

The Gravitational Wave and Neutrino Signatures of Stellar Core Collapse

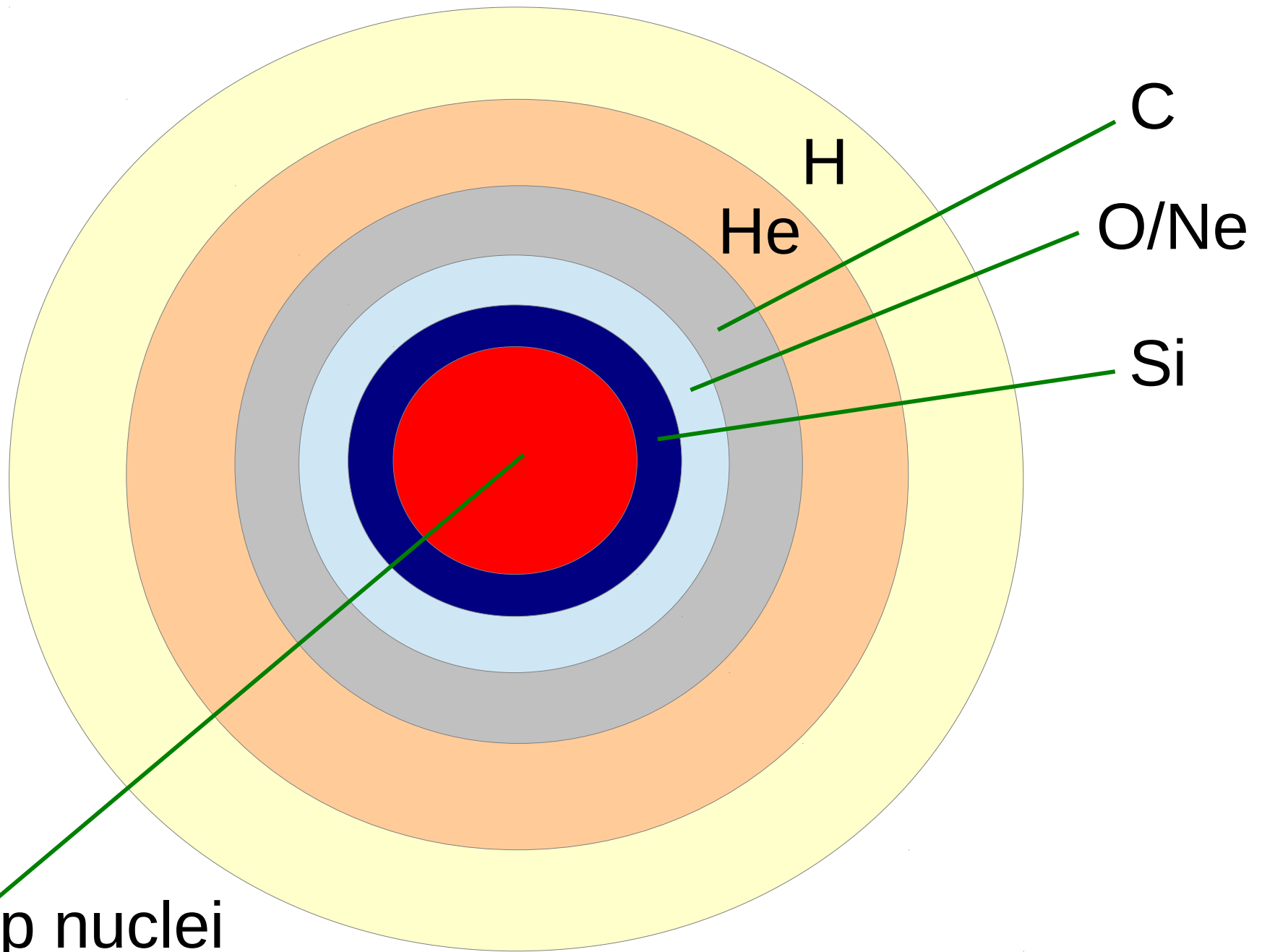
Ernazar Abdikamalov

Caltech

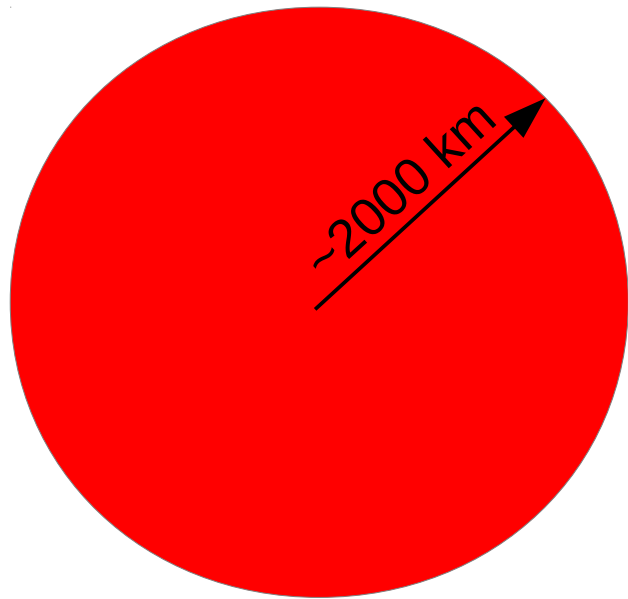
Collaborators:

A. Burrows, P. Diener, R. Haas, P. Kalmus F. Löffler,
E O'Connor, C. D. Ott, C. Reisswig, E. Schnetter, and
O. Korobkin

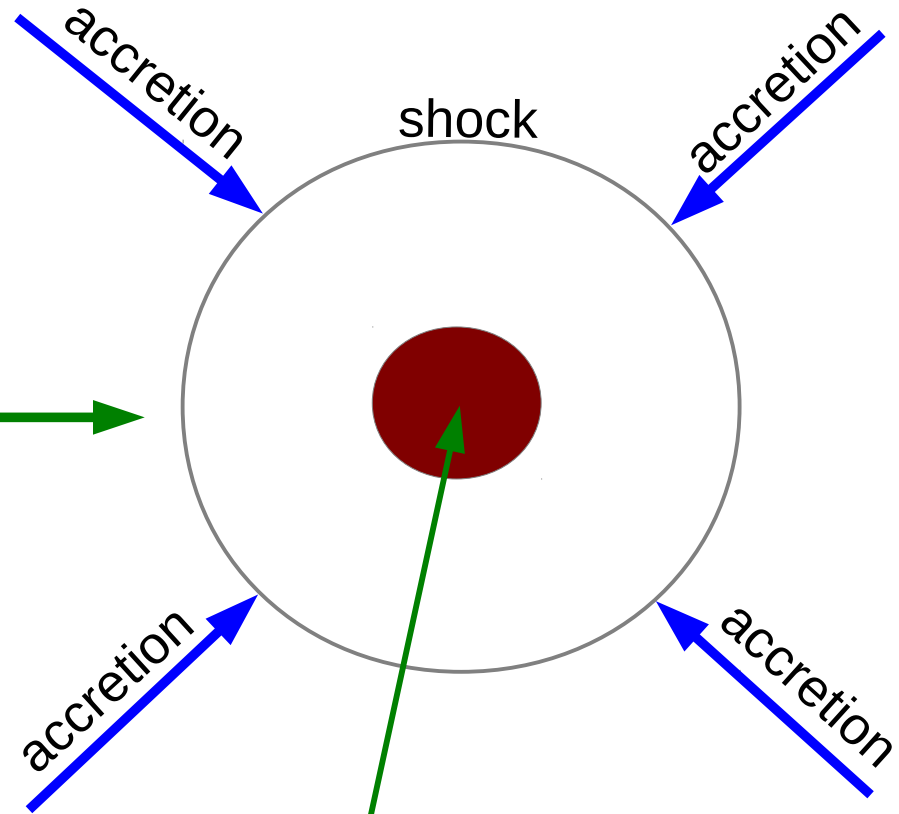
Massive star evolution



Core collapse



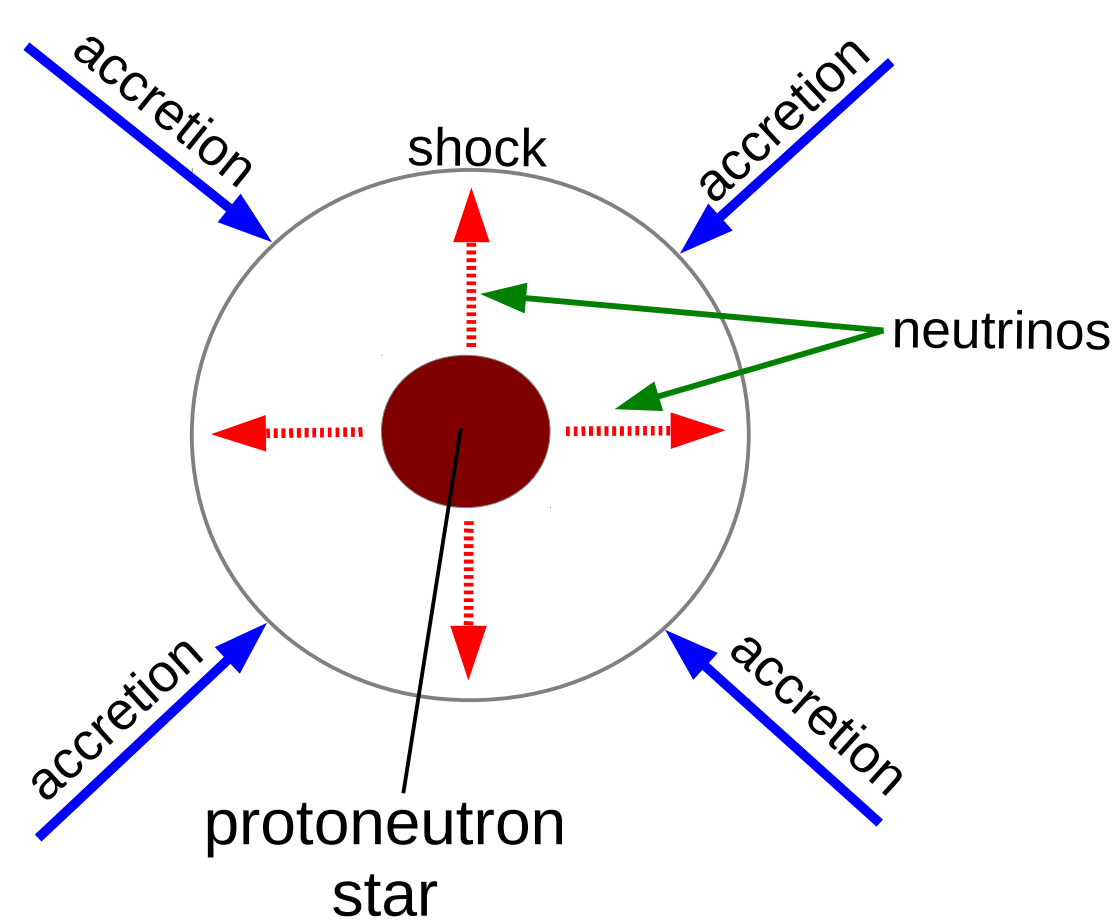
iron core



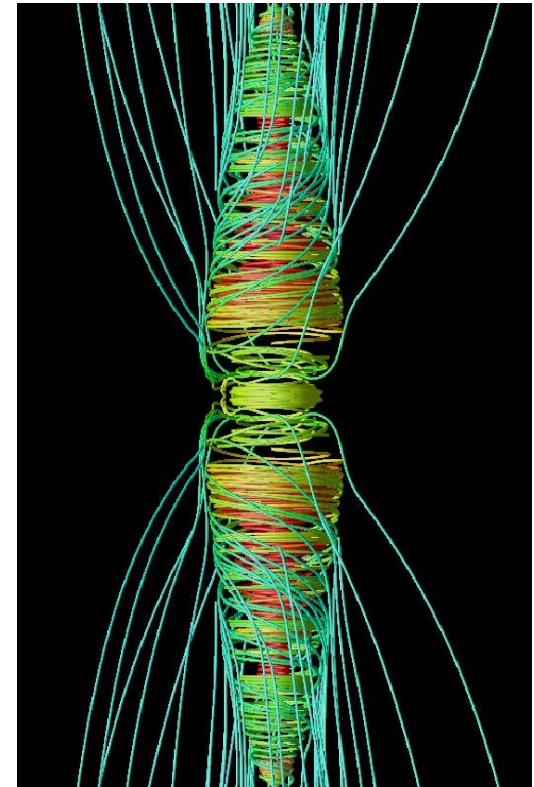
protoneutron star
R~20 km

Shock revival mechanisms

Neutrino mechanism



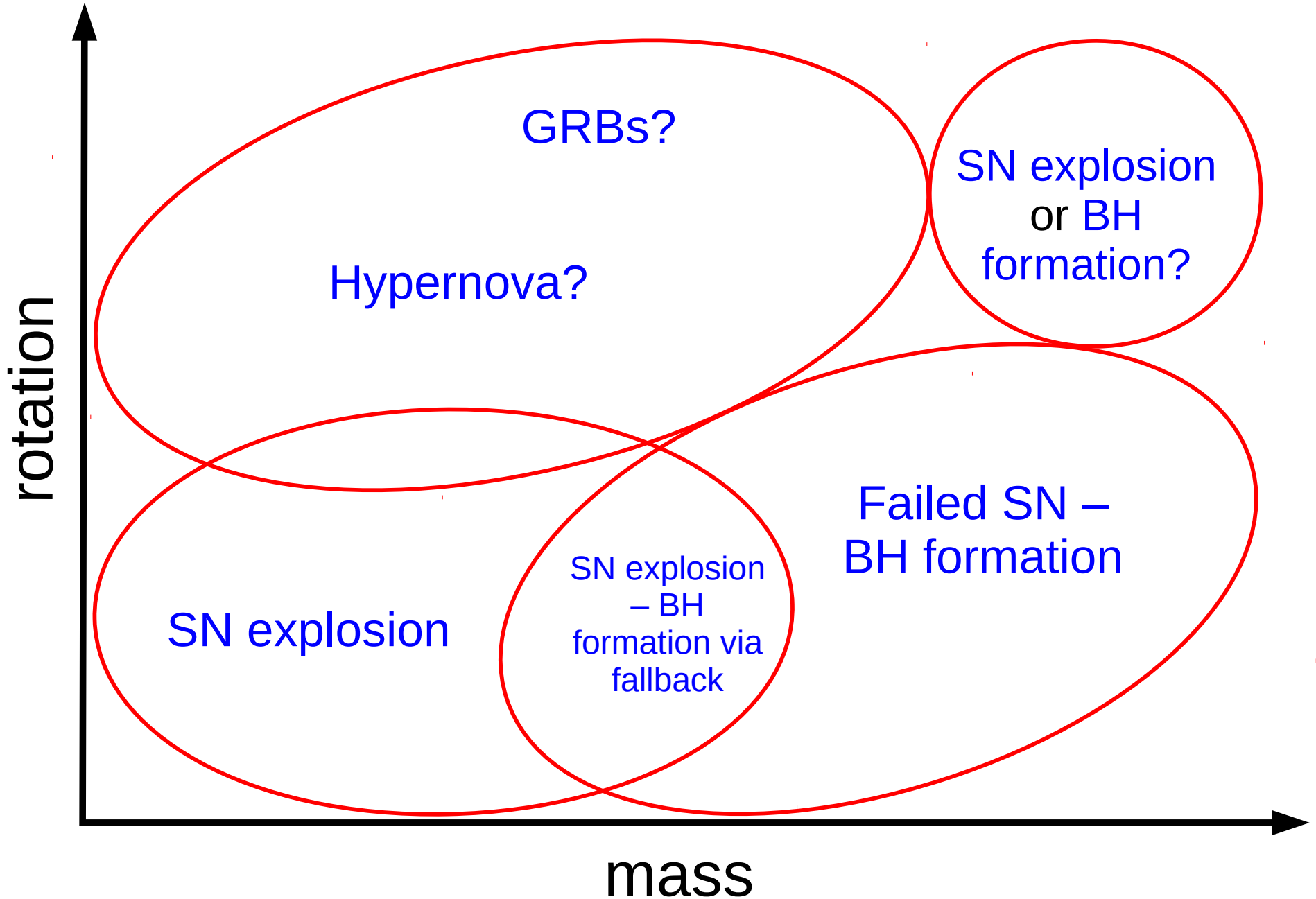
Magnetic mechanism



Burrows et al '07

Other mechanisms: [acoustic mechanism](#) [Burrows et al. '07], [phase-transition](#) [Sagert et al. '09], etc.

