor-scalar gravity, with strong shocks
- Gravitational waves emitted detectable (using constraints from solar-system experiments and binary-pulsar timing) up to 10 kpc
- No detection can give stronger constraints on the theory, if a SN is seen (neutrinos and/or electromagnetic signal) closer than 10 kpc