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 φ,

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

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

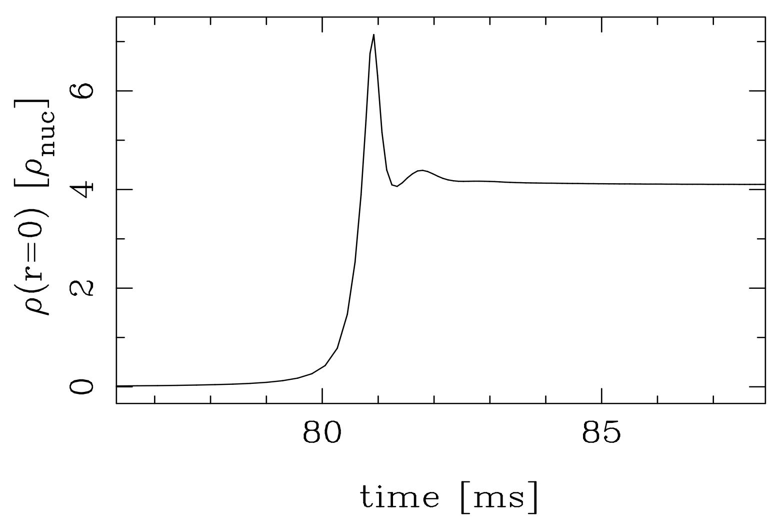
in our model $\alpha(\varphi) = \alpha_0 + \beta_0(\varphi - \varphi_0)$

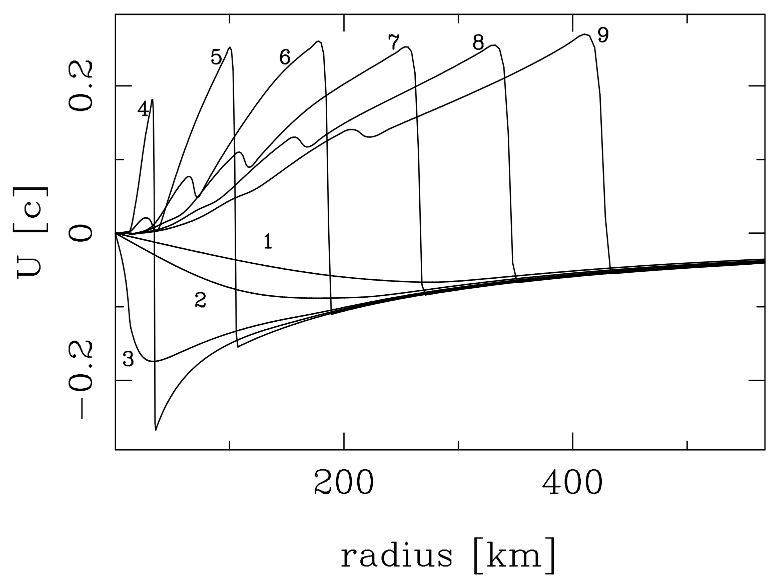
Model

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
$$\gamma = \gamma_{\rm min} + S(\log(\rho) - \log(\rho_{\rm bounce}))$$