Outcome



Observational signatures

- Electromagnetic radiation
- Gravitational Waves
- Neutrino emission

Gravitational Waves

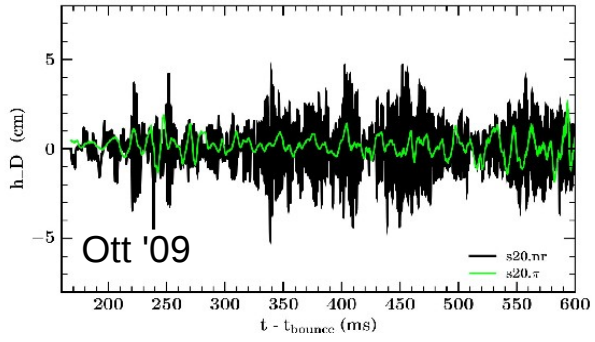
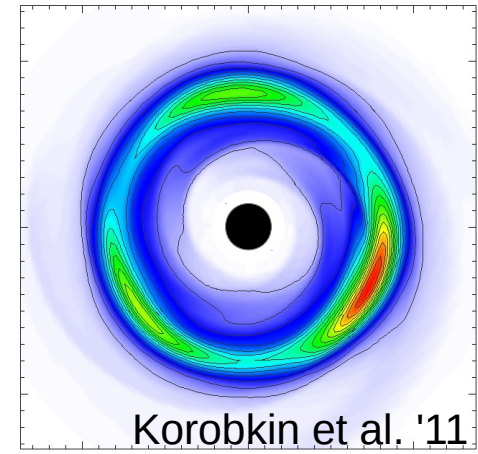
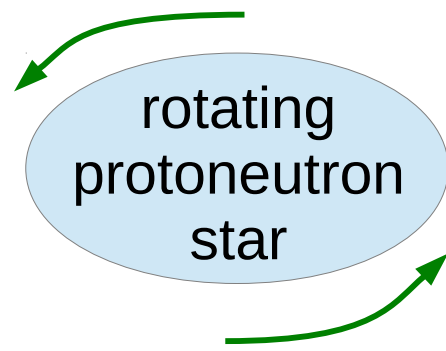
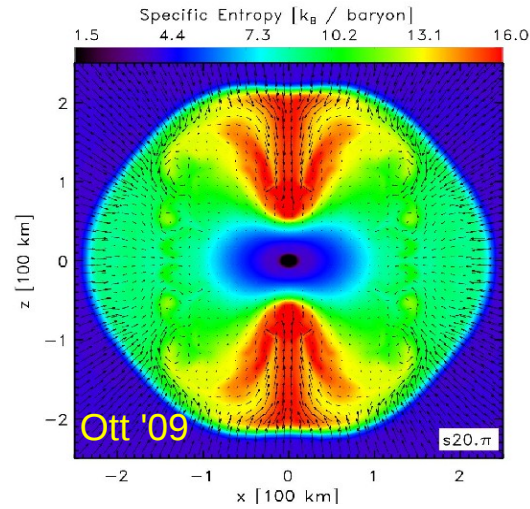
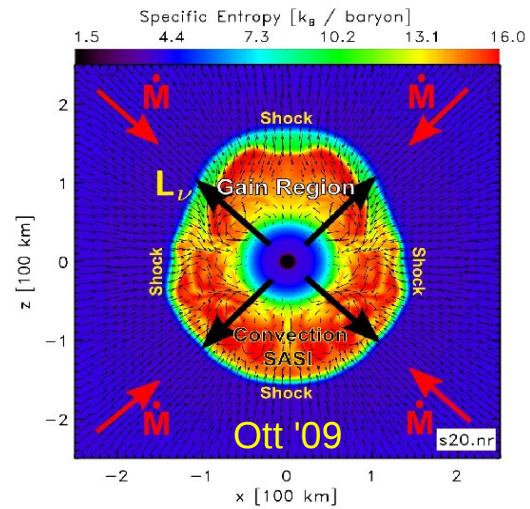
For review: Ott (2009), Kotake et al. (2012)

Convection and SASI

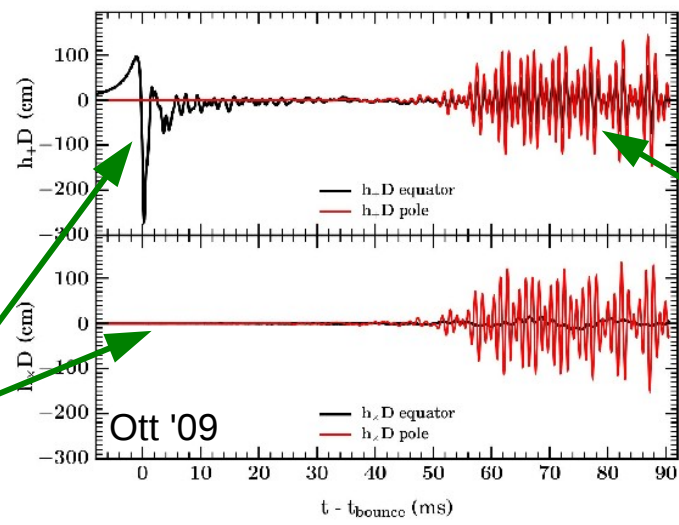
Rotating collapse and bounce

Nonaxisymmetric instabilities

BH formation and accretion disk instabilities



bounce



Nonaxisymmetric instability

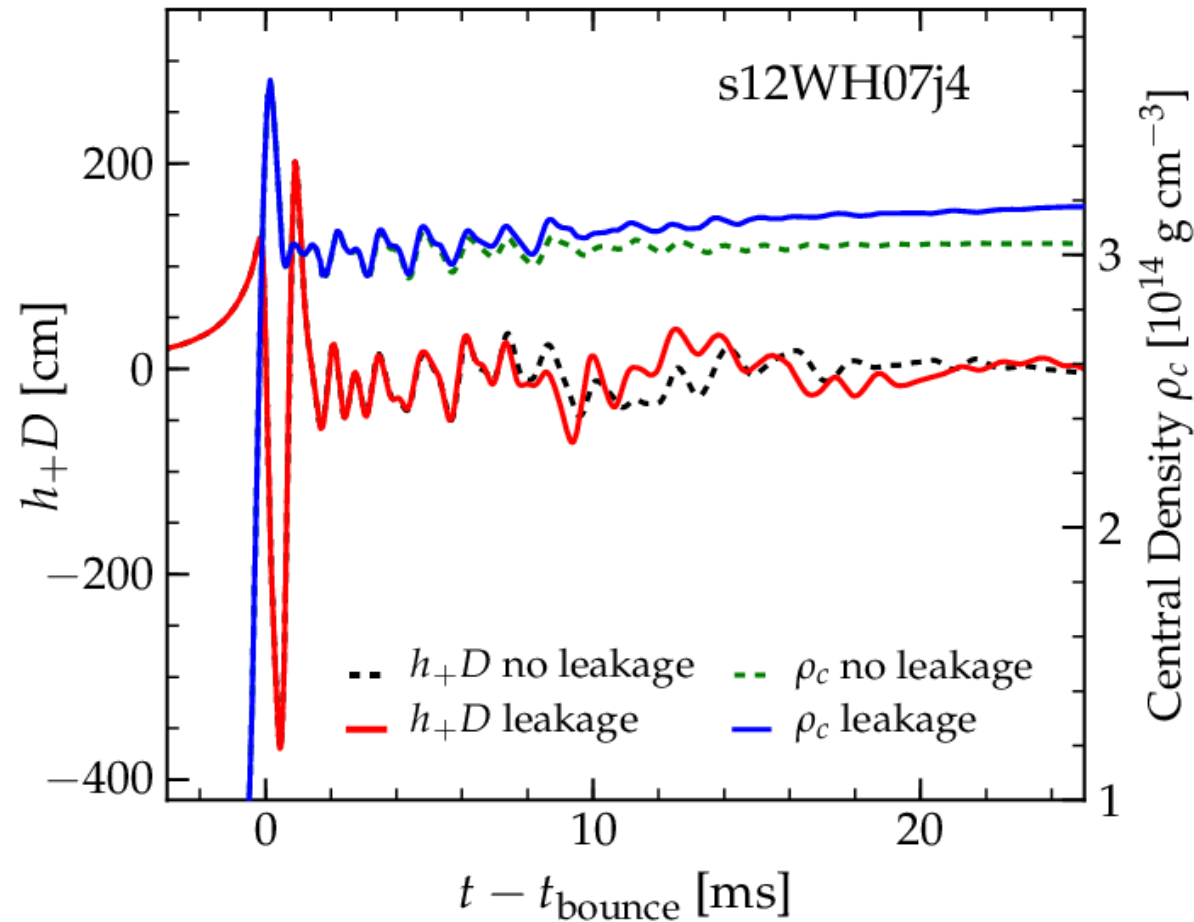
For other alternative scenarios see, e.g., Ott (2009)

Computational modeling

- General relativity
- Hydrodynamics (magnetohydrodynamics)
- Nuclear and neutrino physics
- Three-dimensions
- Neutrino transport

