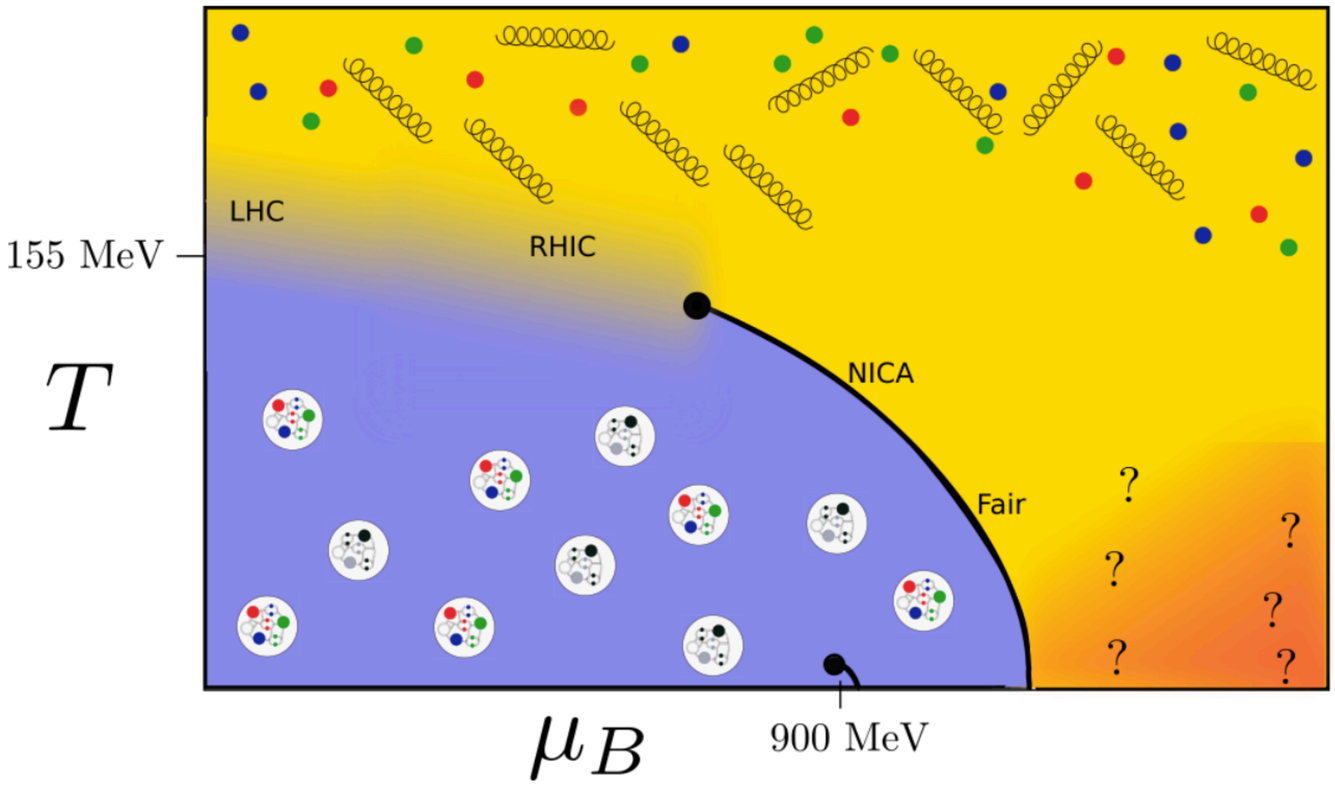
Inferring Phase transitions from Nonparametric EoSs

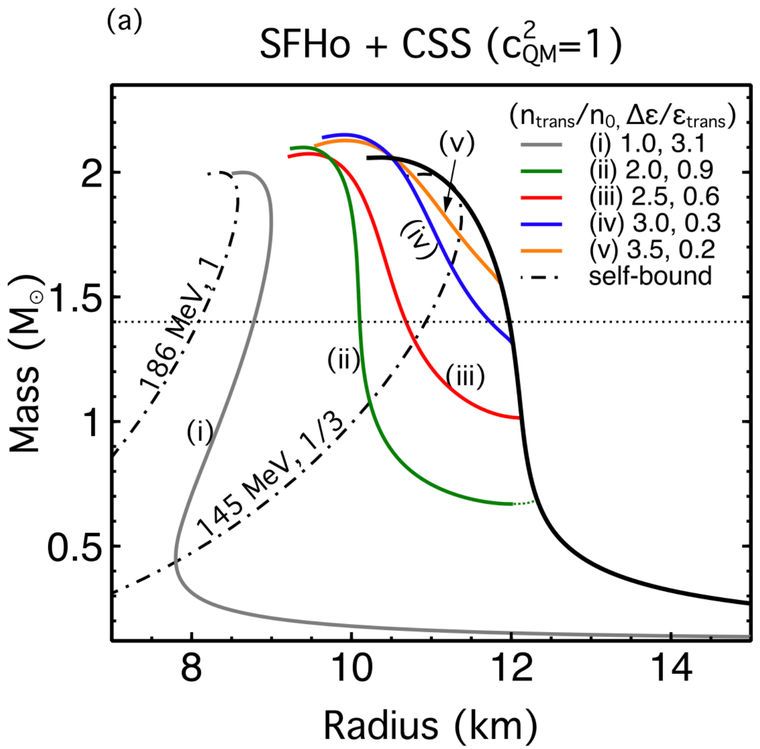
Isaac Legred

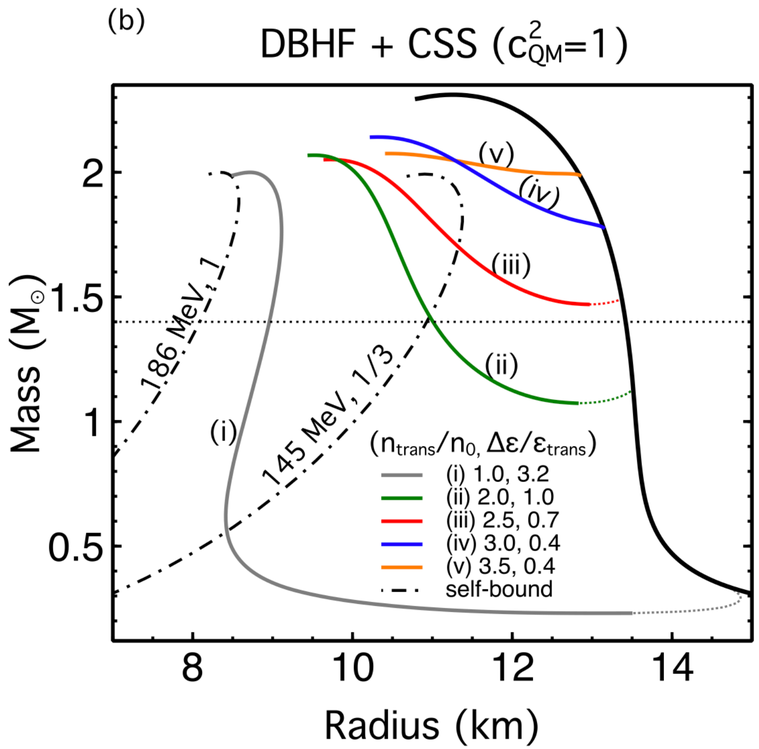
From Essick, Legred, Chatziioannou, Han, and Landry: 2023 (2305.07411)

