Fluid Instabilities in Neutron Star Mergers

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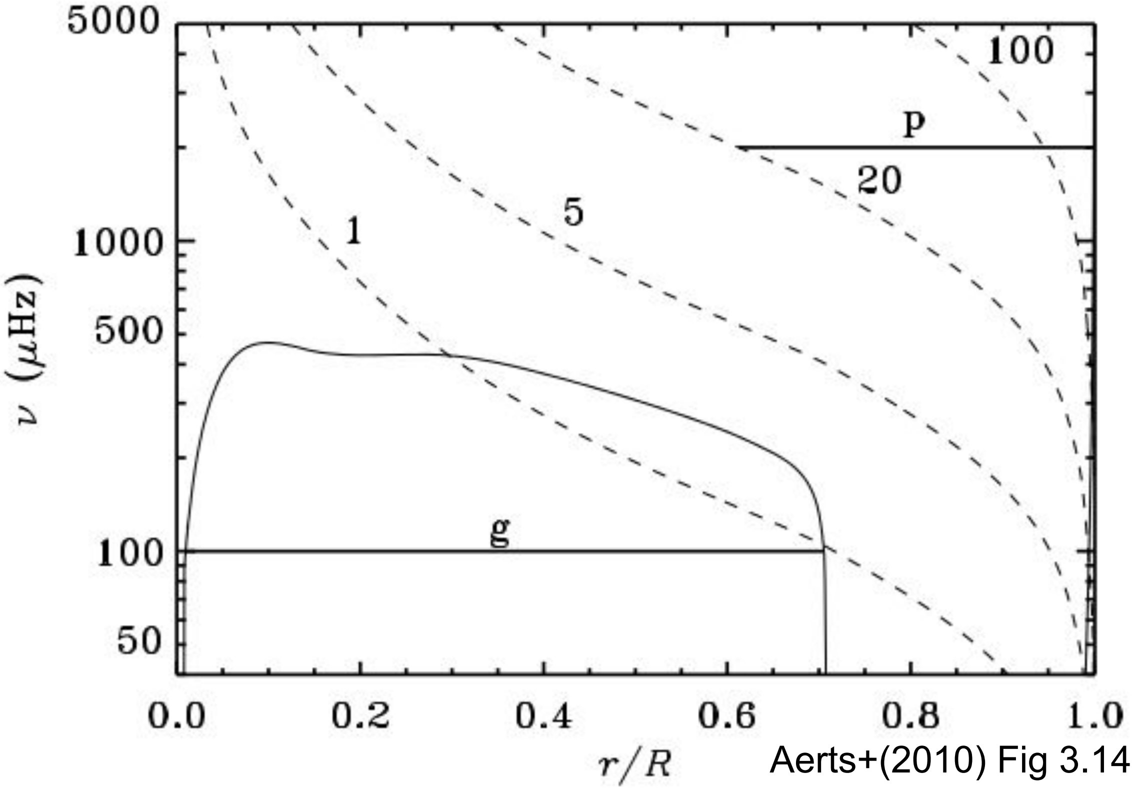
June 26, 2019

stellar modes

basic overview of modes

- ***p*-modes**
  - high frequencies
  - ω∝n (radial order)



Aerts+(2010) Fig 3.14

stellar modes

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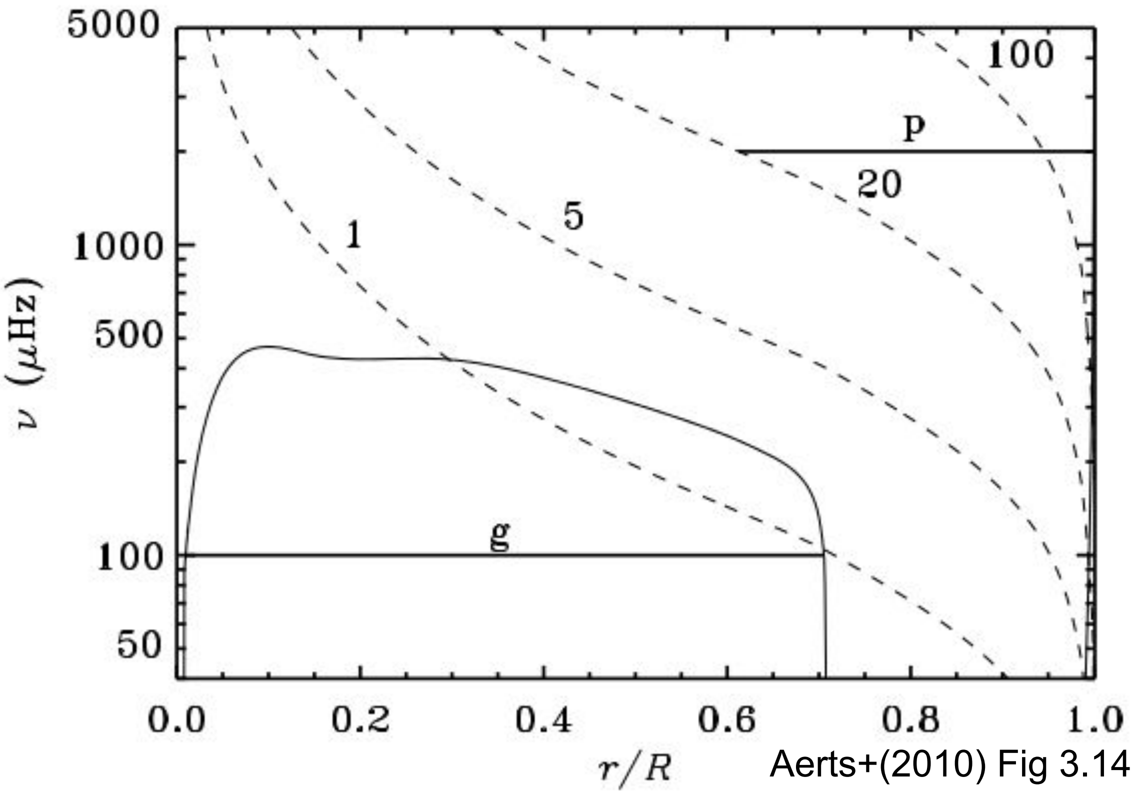
  - $\omega \propto n$ (radial order)
- ***g*-modes**
  - low frequencies
  - $P \propto n$ (radial order)



