Rotational Instabilities in Core-Collapse Supernovae

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SNe might generate gravitational waves through a variety of mechanisms

Ex:

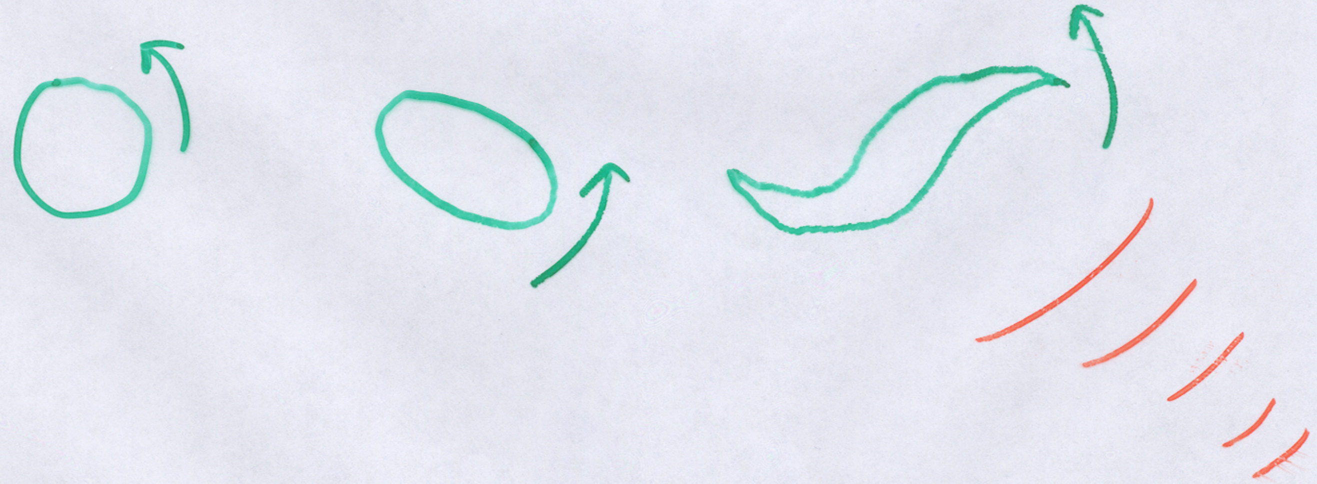
1. Changing oblateness during collapse & bounce (axisymmetric)
2. Dynamical instabilities (3D)
3. ...

Focus on #2

The study of dynamical instabilities in rapidly rotating fluid bodies (stars) has a long history.

Rule of thumb:

A star becomes unstable to bar deformation when $T/|W|$ exceeds ~ 0.27 (T = rotational KE, W = grav. PE)



Result: Gravitational Waves!

Recent simulations show that the bar shape persists for many rotation periods. Good news for GW detection!

- New, Centrella, Tohline (PRD **62**, 064019, 2000)
- Brown (PRD **62**, 084024, 2000)
- Saijo, Shibata, Baumgarte, Shapiro (ApJ **548**, 919, 2001)

Stability properties depend on eos, angular velocity profile, etc. Some stars are unstable to $m=1$ deformations for $T/|W|$ as low as 0.14.

- Centrella, New, Lowe, Brown (ApJ **550**, L193, 2001)

Can unstable fluid bodies form from stellar collapse?

(There may be other ways . . .)

For neutron star scale,

$M \sim 1.4\, M_\odot$

$R_{eq} \sim 25$ km

$\rho_c \sim 5 \times 10^{14}$ g/cm^3

$\gamma \sim 2$

we need a rotation period of

$P \sim 2$ ms

to produce $T/|W| \sim 0.29$. Bar instability yields

$h \sim 10^{-22}$ @ 10 Mpc

$f \sim 500$ Hz

For a centrifugally hung stellar core,

$M \sim 1.5\, M_\odot$

$R_{eq} \sim 200$ km

$\rho_c \sim 10^{12}\ g/cm^3$

$\gamma \sim 4/3$

we need

$P \lesssim 50$ ms

To produce ~~an~~ a bar instability. Then

$h \sim 10^{-23}$ @ 10 Mpc

$f \sim 100$ Hz

<These numbers are rough estimates>

Numerical studies of instabilities from stellar collapse:

- Rampp, Müller, Ruffert
  (AA, 332, 969, 1998)
- Brown, Blondin (in "Astrophysical Sources..."
  edited by J. Centrella)
- Saijo, Baumgarte, Shapiro, Shibata
  (ApJ. 569, 2002)