Phase Transition is fairly common prediction at high densities



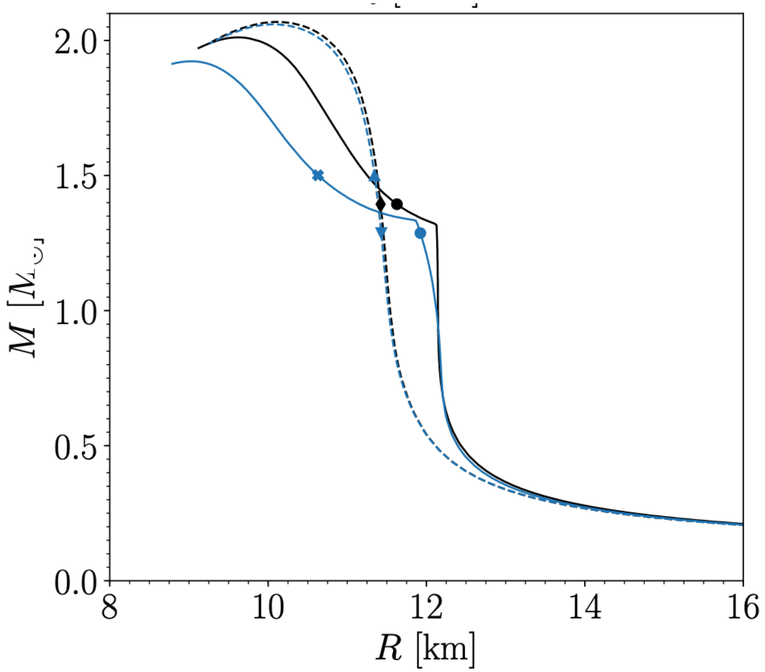
Guenther+2020





Han + Steiner 2018

Ujevic+2022



But Morphology is uncertain

Big Question:

What are the observable signatures of a PT?

(Is it possible to find a model-agnostic signature?)

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What are the observable signatures of a PT?

Rapid change in speed of sound?

How to measure?

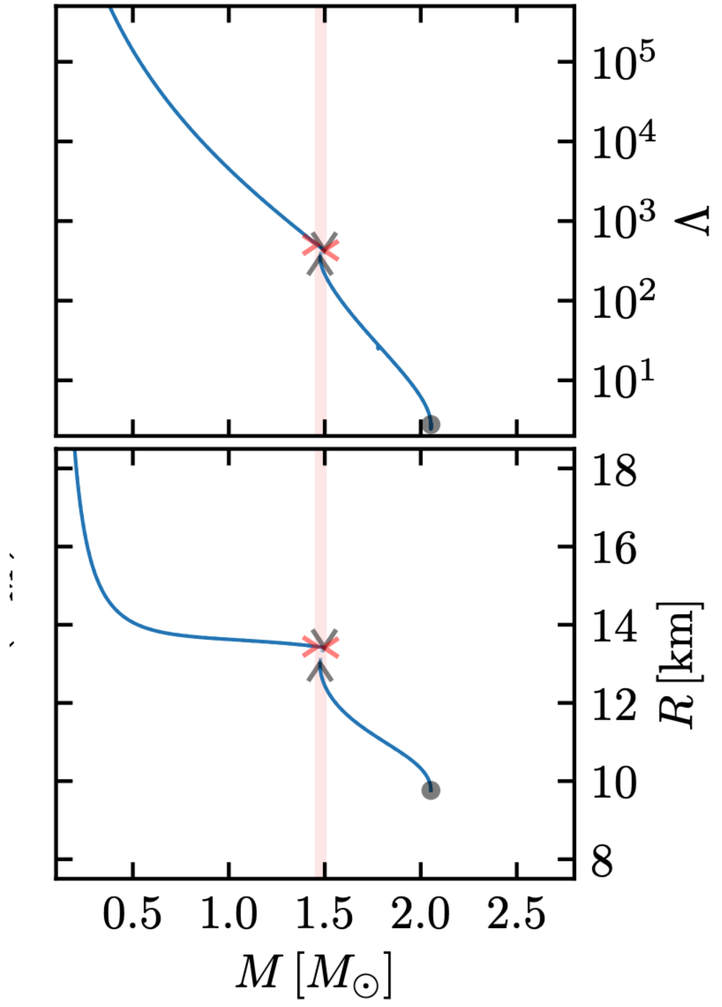
Change in tidal deformability?

Hard to measure

Large change in Radius?

Potentially hadronic / GR effect?

Phase transition may not lead to sharp features/discontinuties in astro observables!