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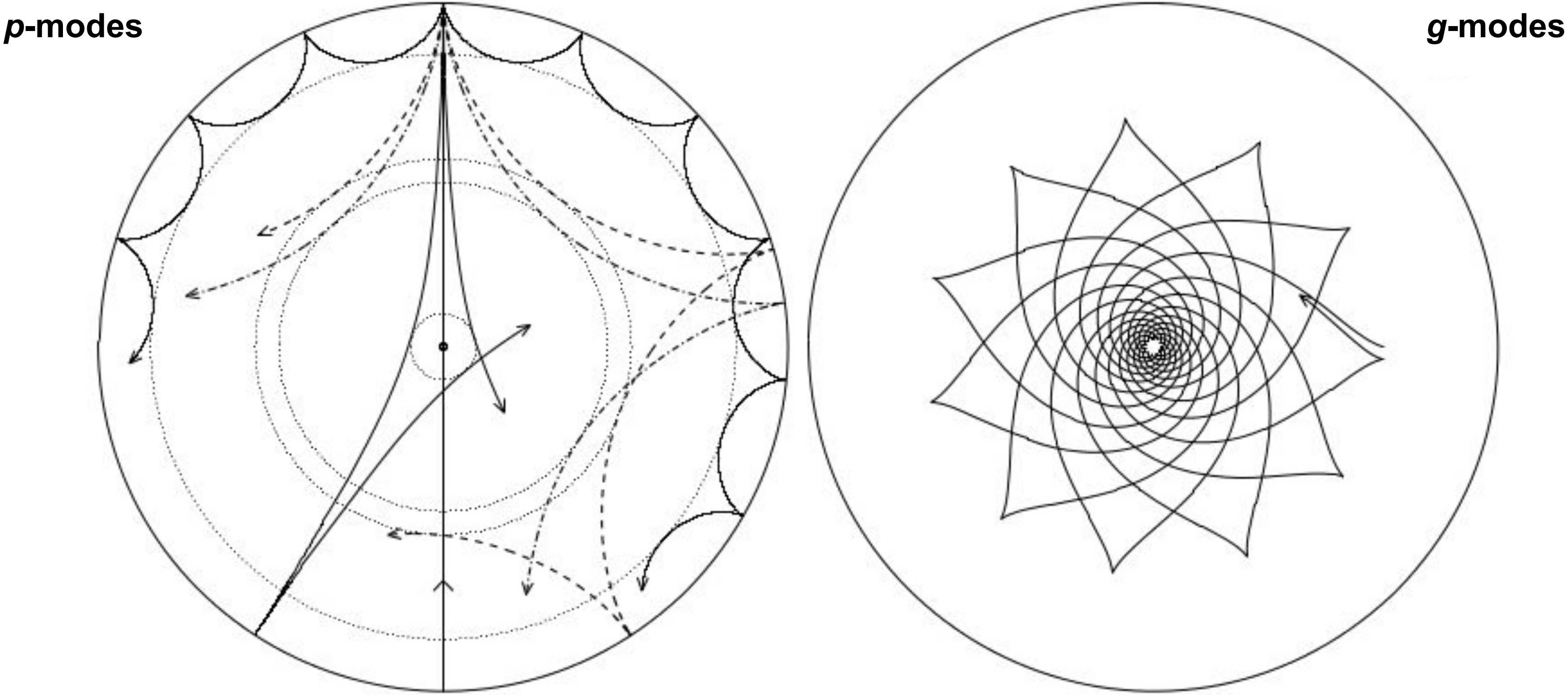
stellar modes



Aerts+(2010) Fig 1.7

stellar modes

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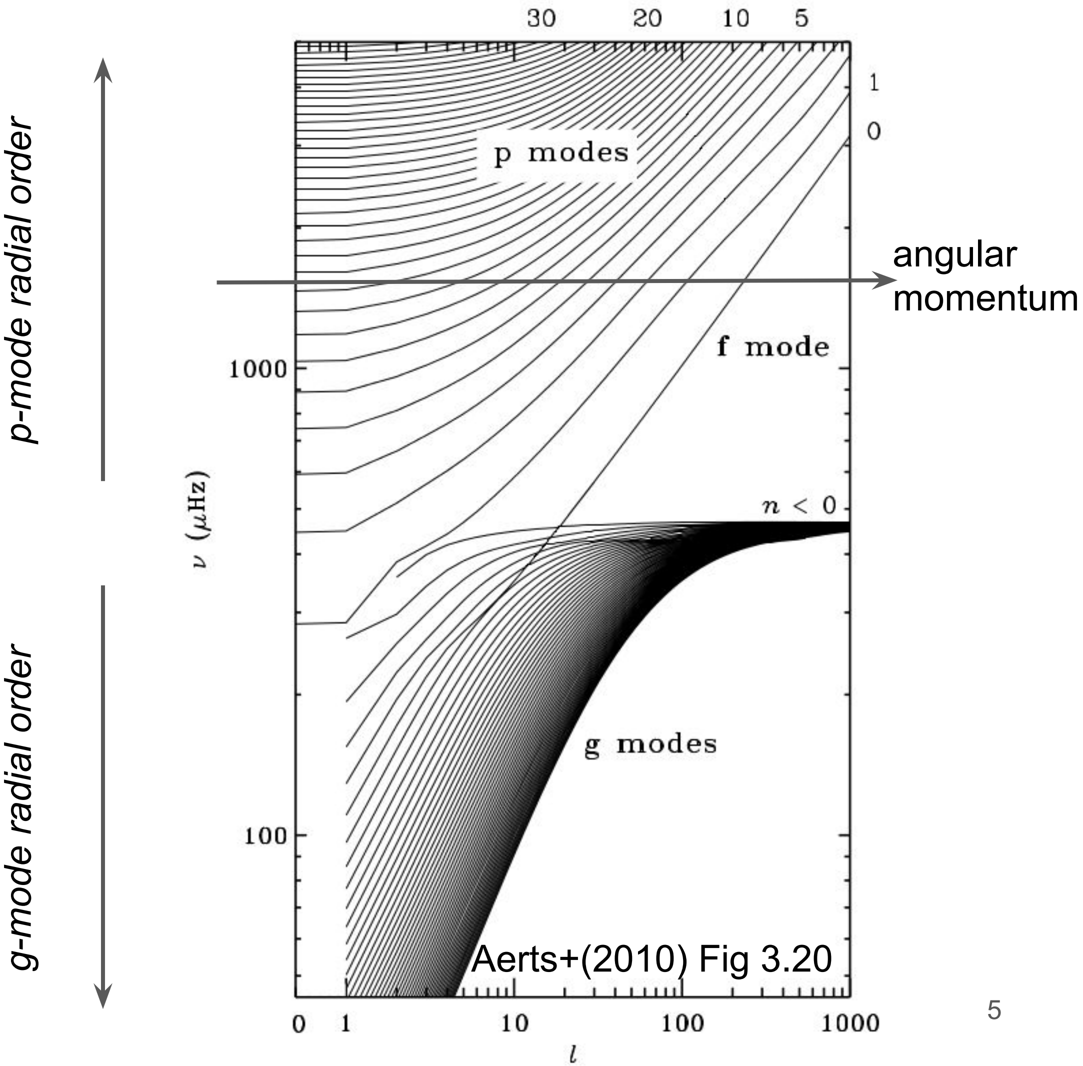