GWs from collapse, bounce, and ring down: leakage vs. non-leakage

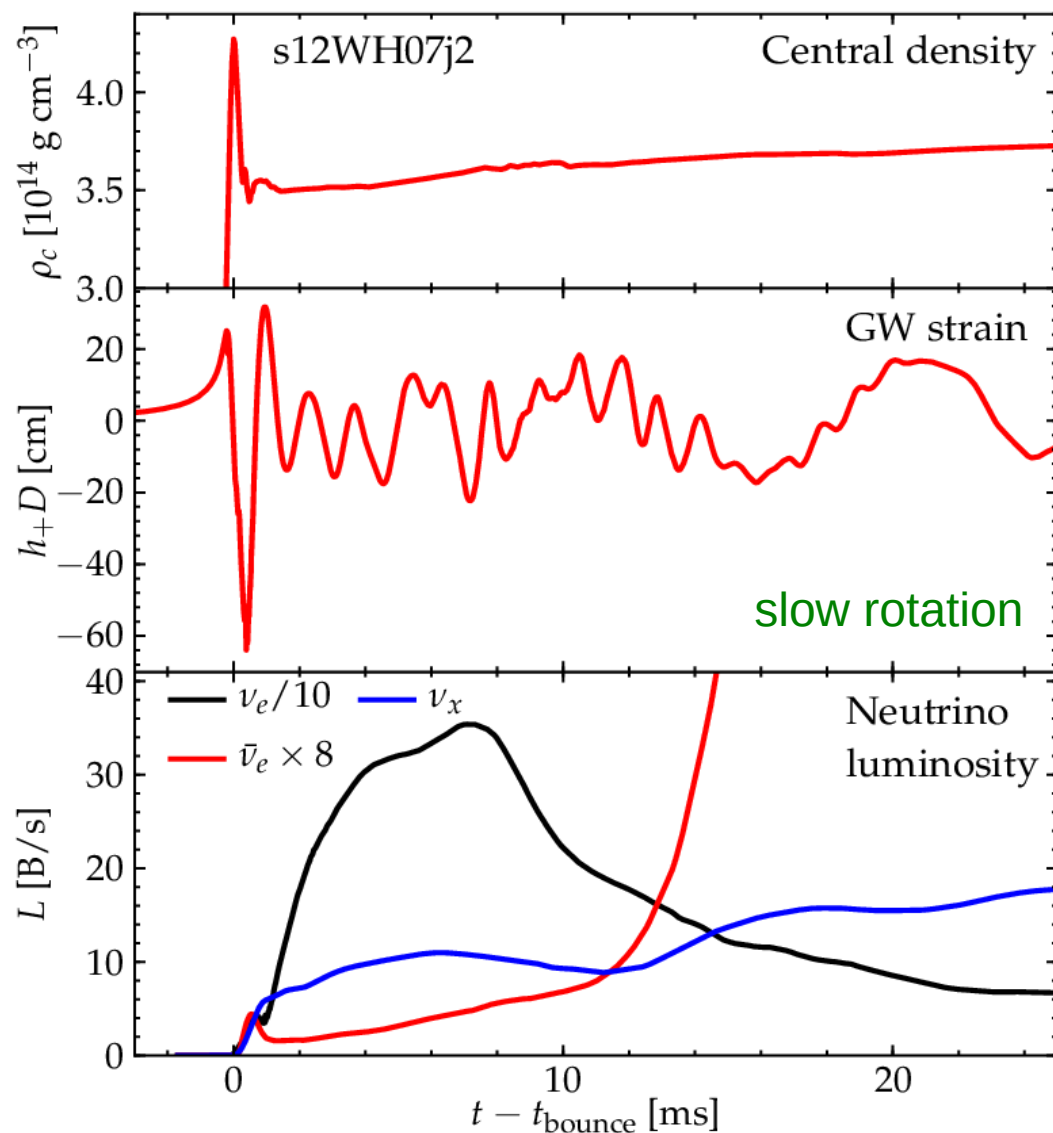
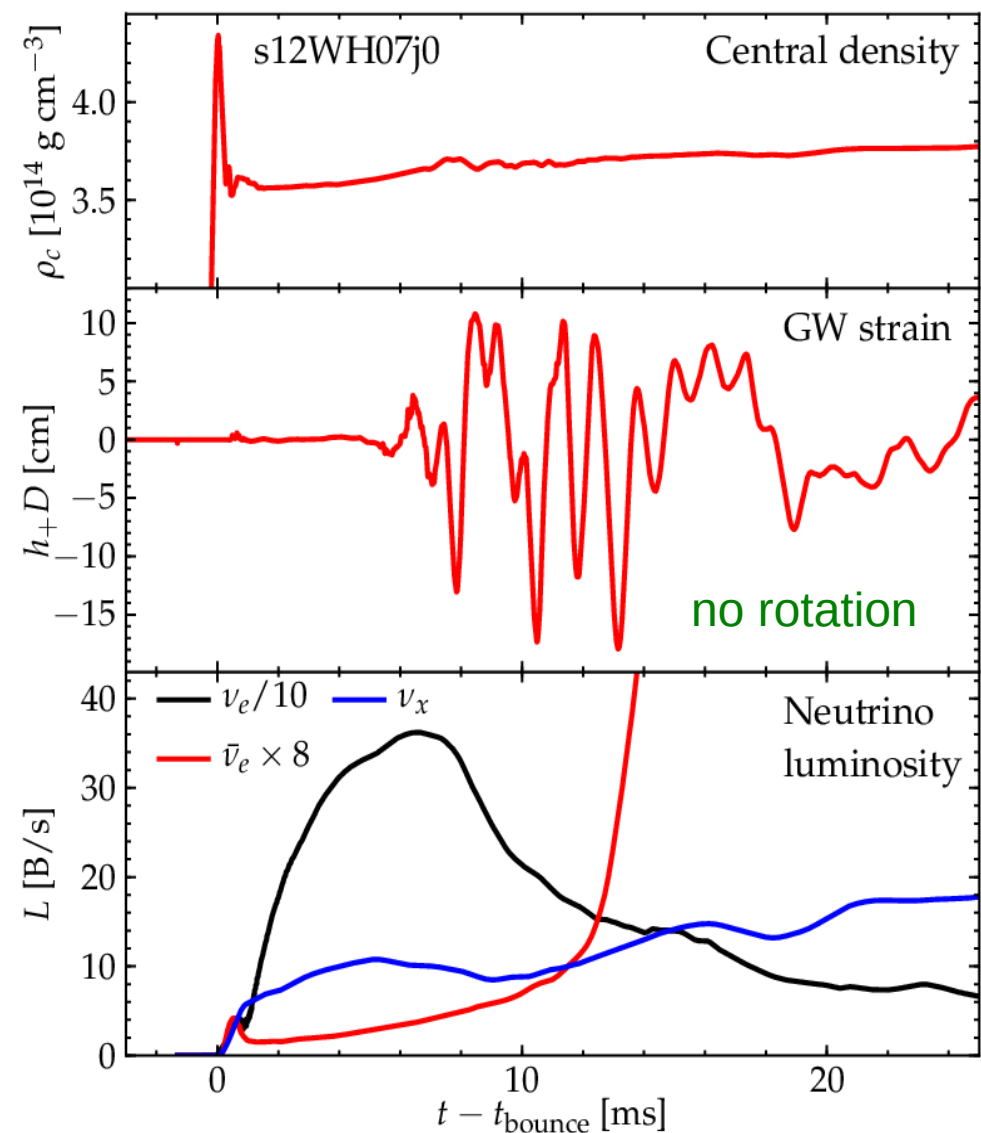
Ott, Abdikamalov et al. '12



Conclusion: postbounce neutrino leakage has little effect on the ring-down oscillations of protoneutron star.