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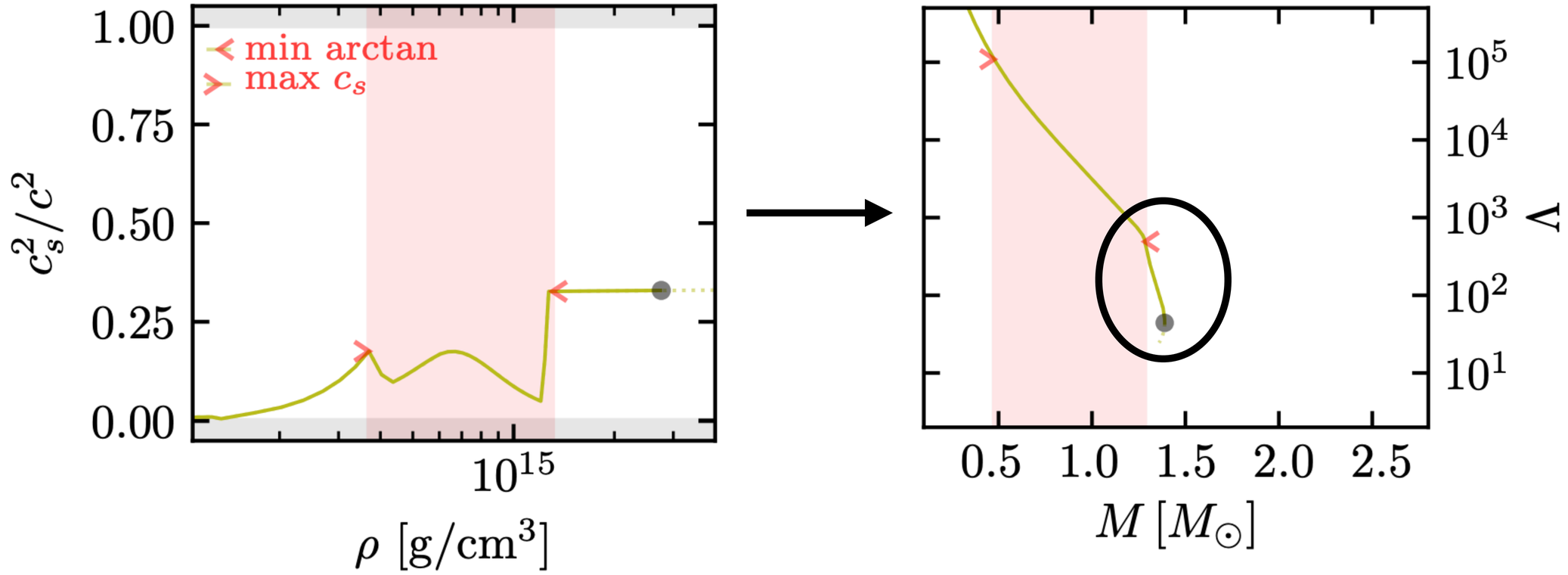
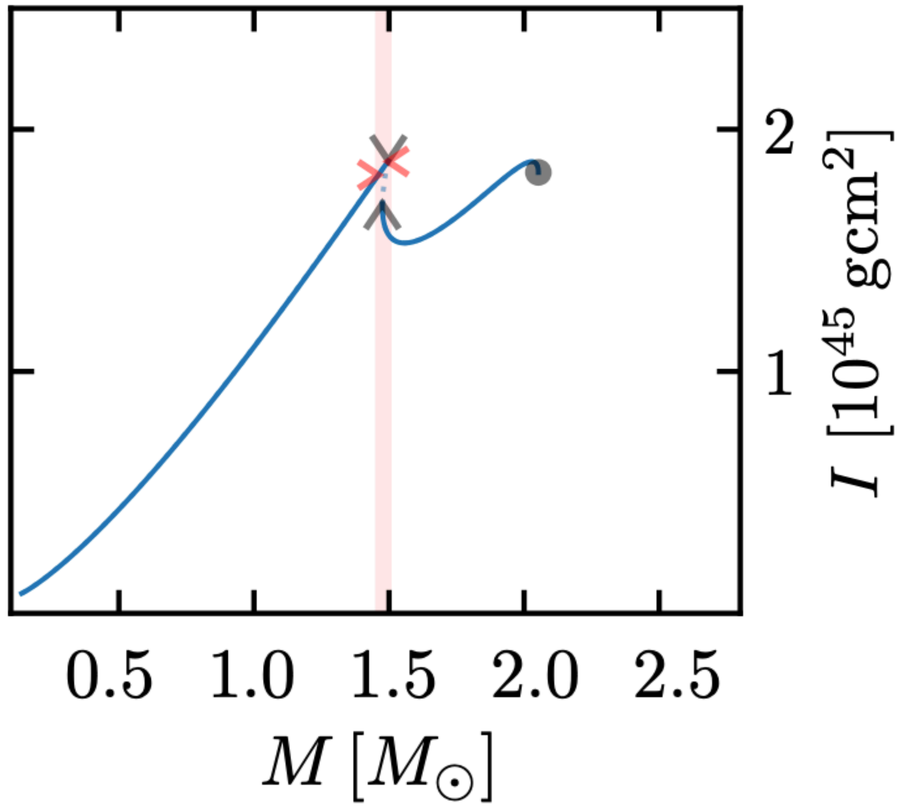
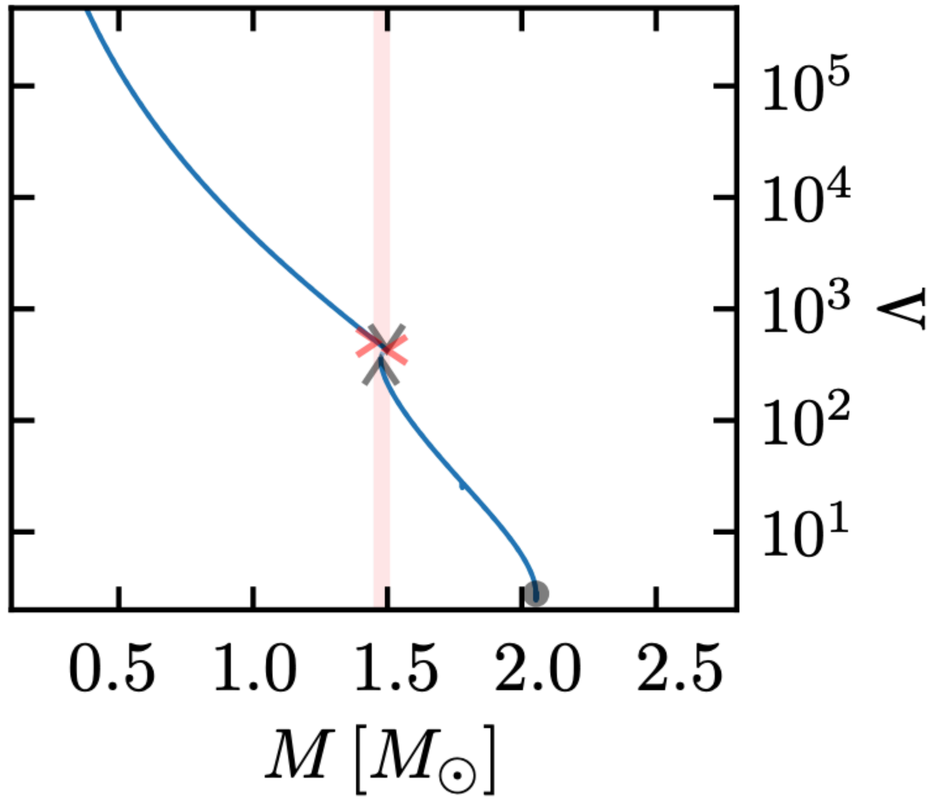


Insight:

Look for observable which is universal within a single phase





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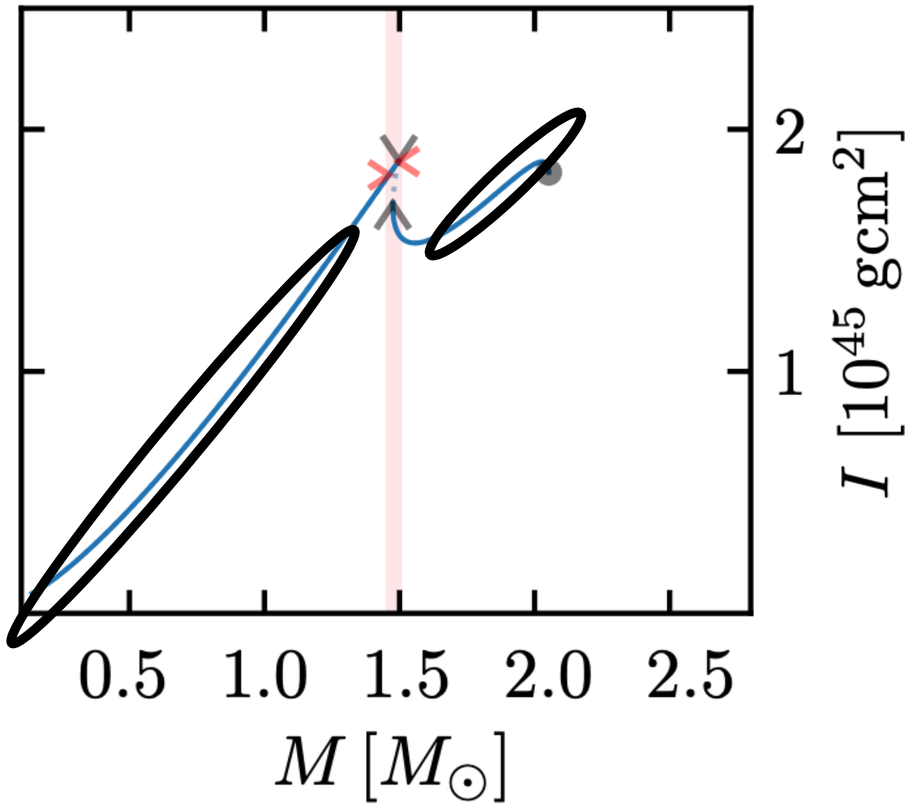
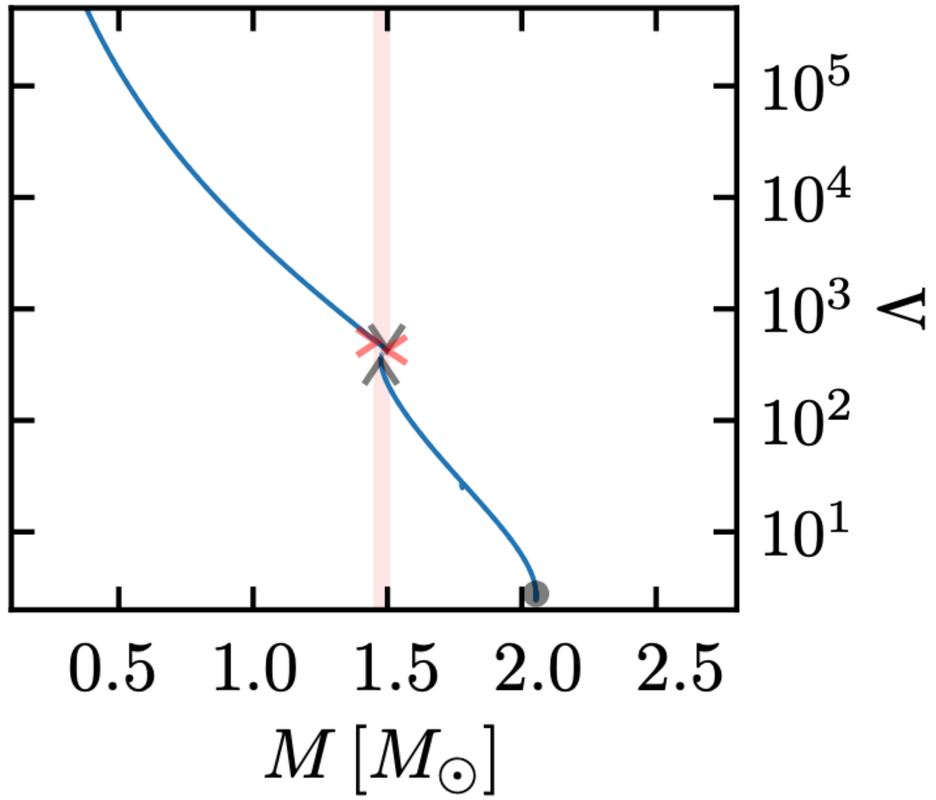
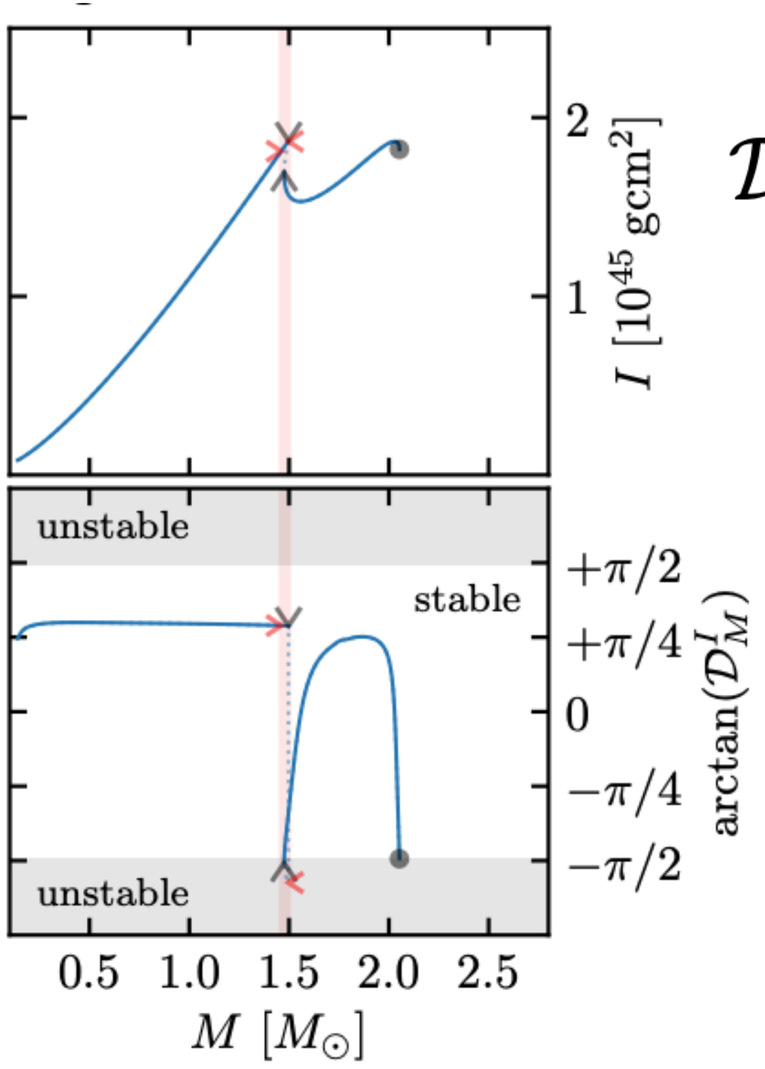




Features in Moment of Inertia:

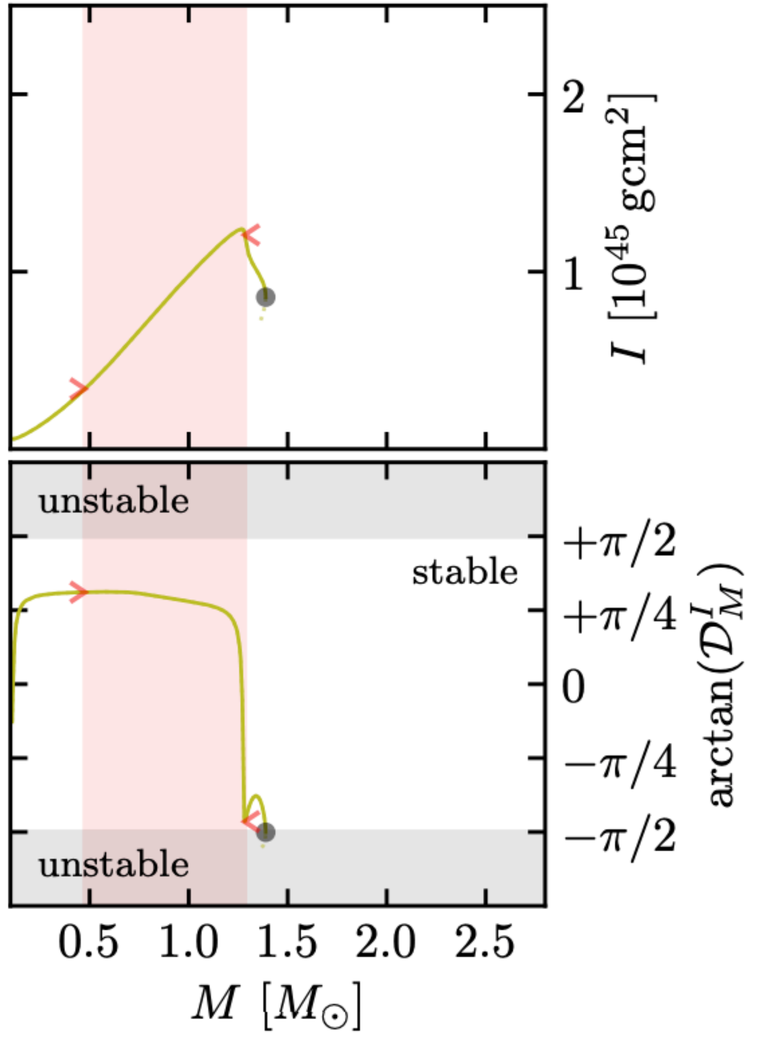


$$\mathcal{D}_M^I \equiv \frac{d\log I/d\log p_c}{d\log M/d\log p_c}$$

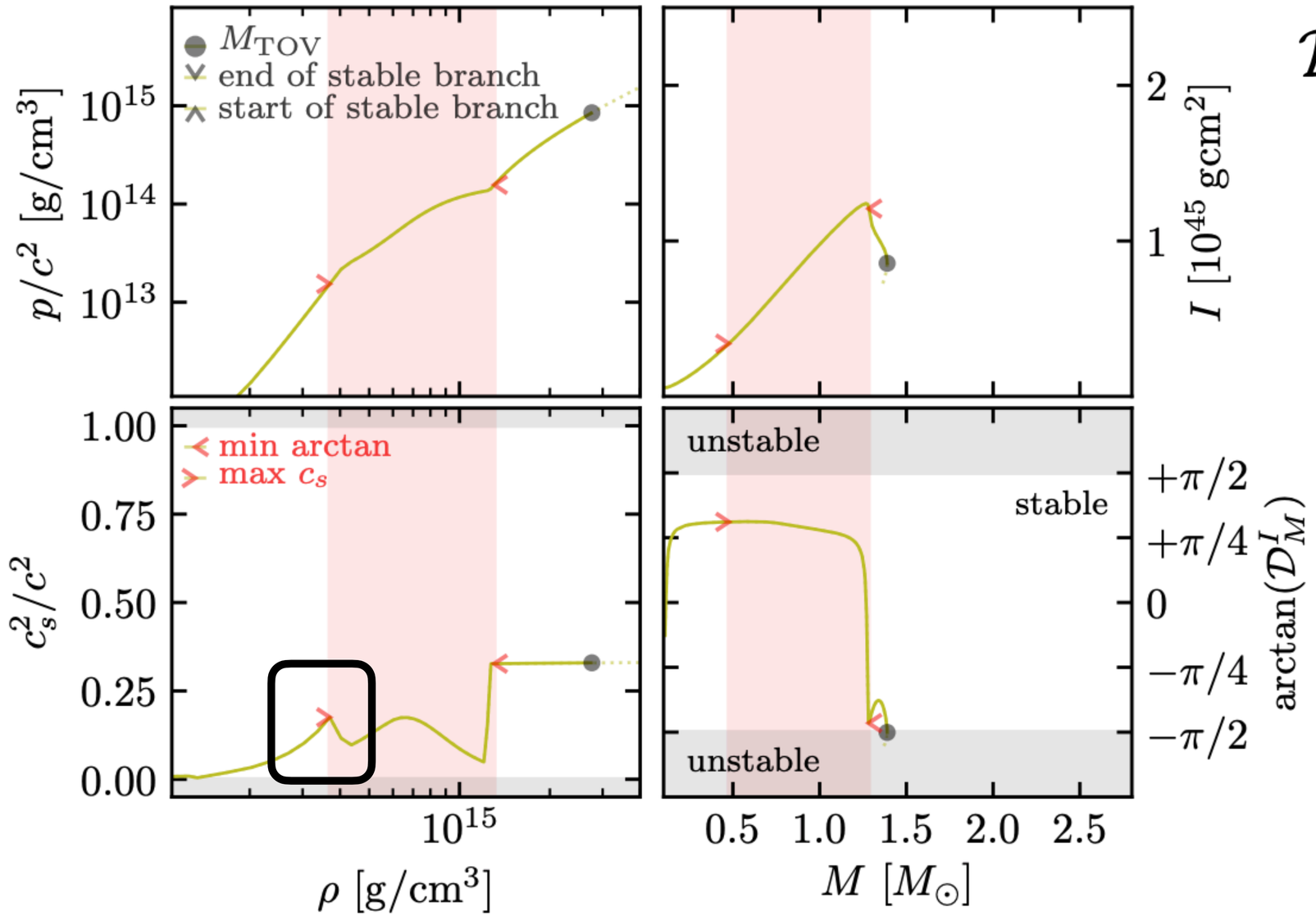
Look for a minimum in the derivative of the moment of inertia