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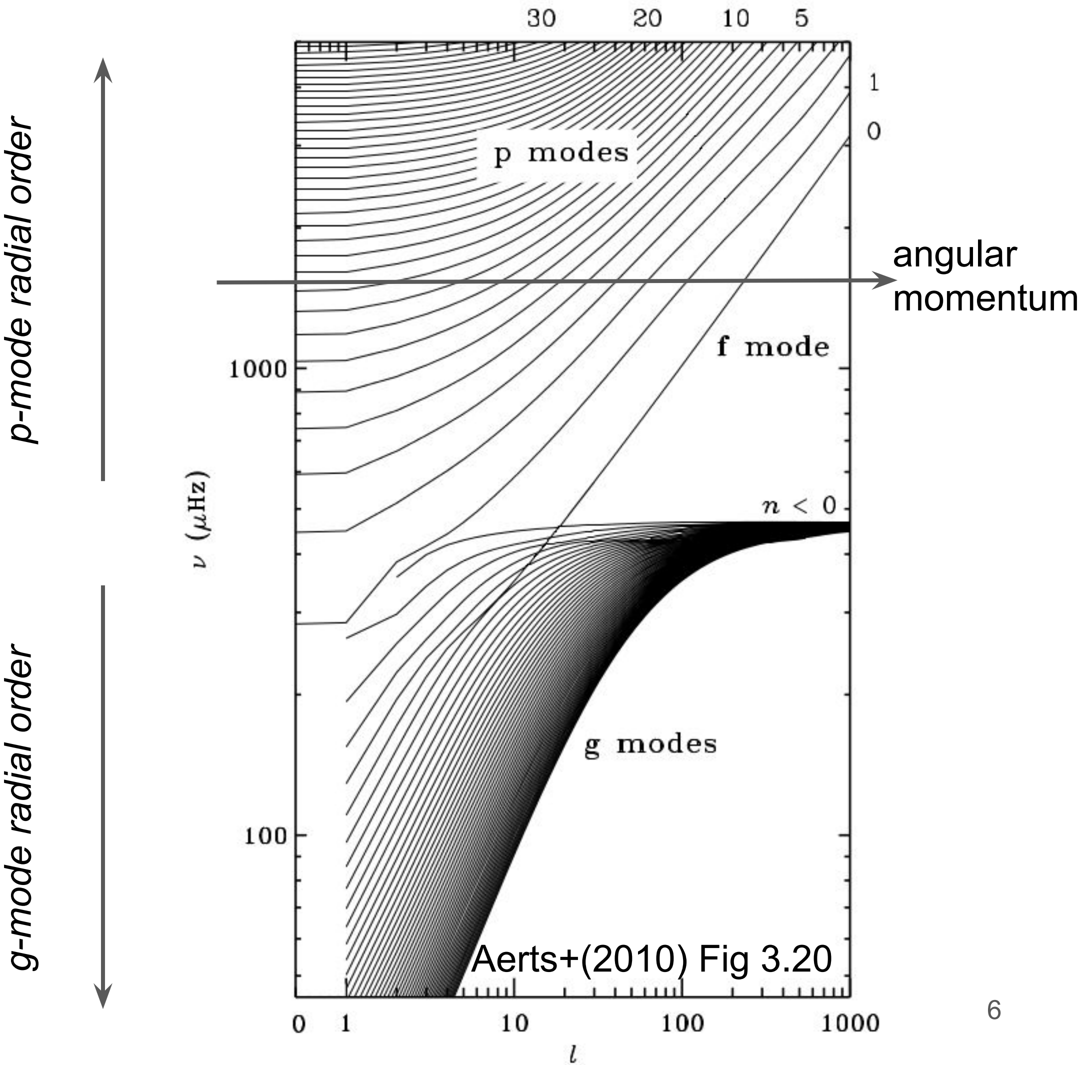
- ***r*-modes**
  - rotational/inertial modes
  - often “mixed” with *g*-modes



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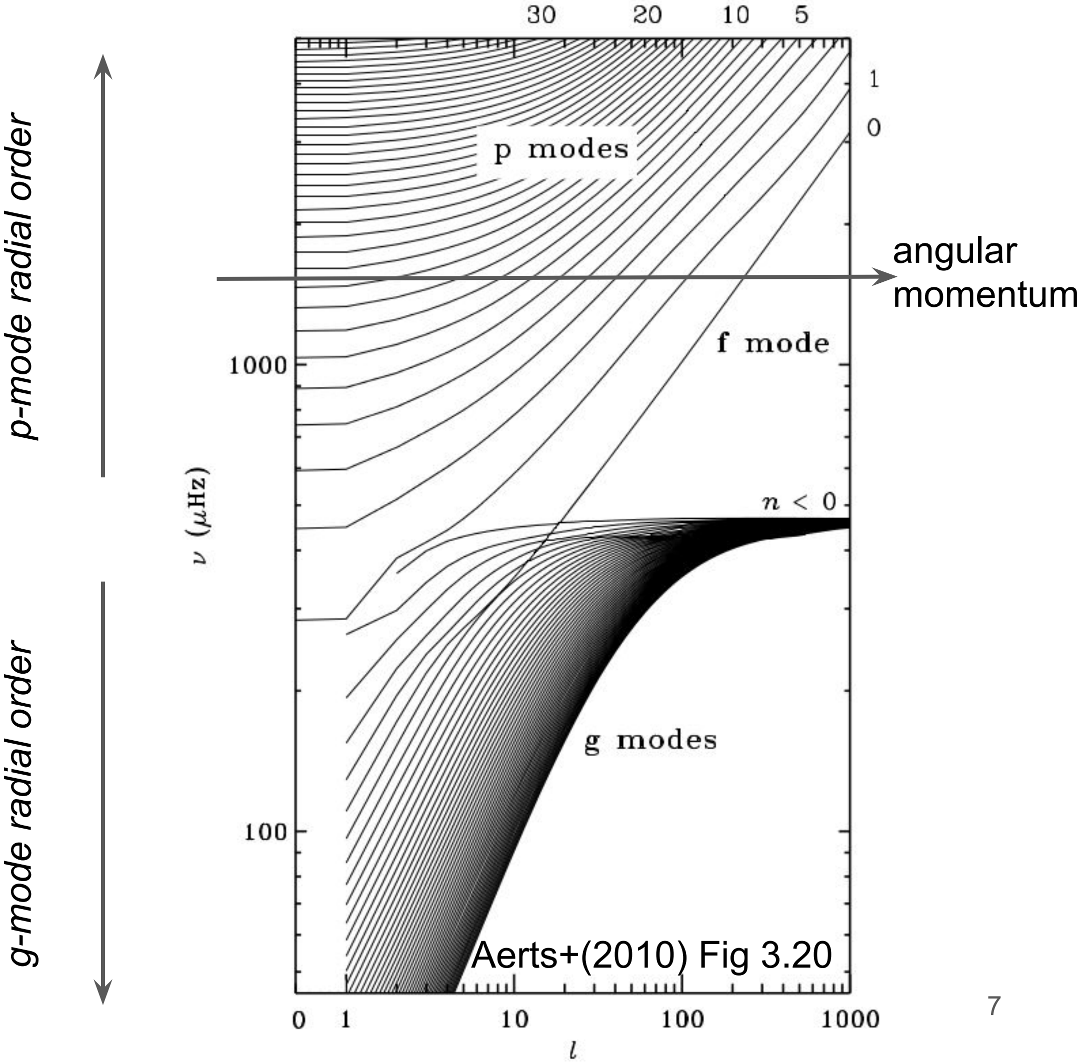
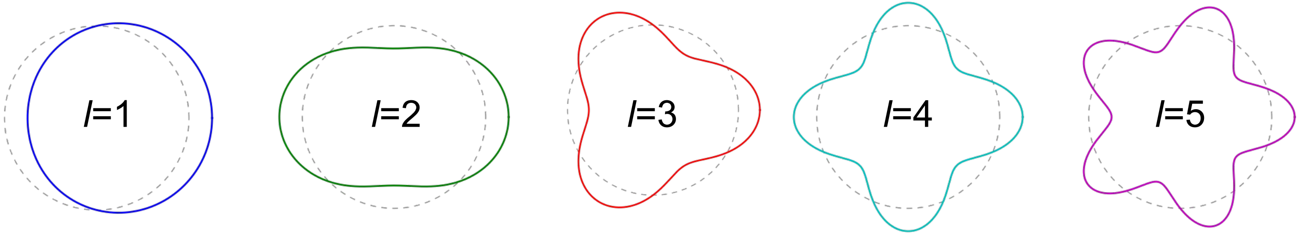
- ***r*-modes**
  - rotational/inertial modes
  - often “mixed” with *g*-modes
- ***w*-modes**
  - metric oscillations
  - only present in relativistic stars



multi-mode interactions

equations of motion for mode amplitudes can be described via a Galerkin decomposition based on the linear eigenmodes.