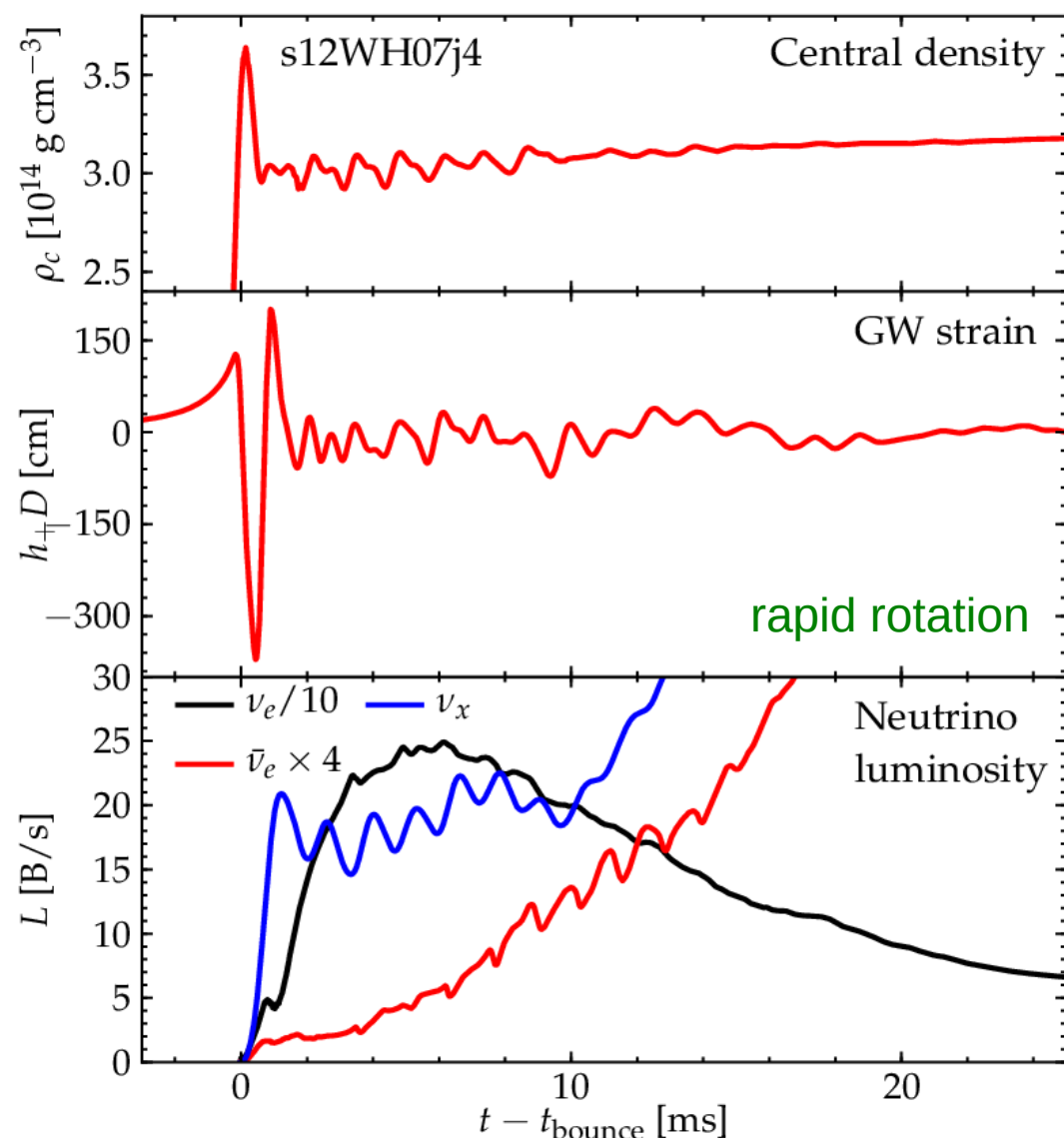
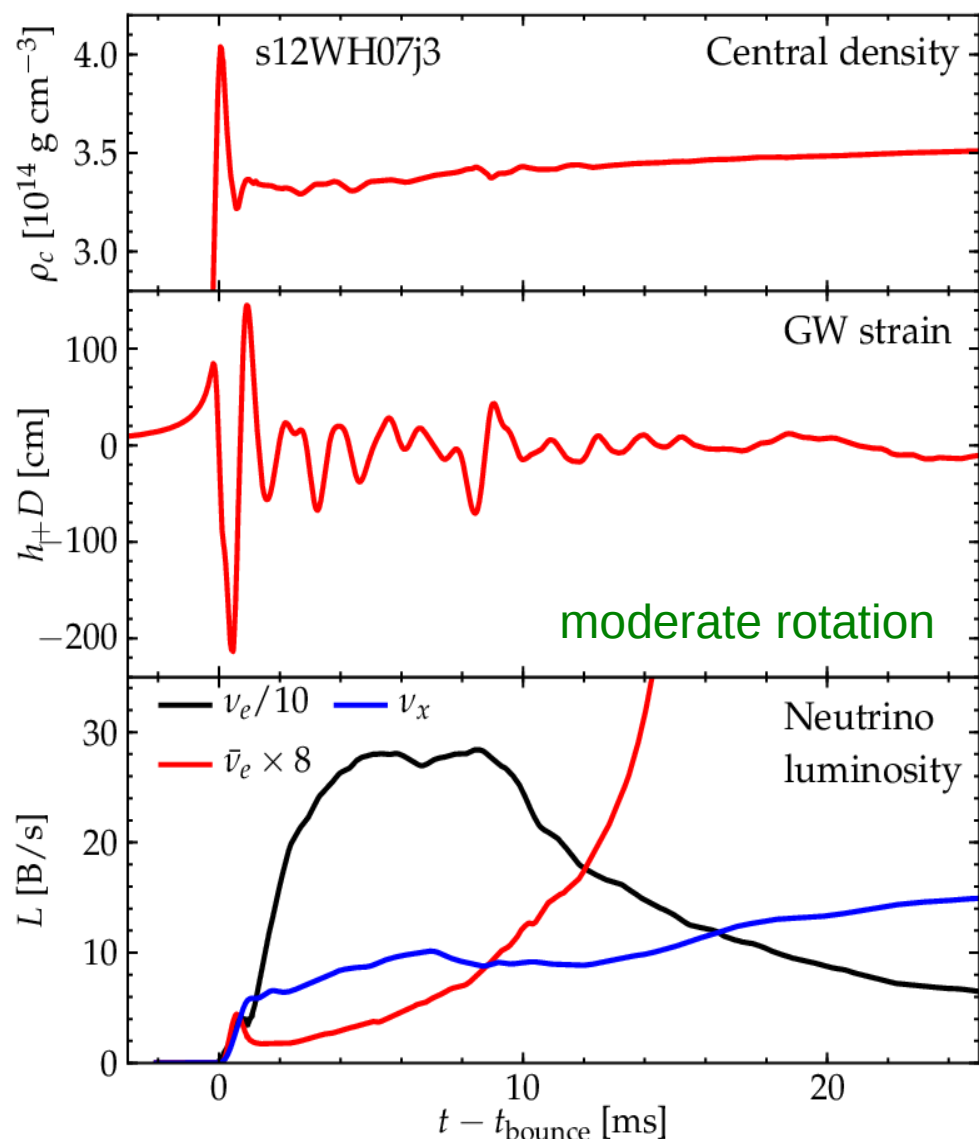
Correlated GW and neutrino signals

Ott, Abdikamalov et al. '12



Correlated GW and neutrino signals

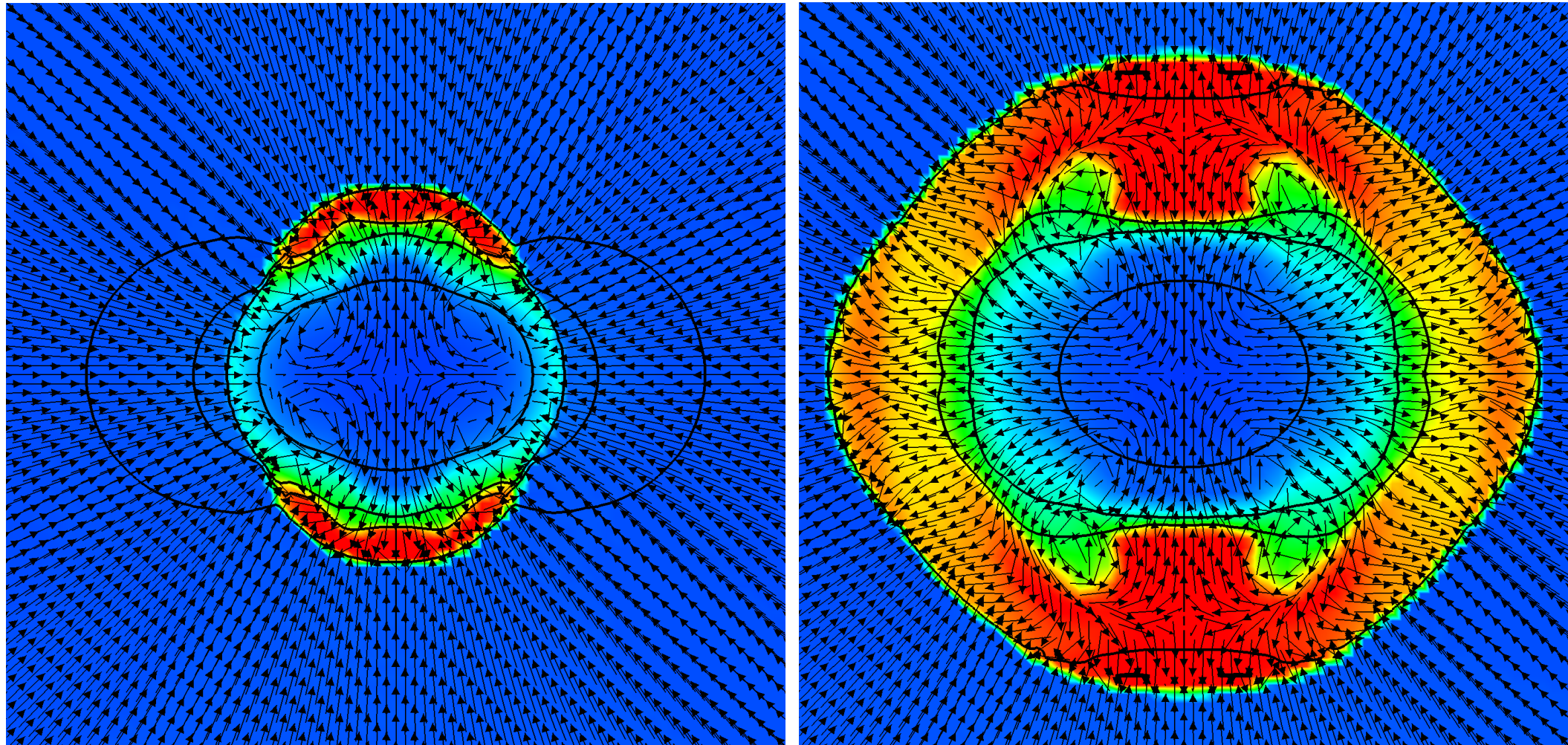
Ott, Abdikamalov et al. '12



GWs and neutrino signal exhibit oscillations in rapidly rotating collapse!

