

# Gravitational Waves from r-modes?

Saul Teukolsky

LIGO-G020162-00-Z

## **r-modes in Neutron Stars**

Category of normal modes of oscillation of rotating stars

$p$  and  $g$  modes: restoring force =  $\nabla P$  or buoyancy

$r$  modes: primarily Coriolis force

Modes  $\sim \delta v$  ( $\delta \rho \sim 0$ )

## Surprise #1

$r$ -modes unstable to GW emission for small  $\Omega$

(Andersson 1998)

Fastest growth time:  $l = m = 2$

## Surprise #2

Growth time short!

$$\sim 20 \text{ s} \left( \frac{1 \text{ kHz}}{\nu} \right)^6$$

Maybe ns rapidly rotating at birth spins down via GW!

## Naive scenario

ns born at  $\Omega \sim \Omega_K$

$T \gtrsim 10^{10}$ : bulk visc. large, stable

$\nu$  emission  $\rightarrow$  cooling  $\rightarrow r$ -mode unstable

Saturates (amplitude?)

Quasi-stationary evolution,  $J \downarrow$ ,  $T \downarrow$

When viscosity dominates again, stable

Estimate:

$$\Omega_{\text{final}} \sim \left( \frac{1}{10} - \frac{1}{20} \right) \Omega_K$$
$$\gtrsim 10 \text{ ms}$$

Naive scenario  $\rightarrow$  detectable GW emission

IF saturation amplitude  $\sim 1$  (LIGO-II)

Rate:  $\sim 1$  SN per yr to Virgo supercluster

(20 Mpc)

BUT:

A lot of dirty astrophysics goes here ...

Need to know nonlinear effects!

1.  $\rightarrow$  saturation amplitude

2.  $\rightarrow$  reheating of crust?

etc.

Determine saturation amplitude by:

1. Numerical simulation of hydrodynamics

2. Mode-mode coupling (2nd order pert. theory)

Numerical simulations:

Stergioulas & Font (2000)

Lindblom, Tohline & Vallisneri (2000)

Instability does not saturate at small amplitude!

But only  $\sim 20$  rotation periods (need  $\gtrsim 10^4$ )

New result:

Phil Arras, Eanna Flanagan, Sharon Morsink, Katrin Schenk,  
Saul Teukolsky, Ira Wasserman, astro-ph/0202345

Saturation amplitude is *very small*

$< 10^{-6}$  in energy units

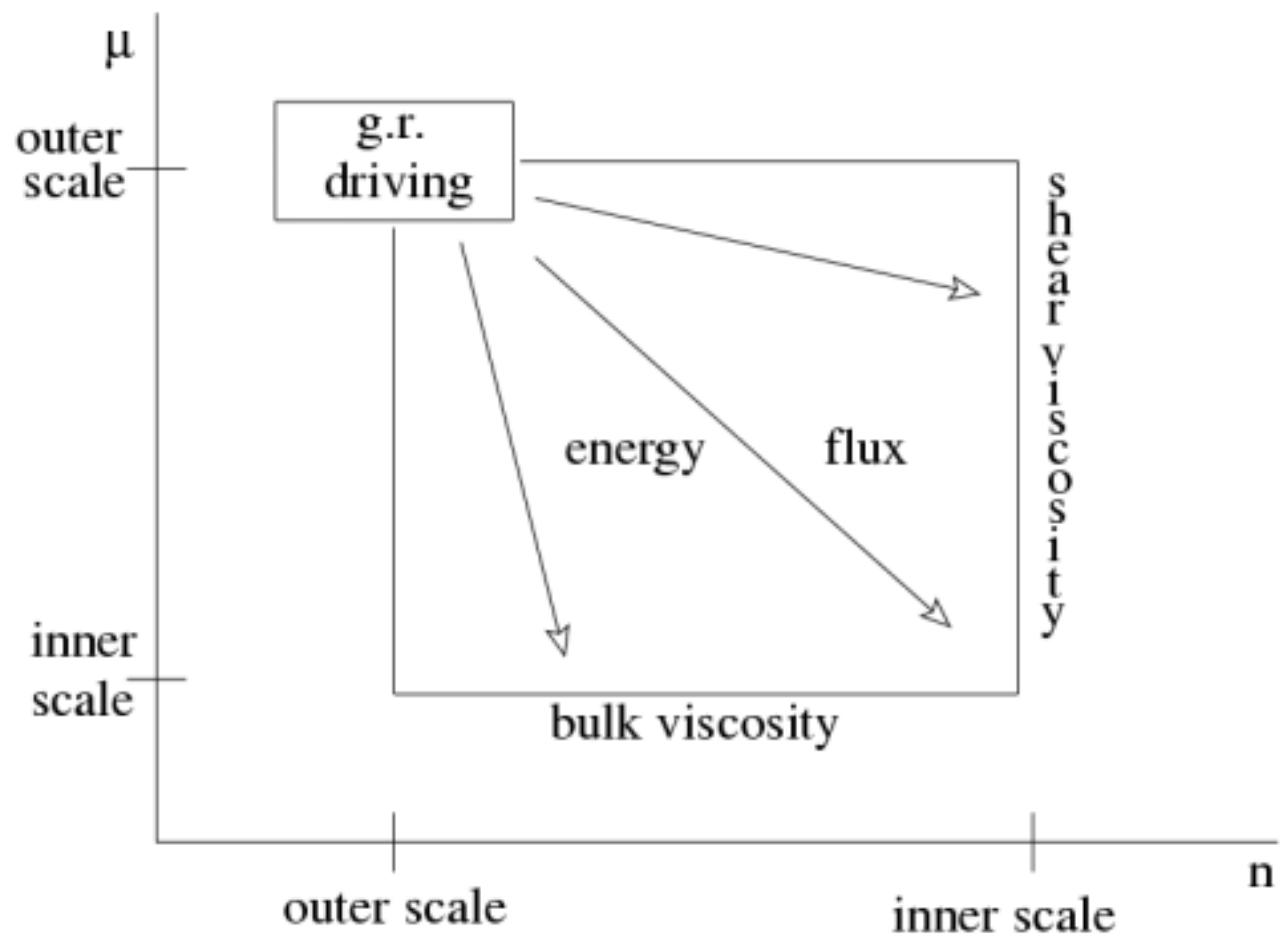
Reason:  $r$  mode driven by GW couples to other  
inertial modes

→ parametric instability

(parent + 2 daughter modes)

Strong driving → whole range of unstable modes





Why doesn't this show up in the numerical simulations?

1.  $\gamma_{\text{gr}}$  bigger by 4500.

2. Can't see small scales on  $128^3$  grid

Complicated analysis!

If result holds up,  $r$ -modes will be undetectable in GW