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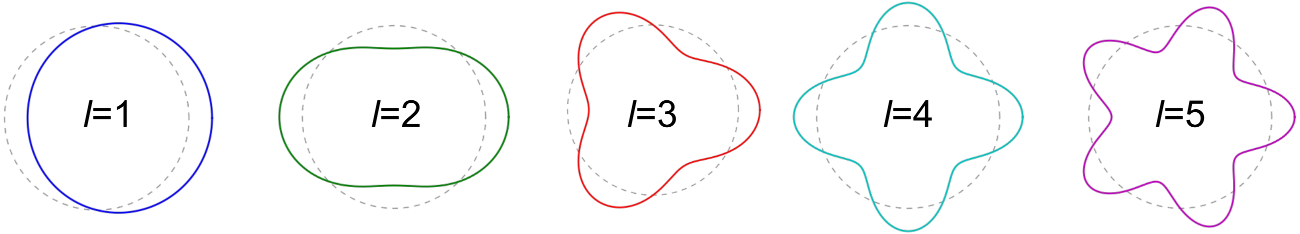
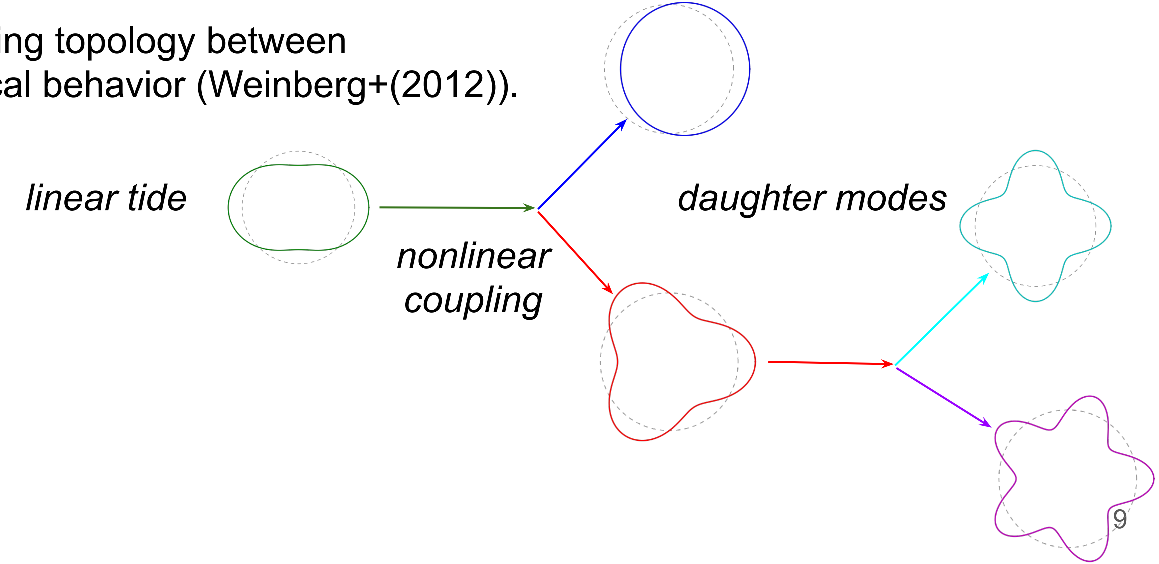


generally produces a complicated coupling topology between modes, which can produce rich dynamical behavior (Weinberg+(2012)).



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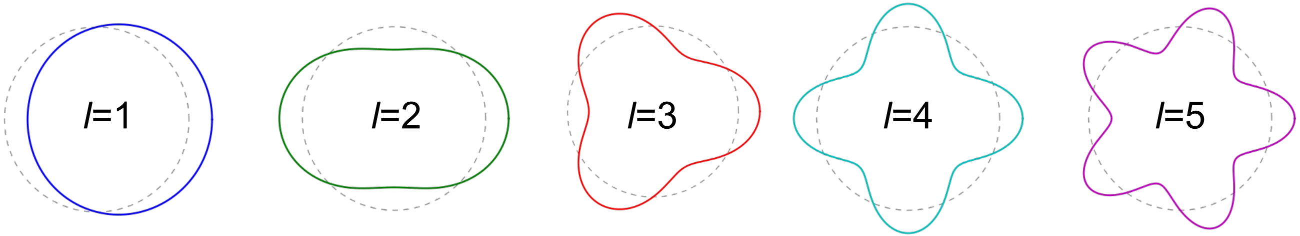

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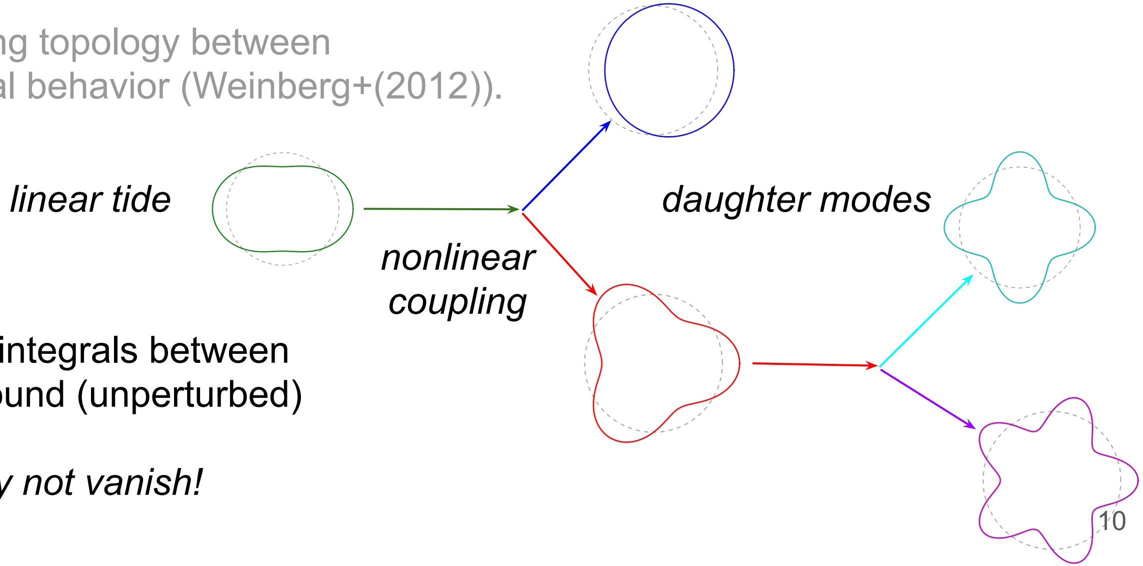