Minimum Exists => Phase Transition exists

Minimum Location => End of Phase Transition



Identifying the Onset



$$\mathcal{D}_M^I \equiv \frac{d\log I/d\log p_c}{d\log M/d\log p_c}$$

$$c_s^2 = \frac{dp}{d\epsilon}$$

Look for *running maximum* in speed of sound

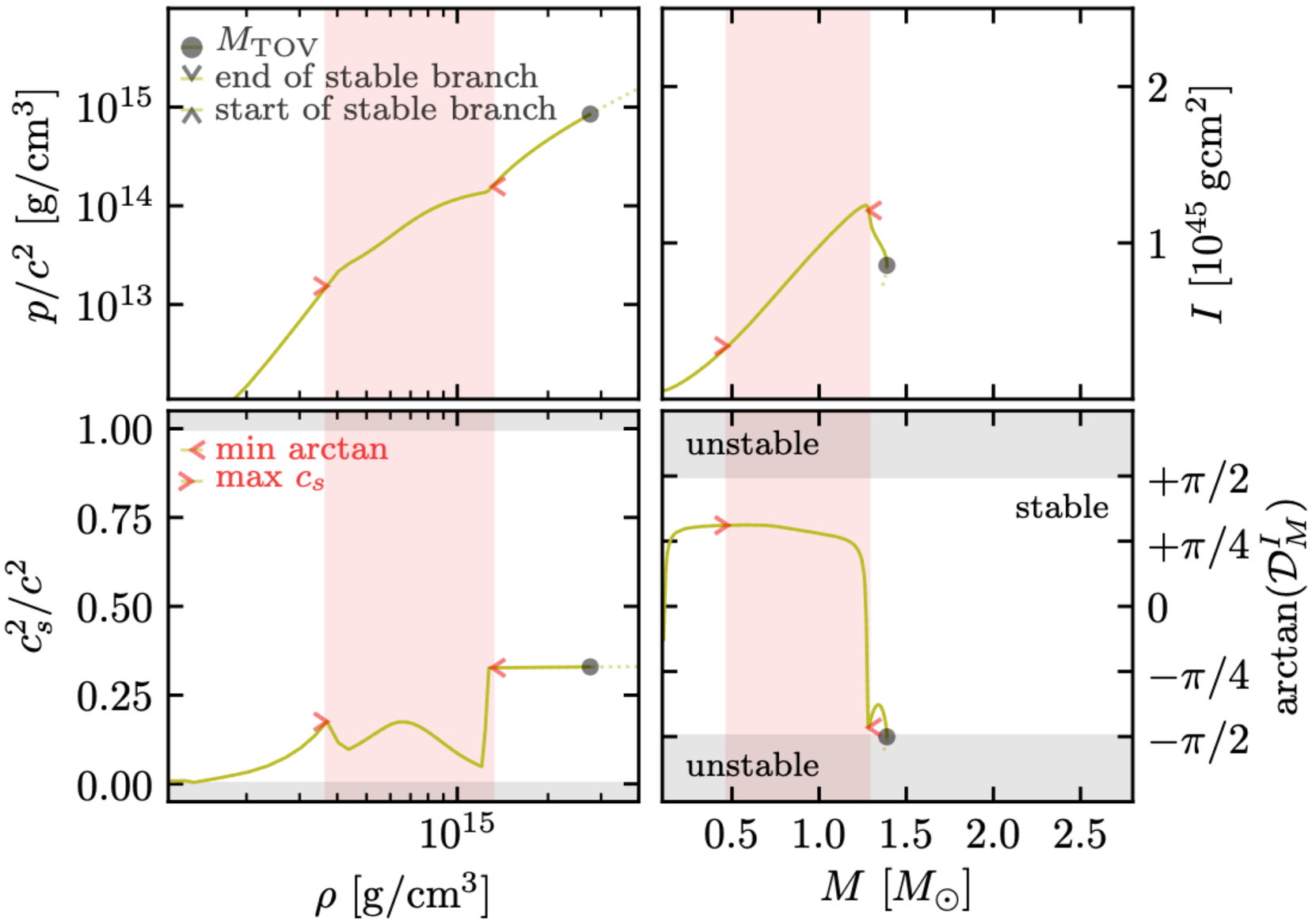
Algorithm

(1) Identify a minimum in MOI derivative (end of transition)

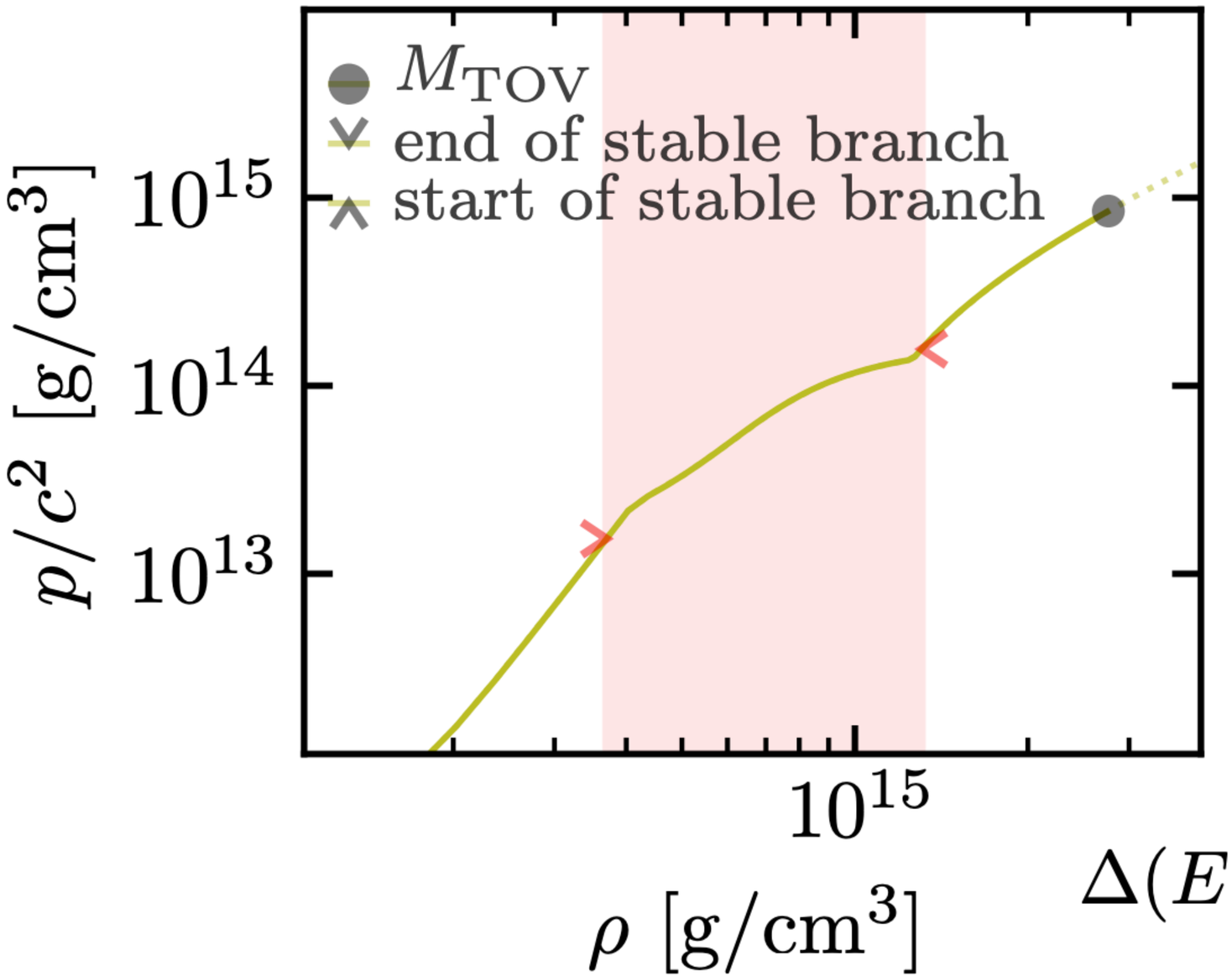
(2) Identify the global maximum in the speed of sound up to that density