RMR, BB } massive star (LIGO), Newtonian, nested grid, little physics*

SBSS } supermassive star (LISA), post-Newtonian, comoving grid, little physics*

* no neutrinos, no $\vec{B}$, simple eos

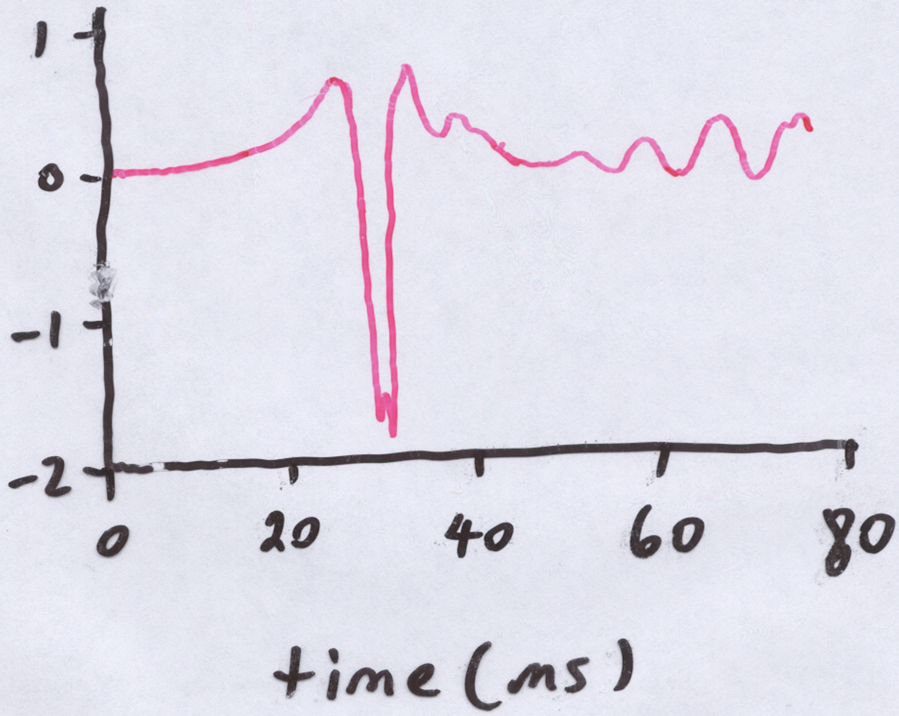
Results:

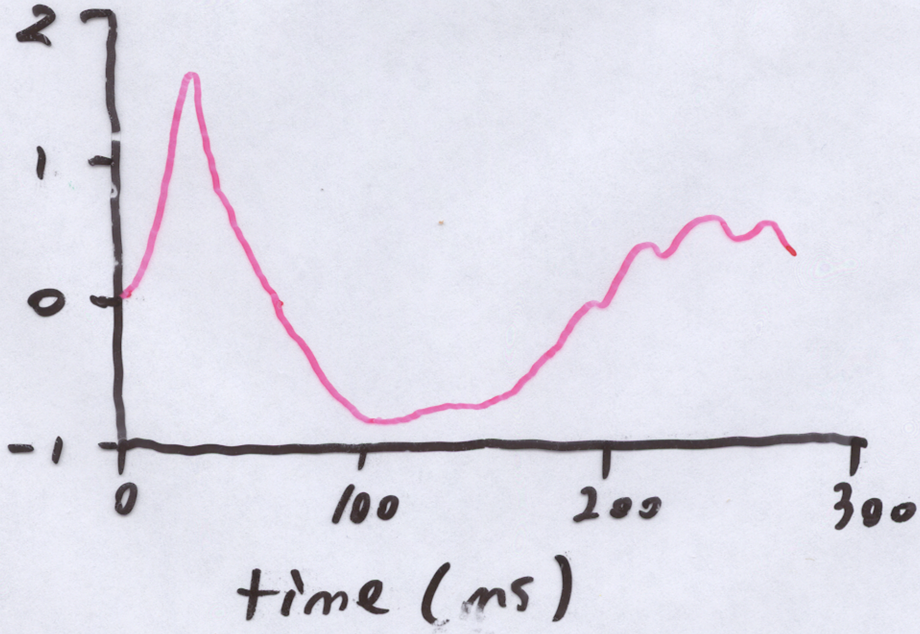
Bad news — Collapse does not necessarily produce large spin-up (centrifugal hang-up). Post collapse inner cores with large $T/|W|$ might be obtained only for "unusual" (unrealistic?) pre collapse conditions.

Good news — Inner core might not need such large $T/|W|$ to be unstable (due to inner core - outer core coupling?)

Bad news — Gravitational wave signals from unstable models is not strong.

$h_+/10^{23}$ at 20 Mpc.





My Plans:

. . . ?

my code has

- too little resolution to follow most models accurately through collapse, bounce, and post-bounce eras.
- too little physics
  (no neutrinos, no $\vec{B}$, simple eos)

Building a code without these deficiencies will require a collaborative effort – TSI