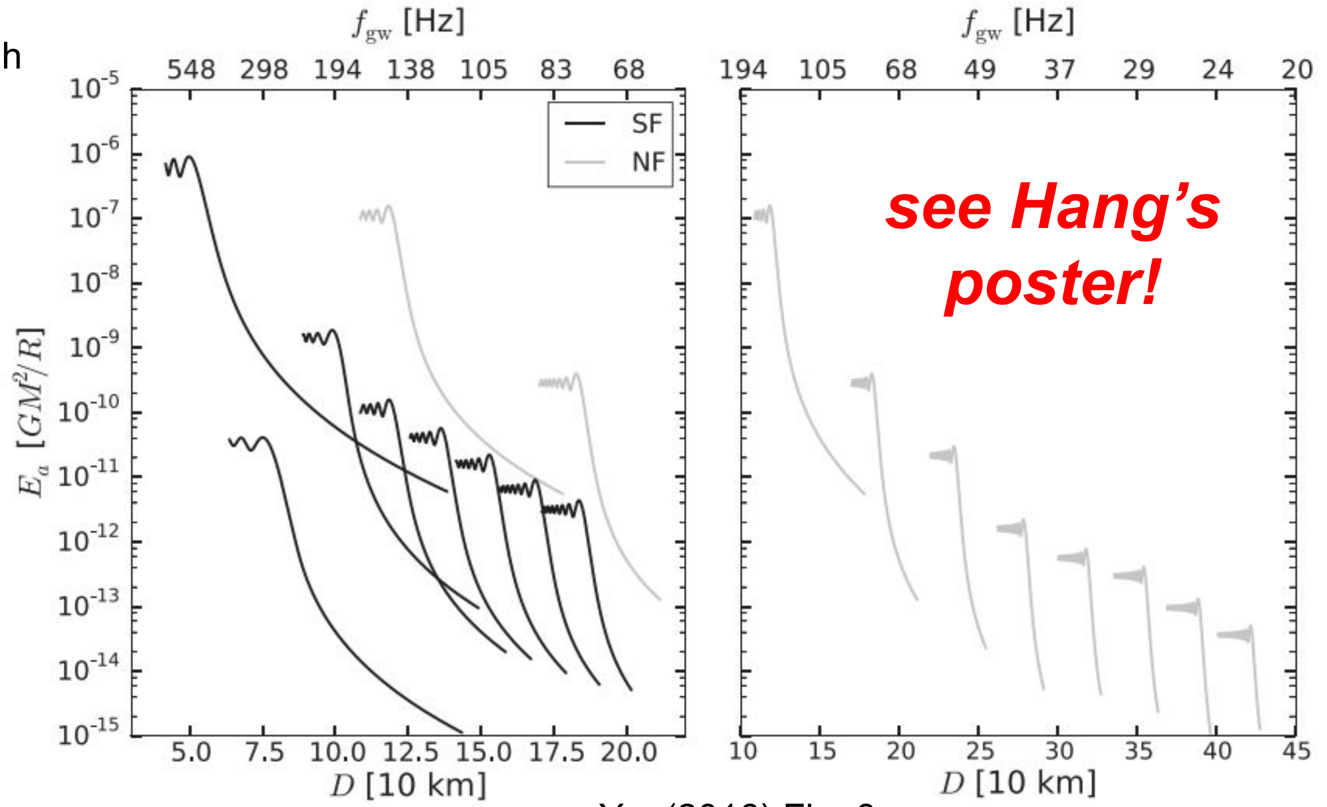
coupling strength determined by overlap integrals between mode shapes with respect to the background (unperturbed) stellar structure.

- *integrals over 3+ mode shapes may not vanish!*

survey of tidal effects

linear dynamical tides and (resonant) nonlinear dynamical tides

GW-driven inspiral sweeps through resonances too fast to efficiently transfer energy through resonant interactions.



Yu+(2016) Fig. 6

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- less time near resonance

low-frequencies

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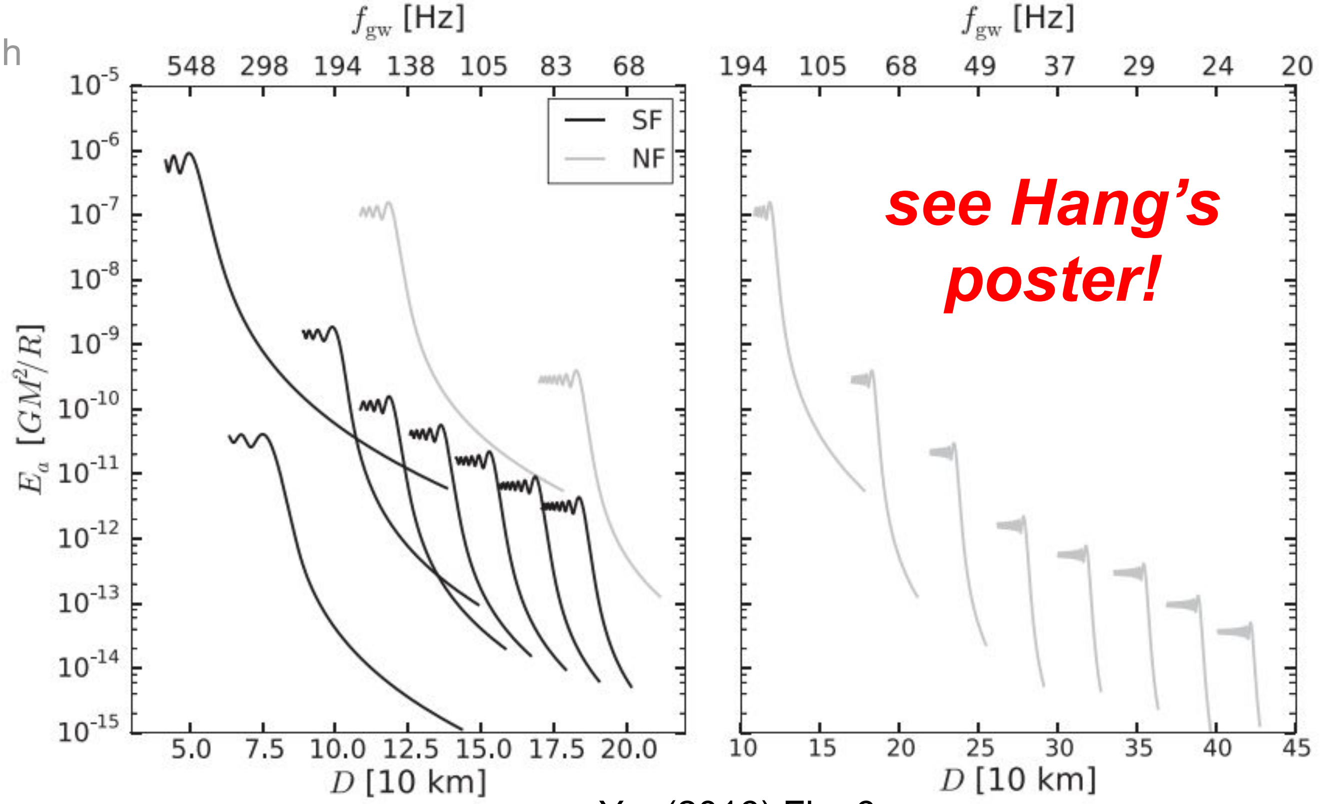