(3) Check certain criteria

(4) If all criteria are satisfied accept running maximum



PT parameters



Can now “extract” PT parameters

$p_{\rm onset}$ $p_{\rm end}$

$\rho_{\rm onset}$ $\rho_{\rm end}$

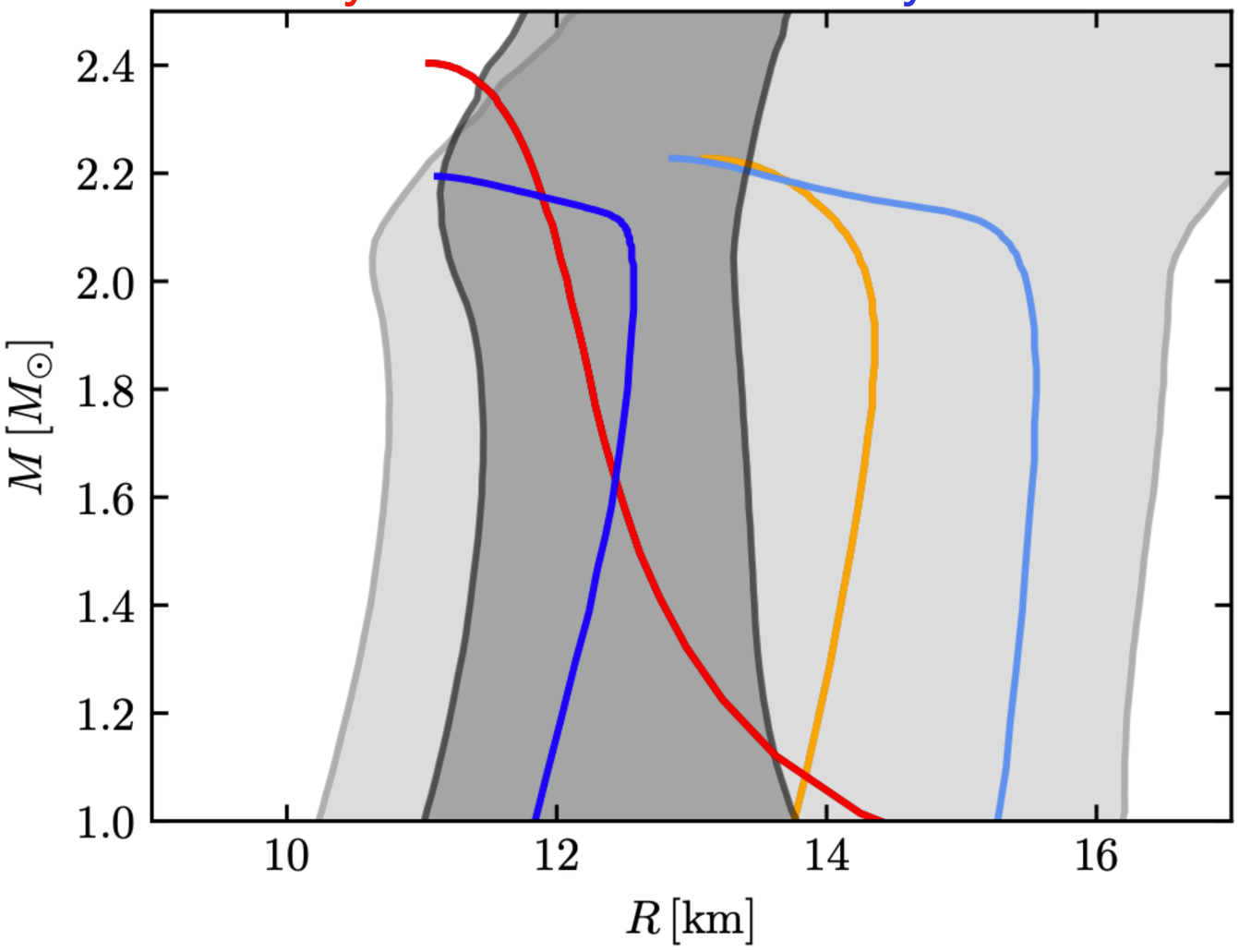
$M_{\rm onset}$ $M_{\rm end}$

Quantify the strength of transition

$$\Delta(E/N) \equiv \left(\frac{\varepsilon}{n}\right)_{\rm end} - \left(\frac{\varepsilon}{n}\right)_{\rm onset}$$

Inference - Search

Most likely - no PT Most likely - w/ PT



PSR

PSR: $\Delta(E/N) \leq 10\,\mathrm{MeV}$

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PGX

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Can we distinguish EoSs with phase transitions in data?

Inference - Search

$1.1 - 1.6 M_\odot$

$\mathcal{D}_M^I$ Features

No evidence against “weak” transitions

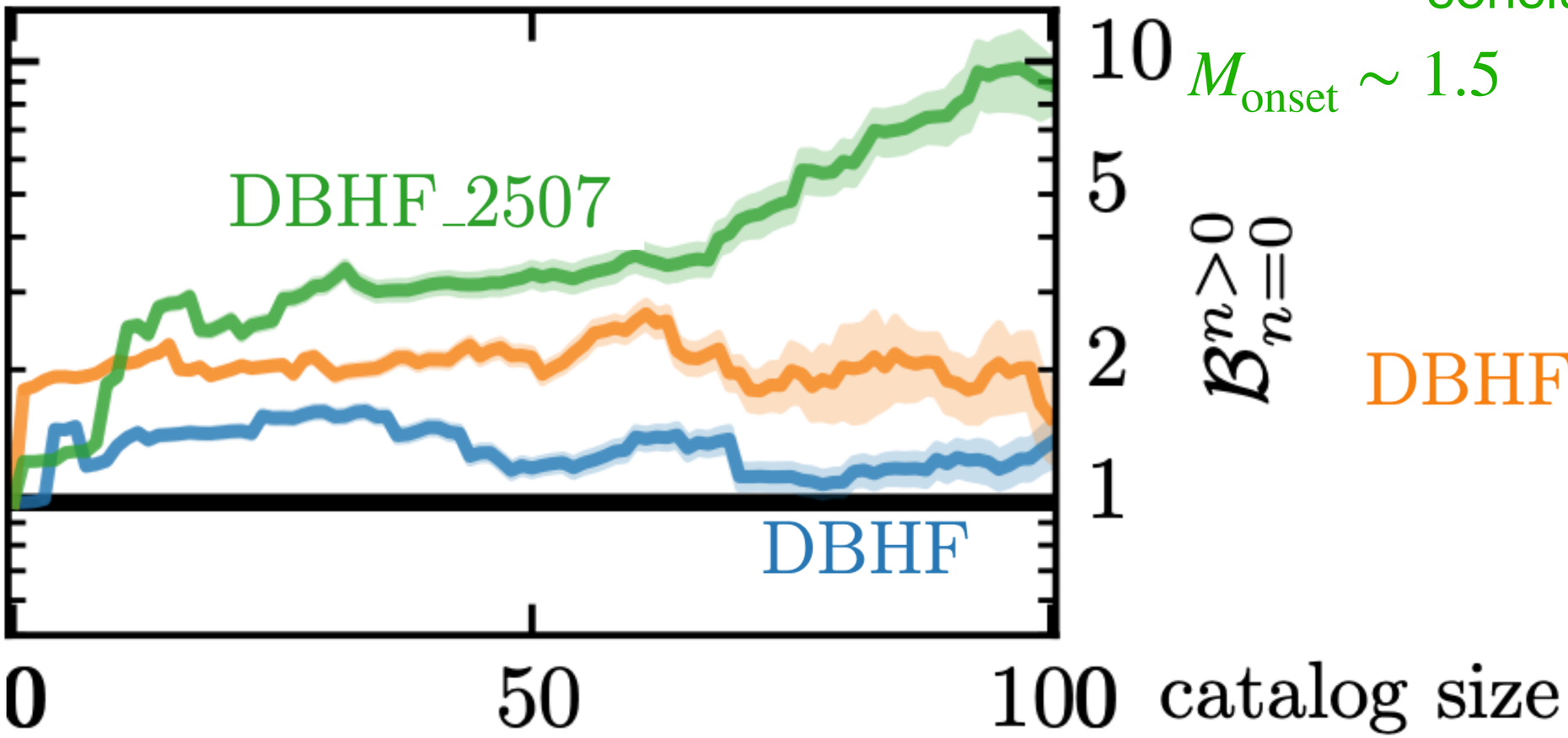
$\min \Delta(E/N)$ [MeV]	$\max \mathcal{L}_{n=0}^{n>0}(\mathrm{PGX})$	$\mathcal{B}_{n=0}^{n>0}(\mathrm{PGX})$
10	0.57	1.043 ± 0.020
50	0.49	0.463 ± 0.013
100	0.26	0.152 ± 0.009

Some evidence against strong transitions

Inference - Search (Injections)

