Higher-order gravitational wave emission in core-collapse supernovae

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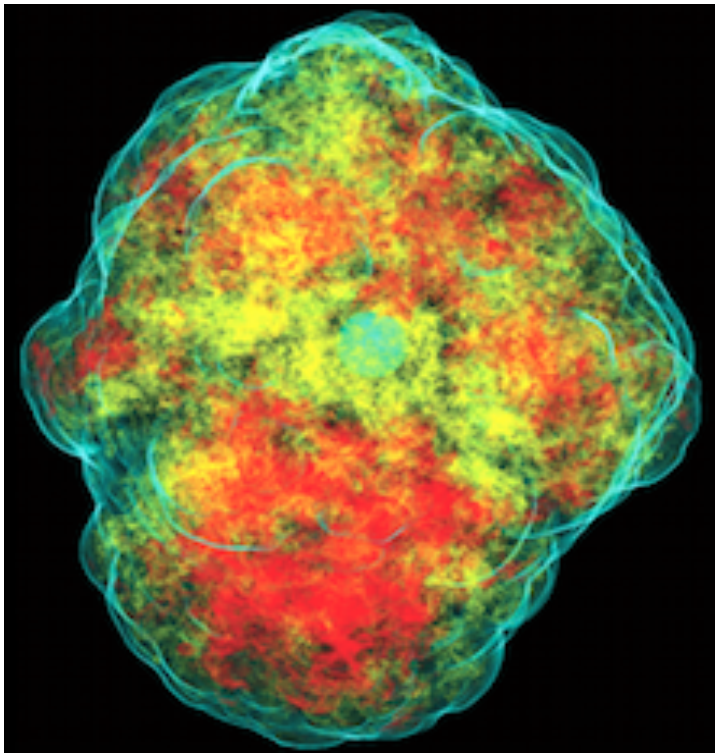
Supernovae

- Star burns fuel. Fuse H into He, He into Li... up until Fe. Fe most stable element. Fusion stops.
- Radiation pressure turns off. Star starts collapsing under gravity.
- Supernova: Star explodes, very bright. Either get black hole or neutron star.



Movie

C. Ott group simulation, visualization S. Drasco
Entropy slice (whiter colors = higher entropy)
h plus in orange, h cross in white

Why we care

- Tells us about how stars work
- All forces at play in extreme limits
  - E&M: matter becomes charged during explosion
  - Nuclear: neutron star, equation of state
  - Gravitational: massive moving object
- A lot of physics deep inside explosion, cannot probe with light
- Use neutrinos and gravitational waves instead

Calculating gravitational waves

- Computer simulation of supernova
- Calculate gravitational waves via series method:

$$f(x+\varepsilon) = f(x) + \varepsilon f'(x) + \mathcal{O}(\varepsilon^2)$$

- First order term is quadrupole moment, second order term is combined mass octupole and current quadrupole (octupole order moment).

Quadrupole order moment

- First term in series

$$h^{ij}_{Quad} = 2\frac{G}{c^4}\frac{1}{x}\partial_t \int d^3x' \ \rho v^i x'^j$$

- Good approximation for matter source
- Stable star perturbed with spherical harmonic; similarity between quadrupole moment and curvature extraction