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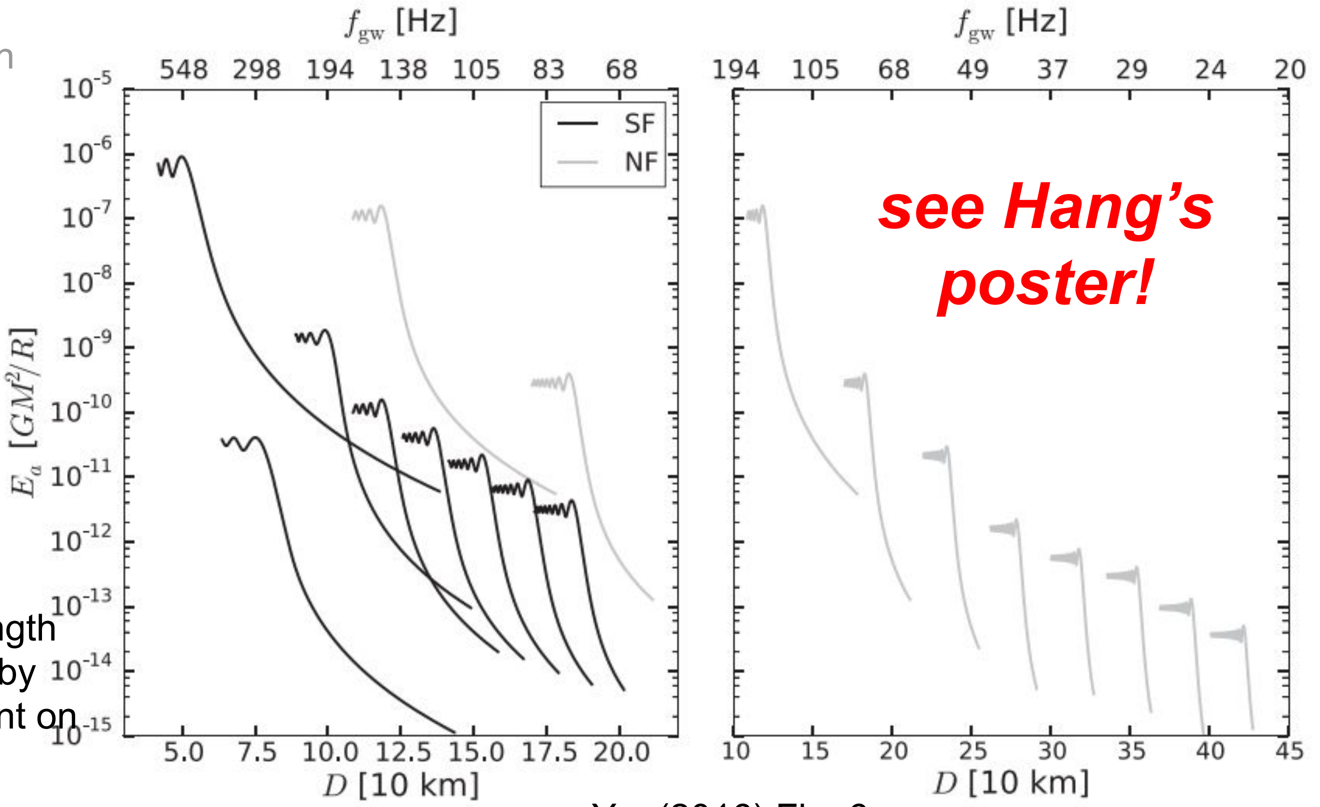
large spins may shift long-wavelength modes to lower frequencies, thereby increasing the amount of time spent on resonance (Ho+1999).



see Hang's poster!

Yu+(2016) Fig. 6

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(nonresonant) *p*-*g* secular instabilities

- instability of the *linear tidal bulge* coupled to a *high-frequency p-mode* and a *low-frequency g-mode* (Weinberg+(2012)).

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- present in degenerate stars because *p*- and *g*-mode propagation regions overlap significantly.
    - coupling coefficients in the Galerkin decomposition can be large.
    - could be important for compact systems containing *either* Neutron Stars or White Dwarfs.

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    - coupling coefficients in the Galerkin decomposition can be large.
    - could be important for compact systems containing *either* Neutron Stars or White Dwarfs.
- *nonresonant* and active whenever the linear tidal perturbation is above some threshold.
    - equivalently, when orbital separation is below some threshold or when orbital frequency is above some threshold.
    - 4-mode couplings are also important (Venumadhav+(2016)) and can dynamically cancel part of the instability, but an instability still exists for dynamical tidal fields.
    - finite-frequency and other non-adiabatic effects on mode shapes spoil the cancellation between 3- and 4-mode interactions, resulting in smaller but still possibly relevant growth timescales (Weinberg (2016)).
- *difficult to simulate*
    - spatial grid required to resolve high-order *g*-modes is prohibitively expensive.
    - larger number of relevant coupled modes makes Galerkin amplitude equations difficult to simulate.

survey of tidal effects

(nonresonant) *p*-*g* secular instabilities

- phenomenological model
  - dissipation by *p*-*g* instability modifies orbital evolution and Gravitational-Wave phase (Essick+(2016)).

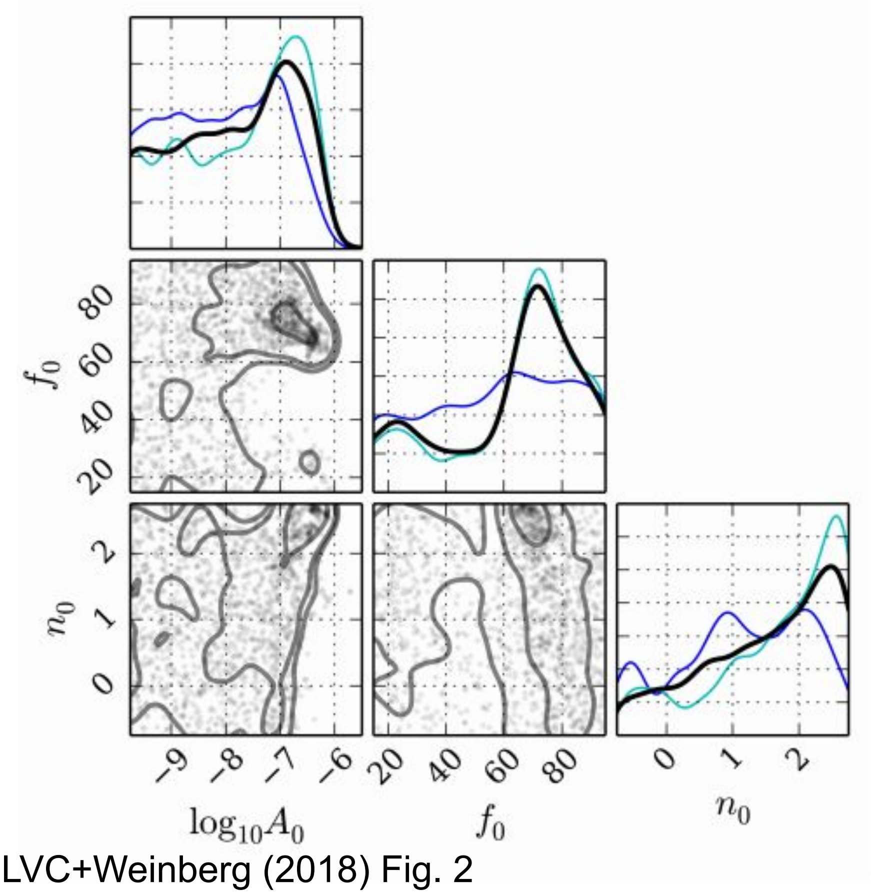
A_0: overall amplitude of induced phase shift