What is producing oscillations?

Ott, Abdikamalov et al. '12

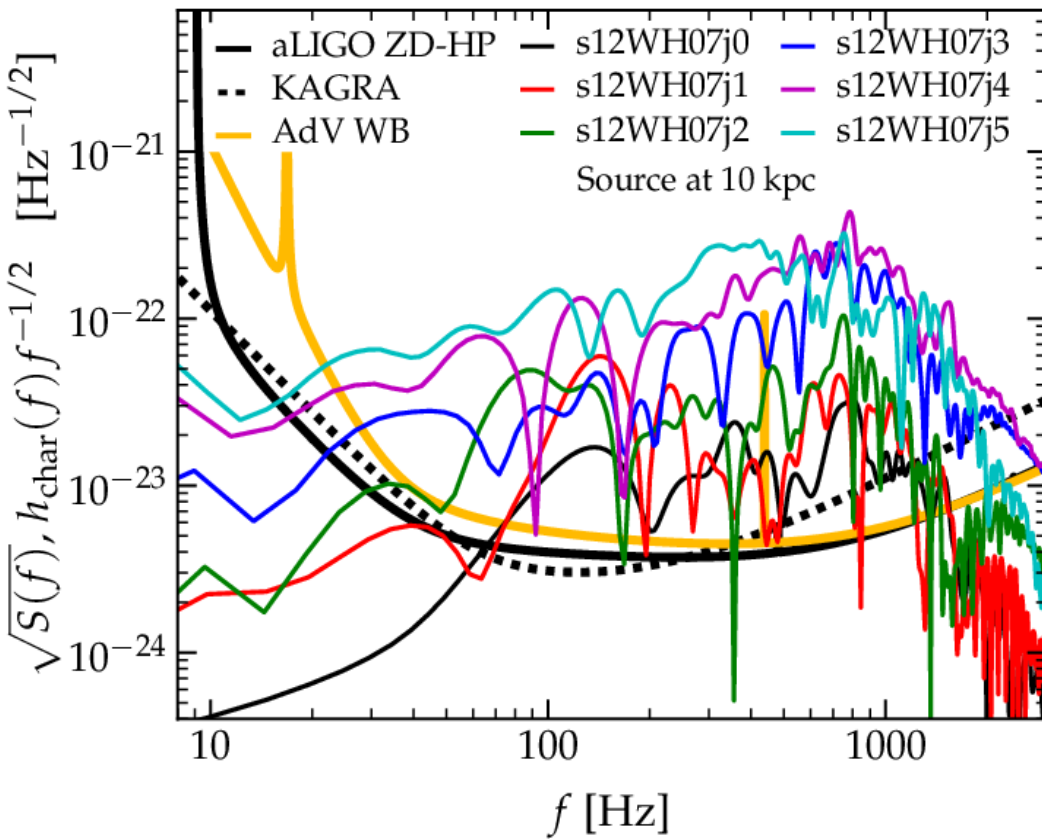


Initial rotationally flattened bounce excites **fundamental quadrupole mode** of the protoneutron star.