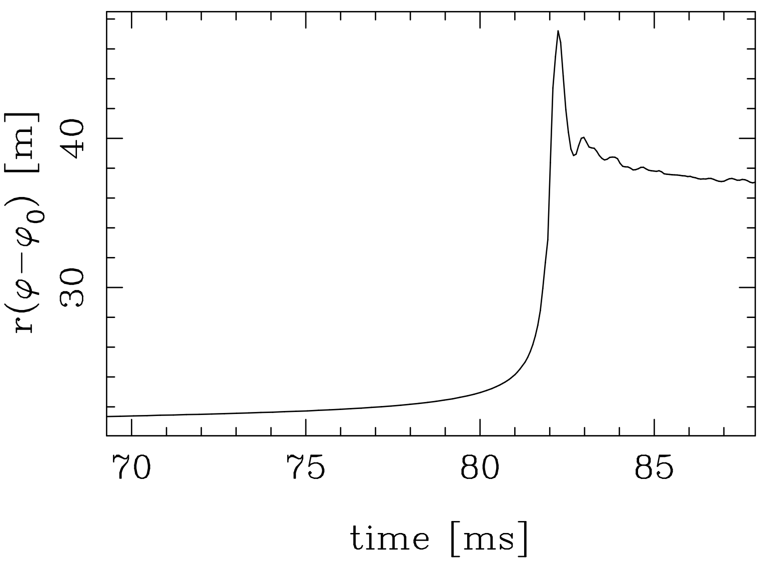


Gravitational Radiation

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

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

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

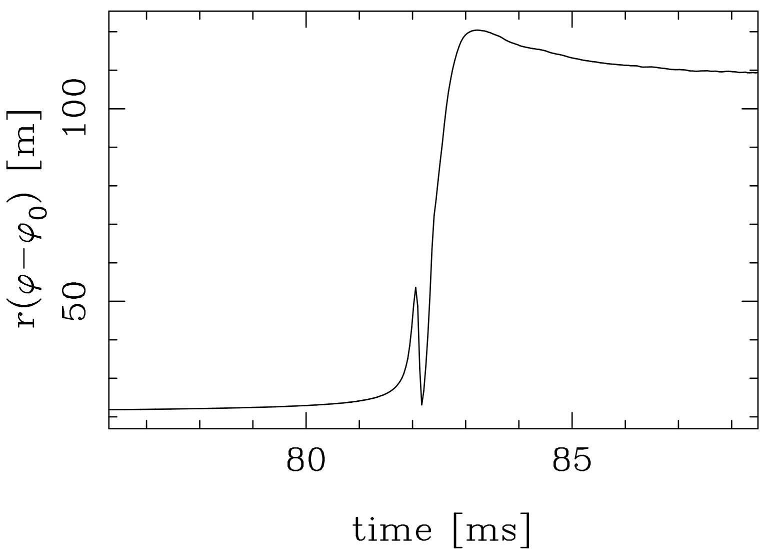


$M_g = 1.2 M_\odot$, $N_{\text{min}} = 0.7$,

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

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

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



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

$E_{rad} = 5.8\ 10^{-2}$ FOE

Combined code

High Resolution Shock Capturing schemes →
Hydrodynamics
+
Spectral Methods → smooth fields (only scalar field)

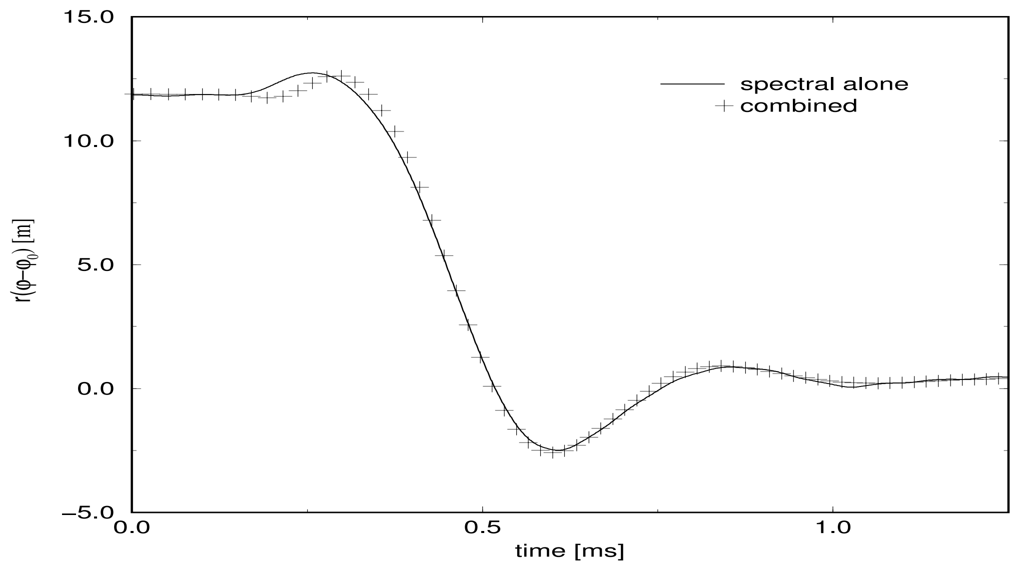
⇒ 2 numerical grids:

Spectral → HRSC one: summation of the truncated series of Chebyshev polynomials

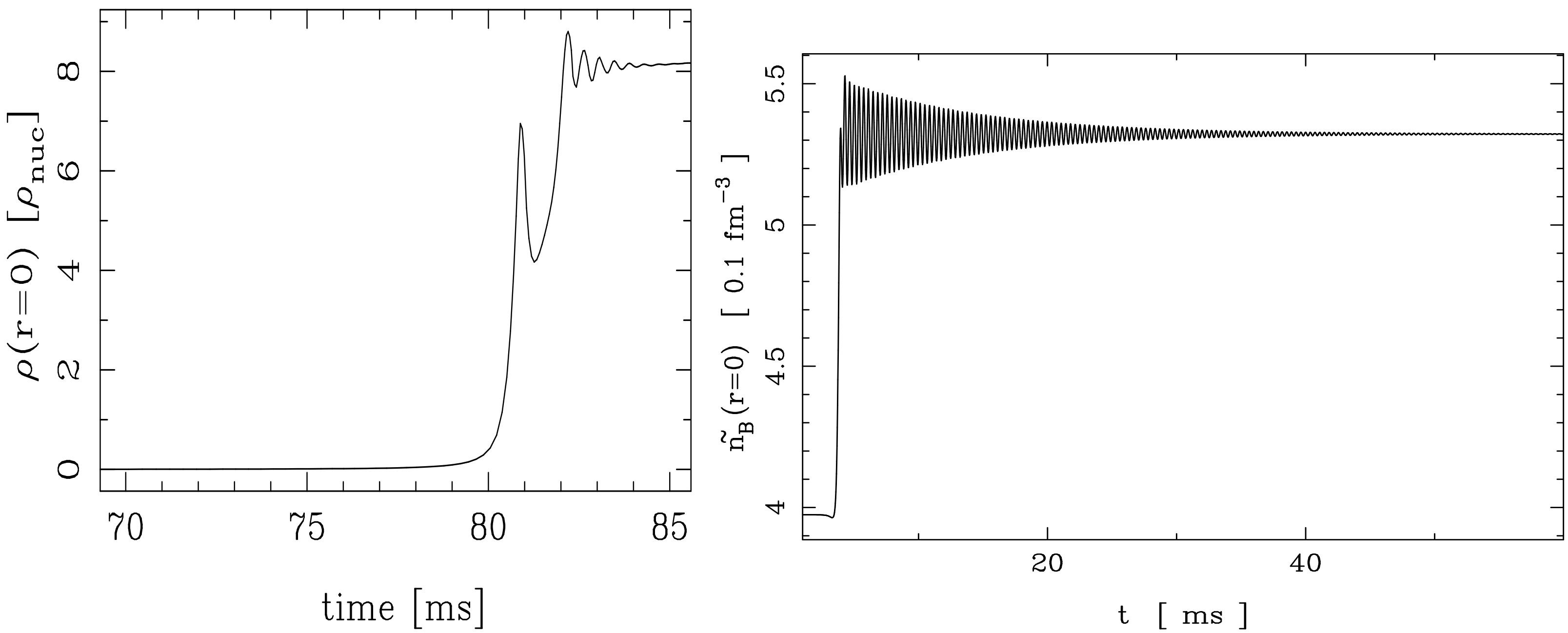
HRSC → Spectral one: smooth interpolation (minimizing the second derivative)

Tests

- 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"



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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