f_0: saturation frequency ~ instability threshold *assuming modes grow quickly*

n_0: scaling of energy dissipated as a function of frequency

worked example: *p*-*g* instabilities with GW170817

(nonresonant) *p*-*g* secular instabilities



LVC+Weinberg (2018) Fig. 2

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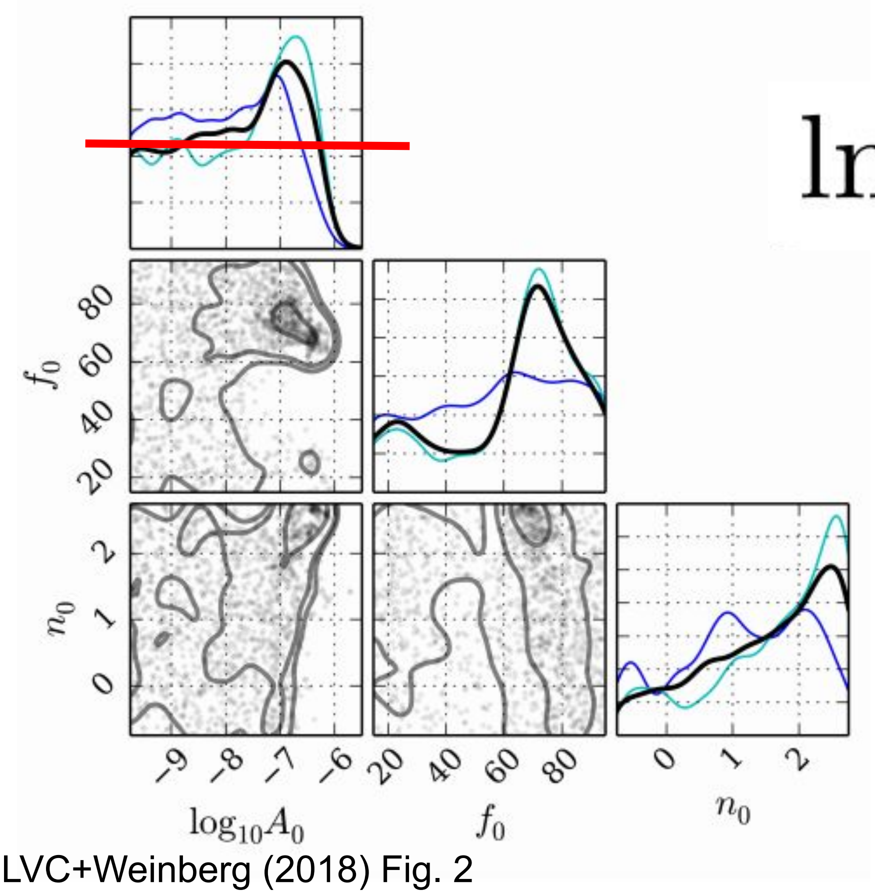
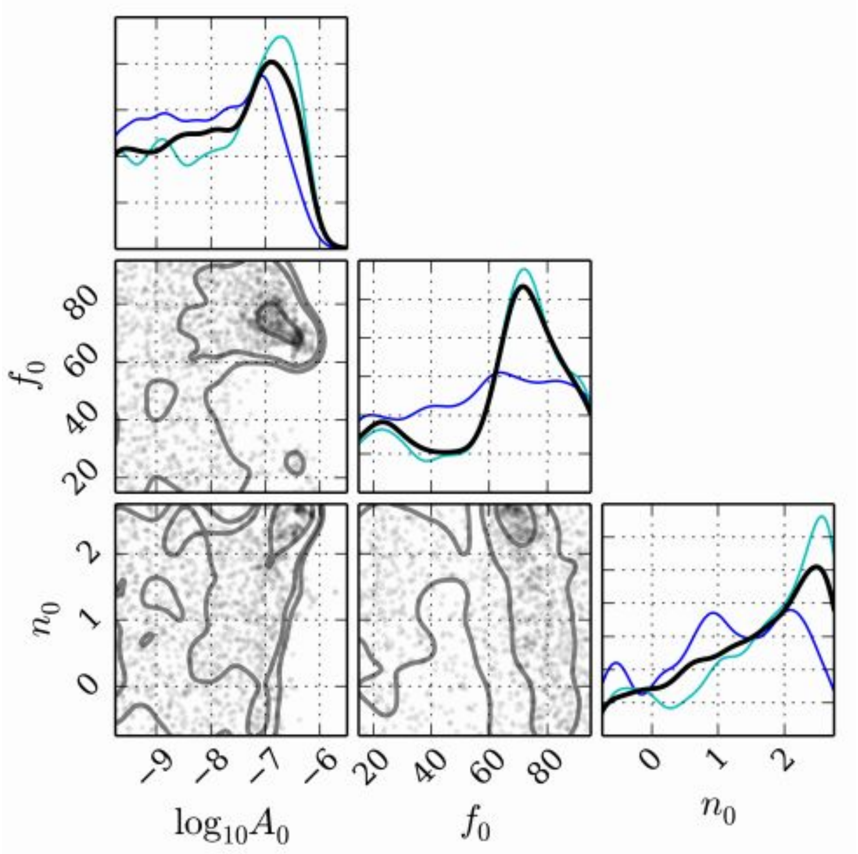