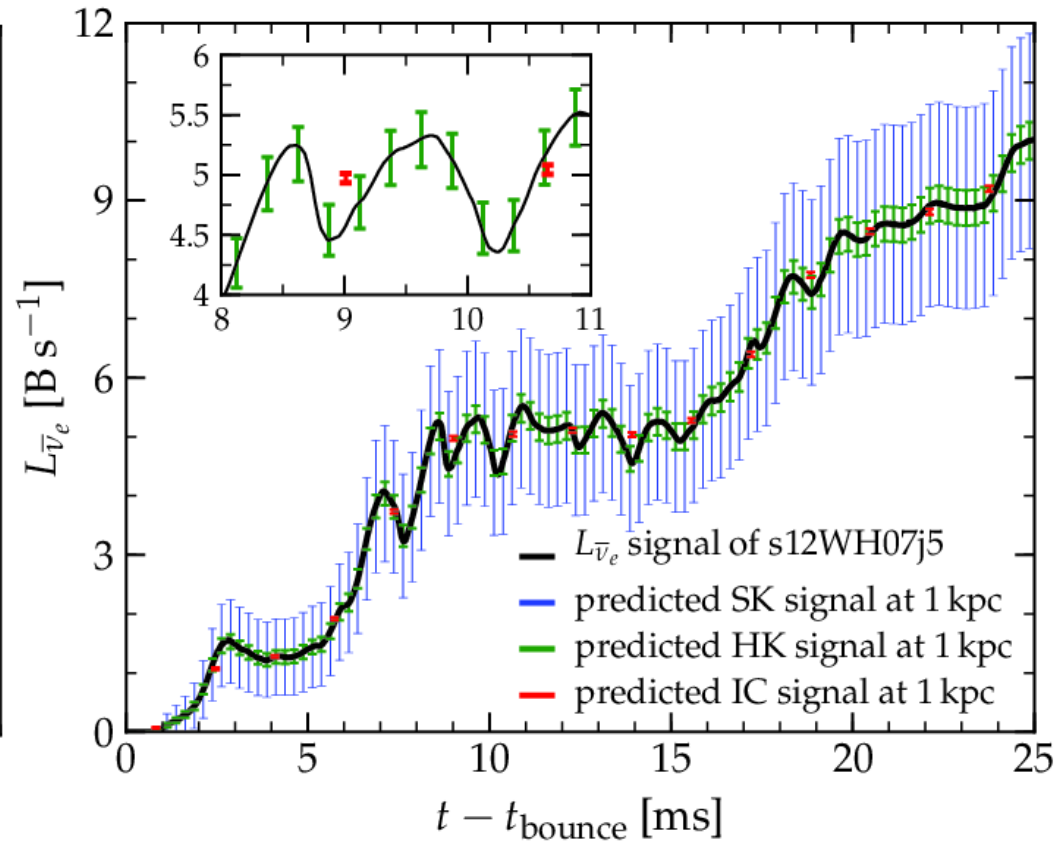
Detectability

Ott, Abdikamalov et al. '12

Gravitational waves

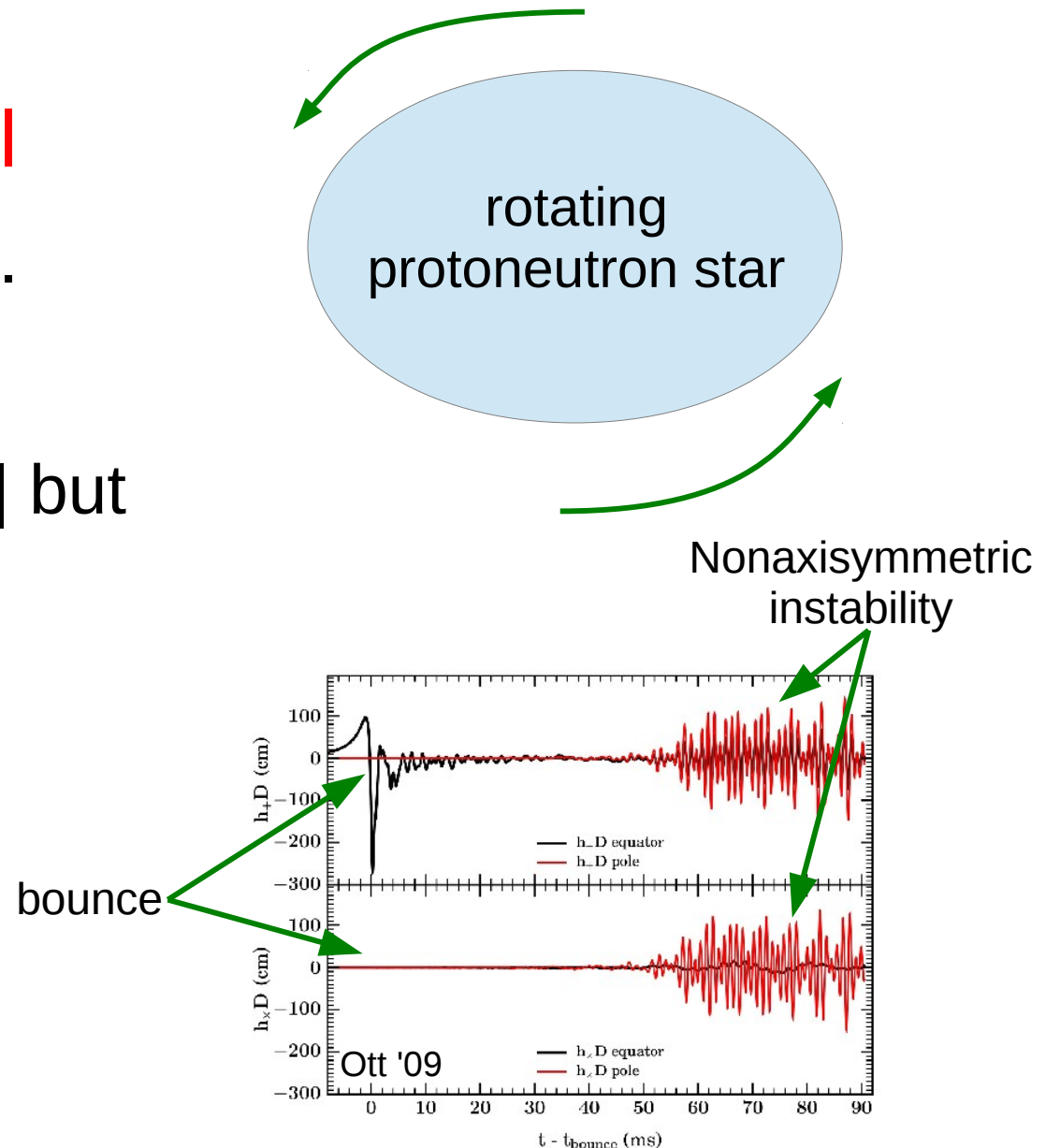


Neutrinos



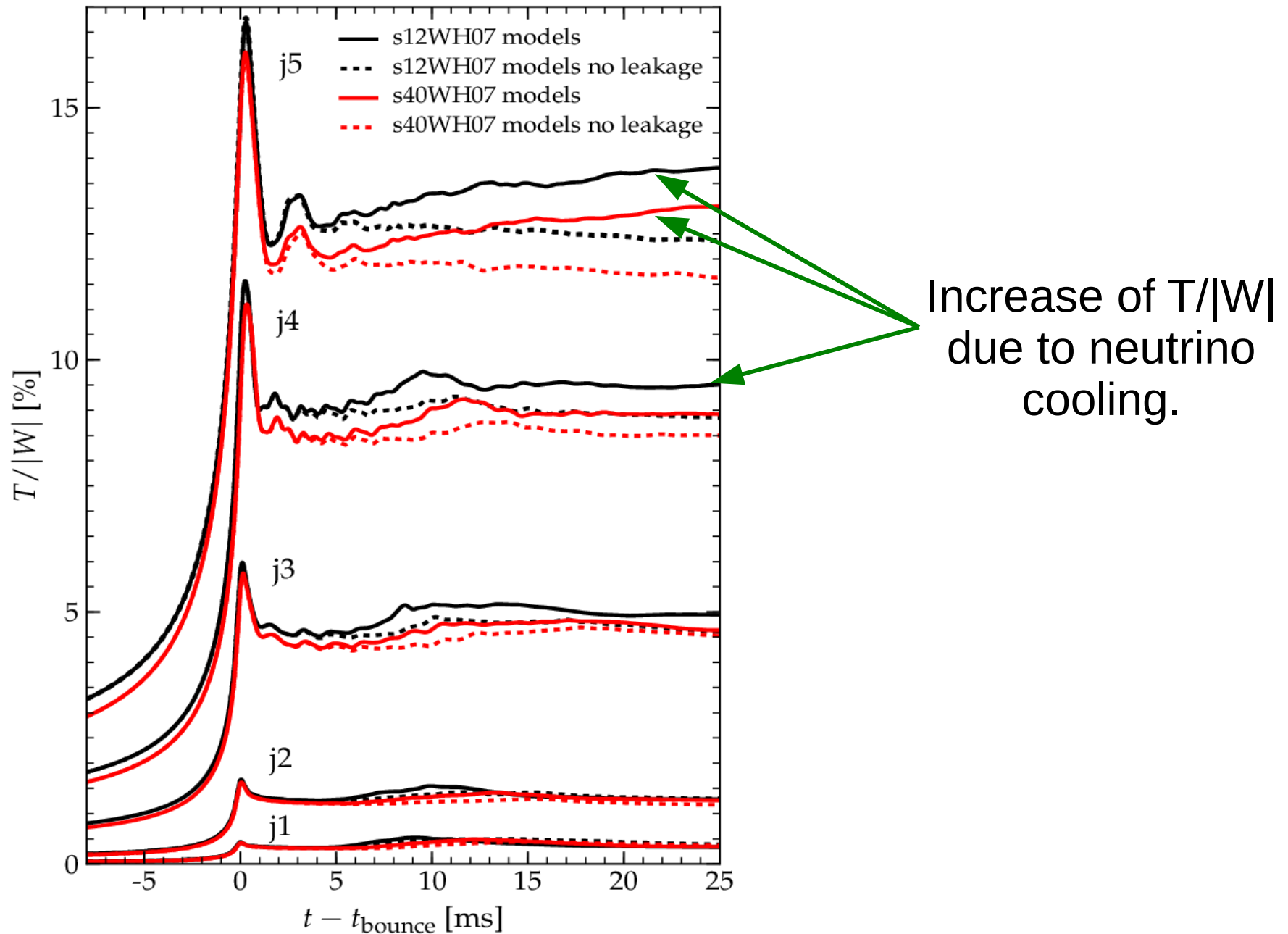
Postbounce rotational instabilities

- **High- $T/|W|$ dynamical**
 - Occurs at $T/|W| \geq 0.26$.
- **Low- $T/|W|$ dynamical**
 - Occurs at lower $T/|W|$ but requires differential rotation.
- **Secular**