Quadrupole moment 2

Reisswig et al
Phys Rev D 87
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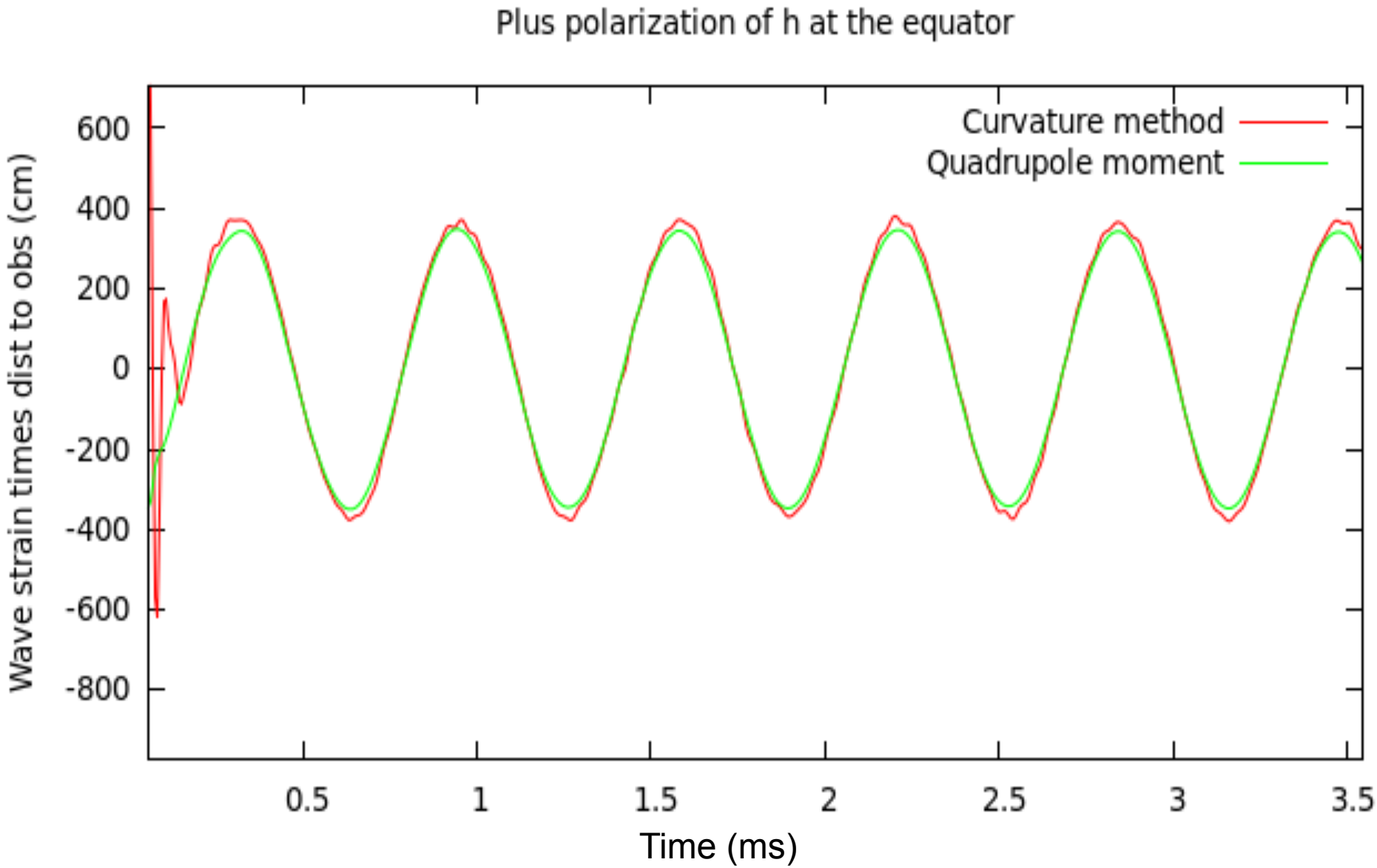

Mass octupole current quadrupole moment

- Second order term

$$h^{ij}_{Oct} = 2\frac{G}{c^5}\frac{1}{x}n_k\partial_t^2\int d^3x' \left[\rho v^i x'^j x'^k + \rho v^j x'^i x'^k - \rho v^k x^i x^j\right]$$

- Quantitative measure of how well quadrupole moment approximates gravitational waves
- Being added to simulation

Summary

- Calculated correction term to quadrupole moment
- Implemented octupole order moment in perturbed star simulation
- Future work: additional simulations with octupole order moment