$$\ln B^{pg}_{!pg} = 0.03^{+0.70}_{-0.58}$$

LVC+Weinberg (2018) Fig. 2

worked example: *p*-*g* instabilities

(nonresonant) *p*-*g* secular instabilities



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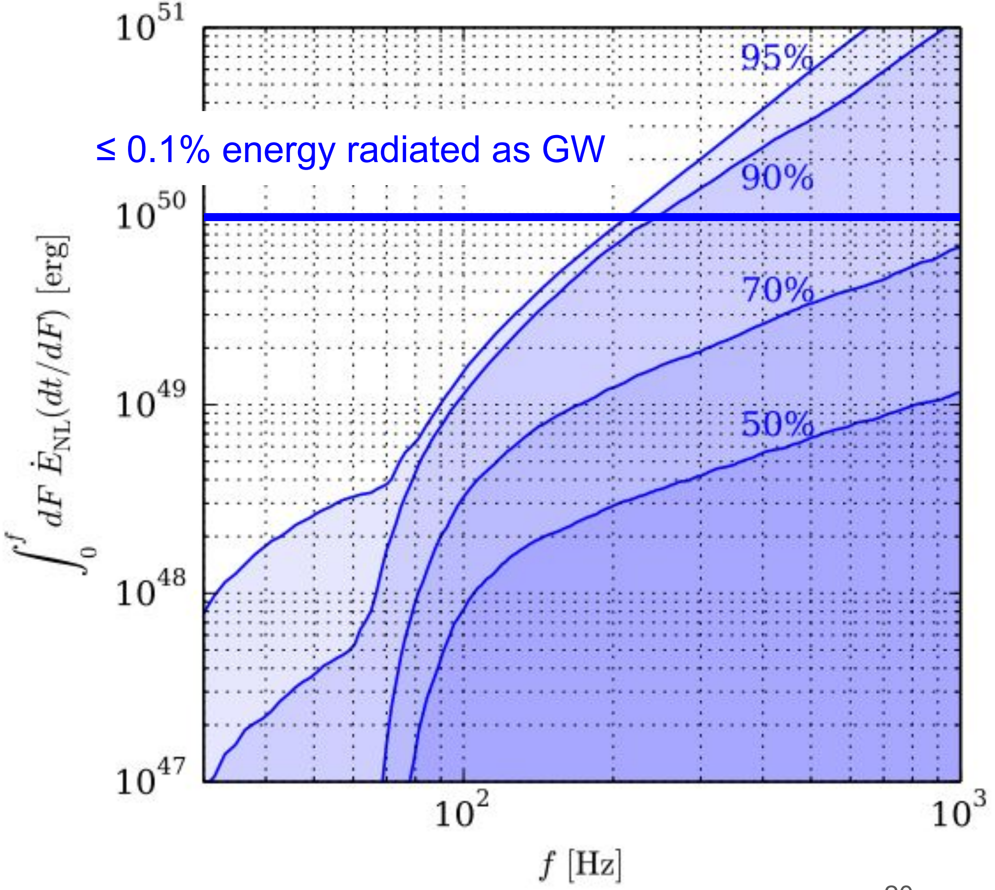
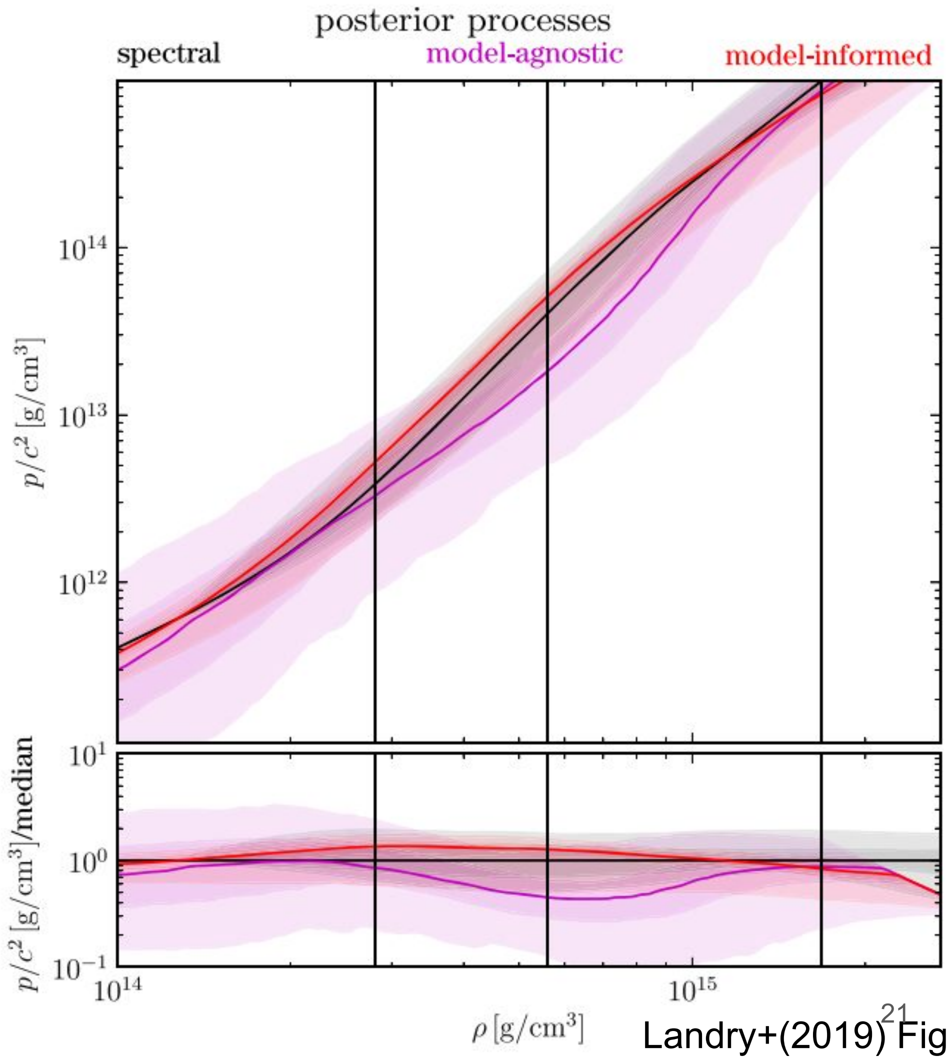


LVC+Weinberg (2018) Fig. 3

Can Equation of State Constraints help?

linear resonant tides

- *yes!*
- knowledge of the EOS specifies the mode spectra and shapes.
- but these effects are likely to be negligible anyway...



Landry+(2019) Fig. 3

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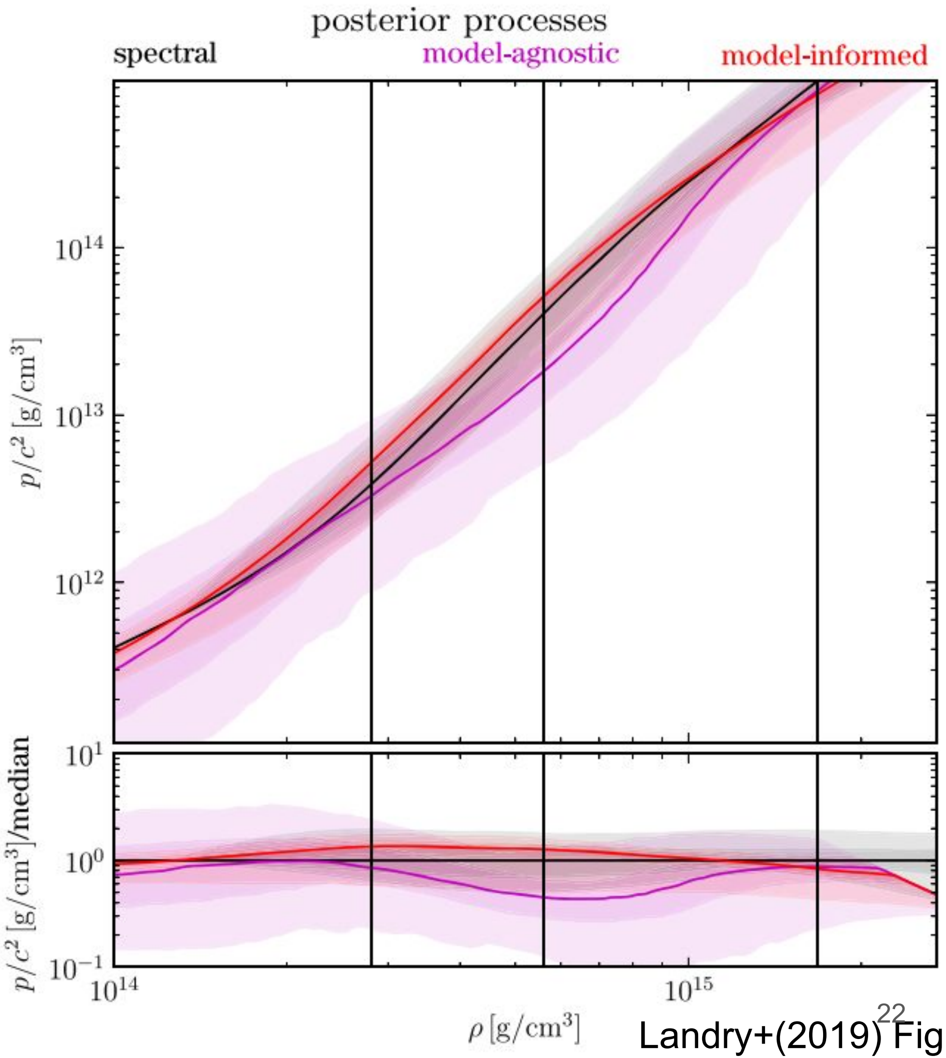
nonlinear (non)resonant tides, CFS instabilities

- *not clear…* (e.g., Zhou+(2017))
- uncertain physics within NS core
  - damping mechanisms
  - saturation mechanism
- difficult calculations

Observations and phenomenological models may be the fastest way to constrain these effects...



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