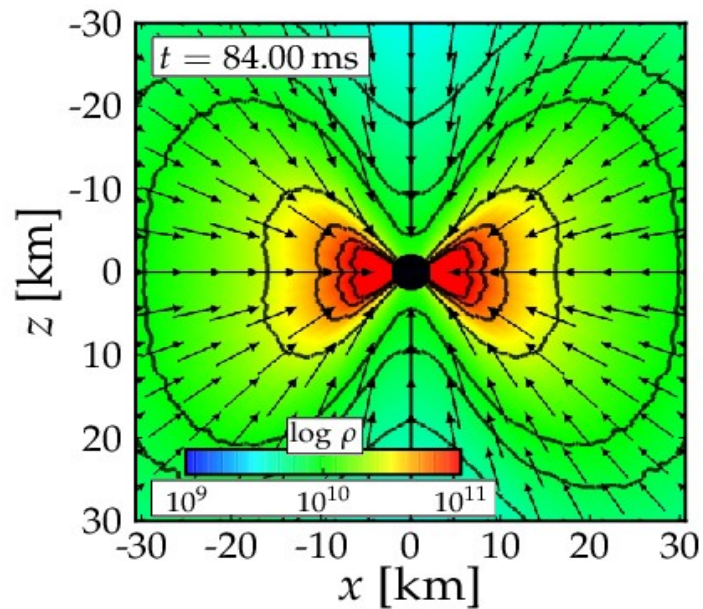
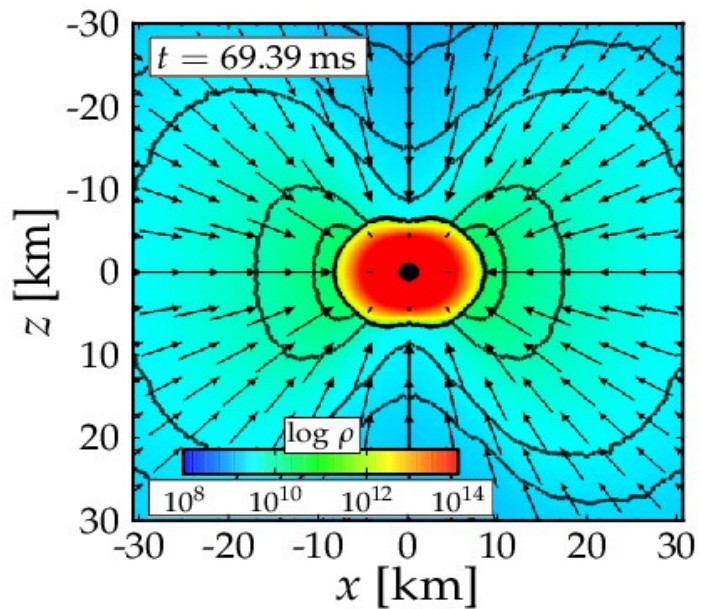
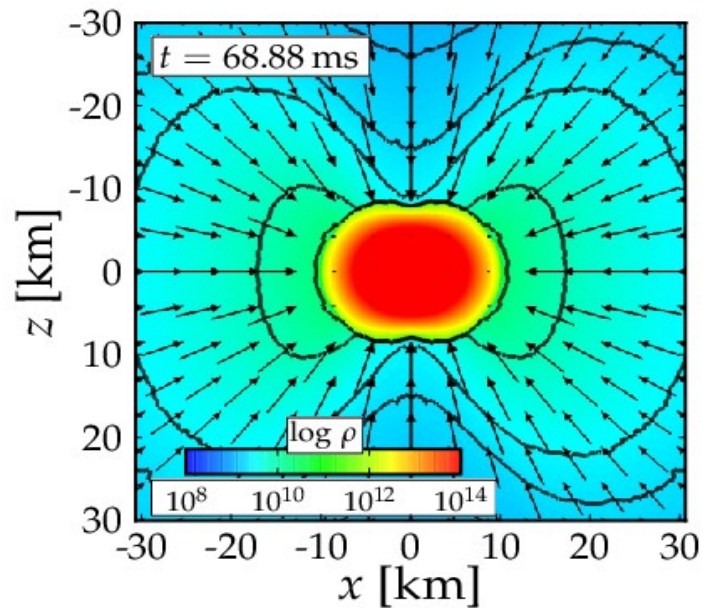
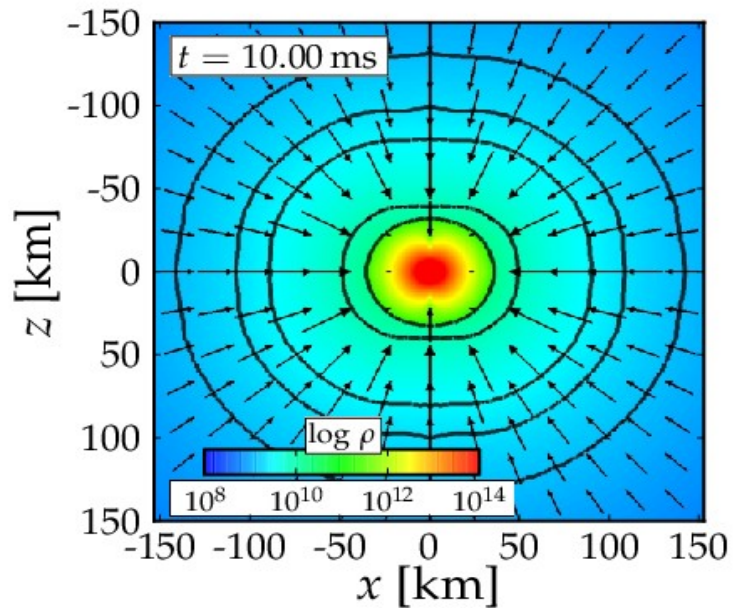
Postbounce rotational instabilities

Ott, Abdikamalov et al. '12



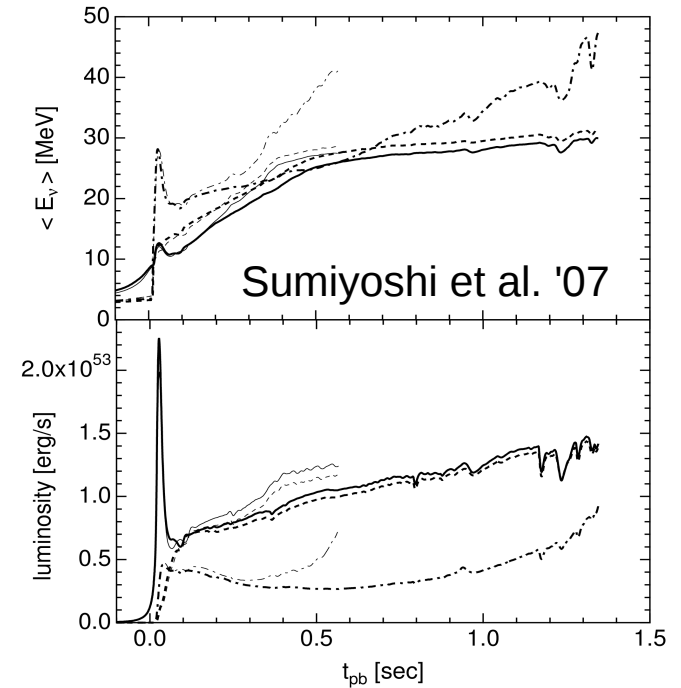
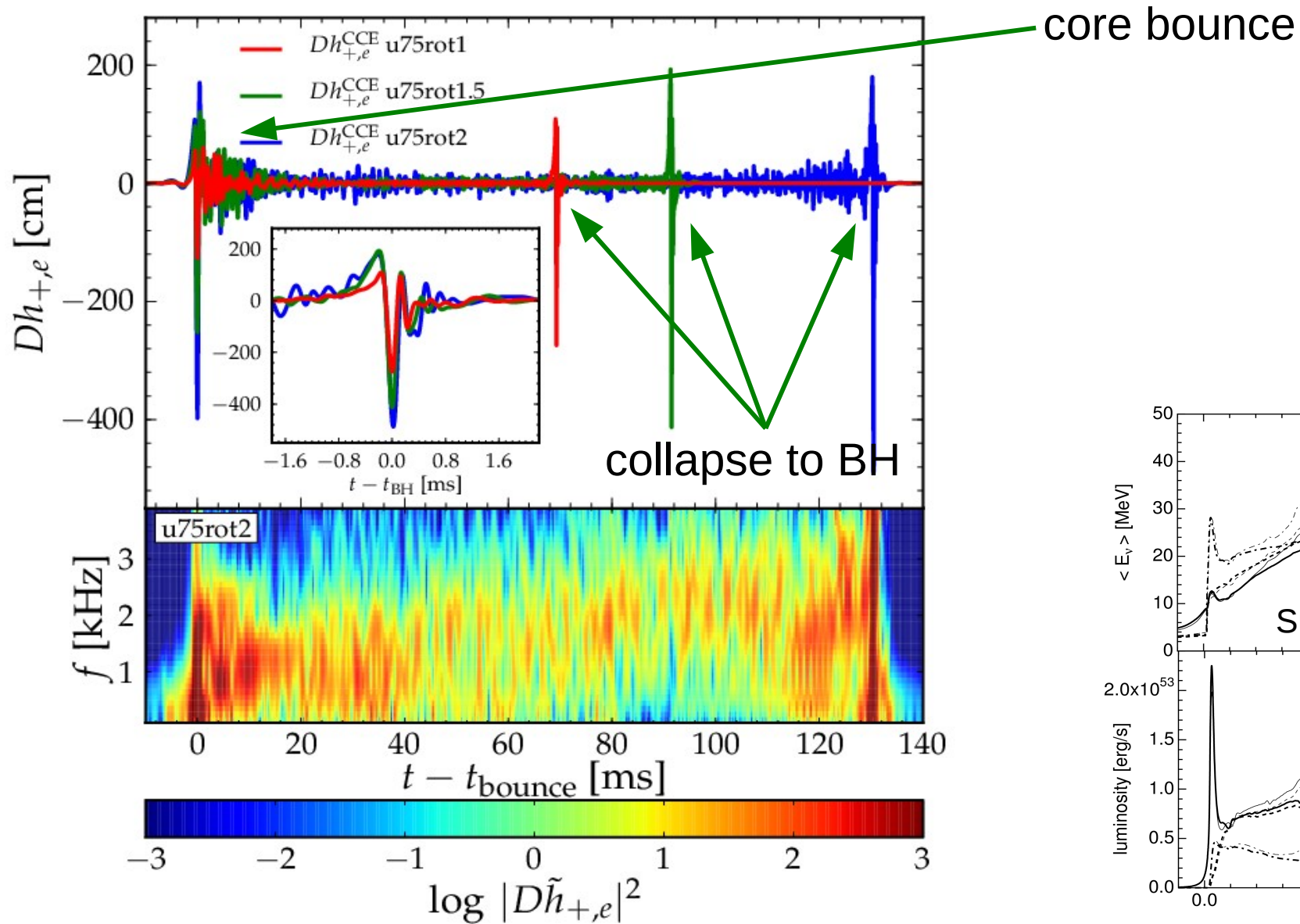
Black hole formation

Ott et al. '11



Black hole formation

Ott et al. '11



Summary

- Postbounce neutrino leakage has little effect on the ring-down oscillations.
- But can be important at a later time.
- Correlation between GWs and neutrino signal in rotating core collapse.
- GW emission from collapse to BH.