$\Delta(E/N) > 50\,\mathrm{MeV}$ $1.1 - 1.6 M_\odot$

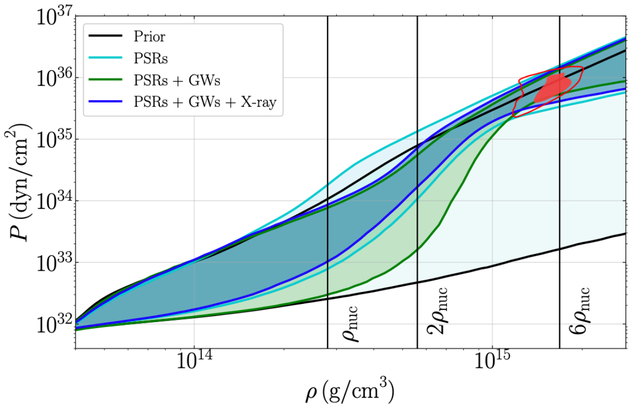
100 GW Events ->
Injected EoS w/ PT =>
Some evidence (not conclusive)



$M_{\mathrm{onset}} \sim 1.5$

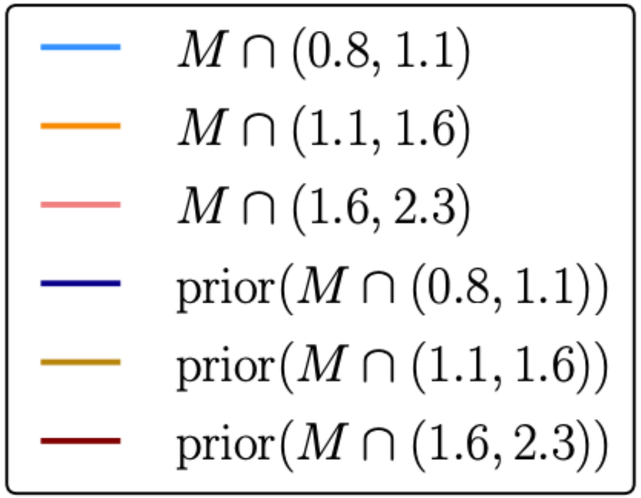
DBHF_3504

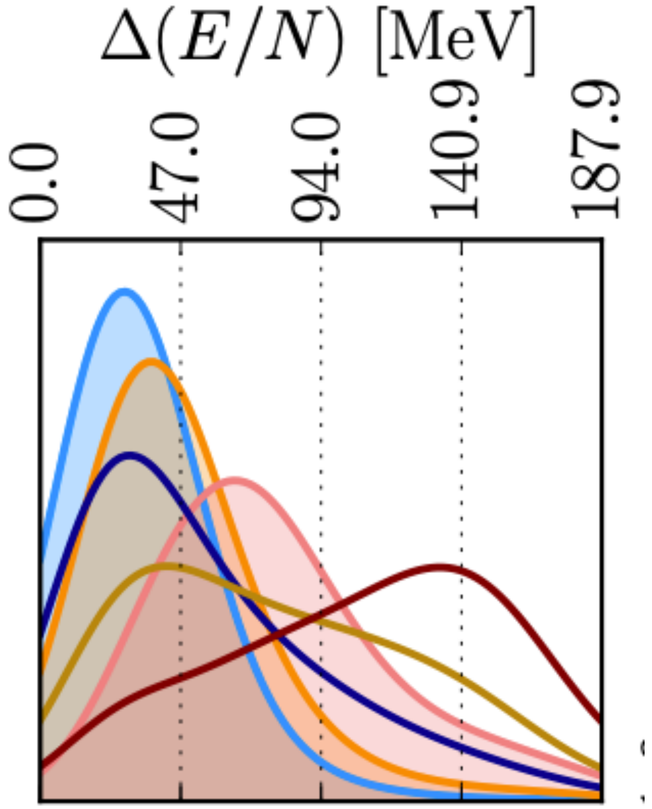
Inference - Characterization



Distribution on EoSs

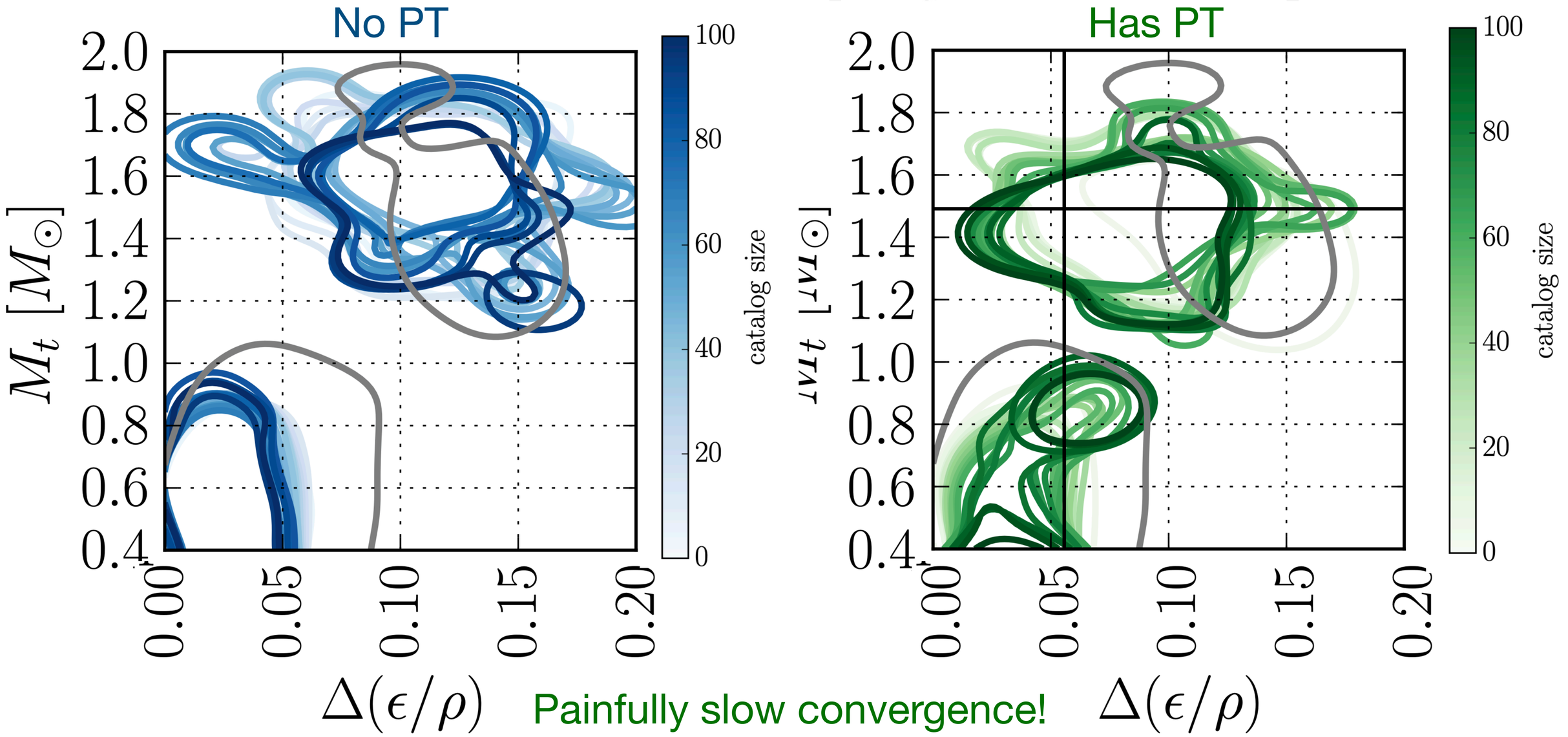
Feature Extraction





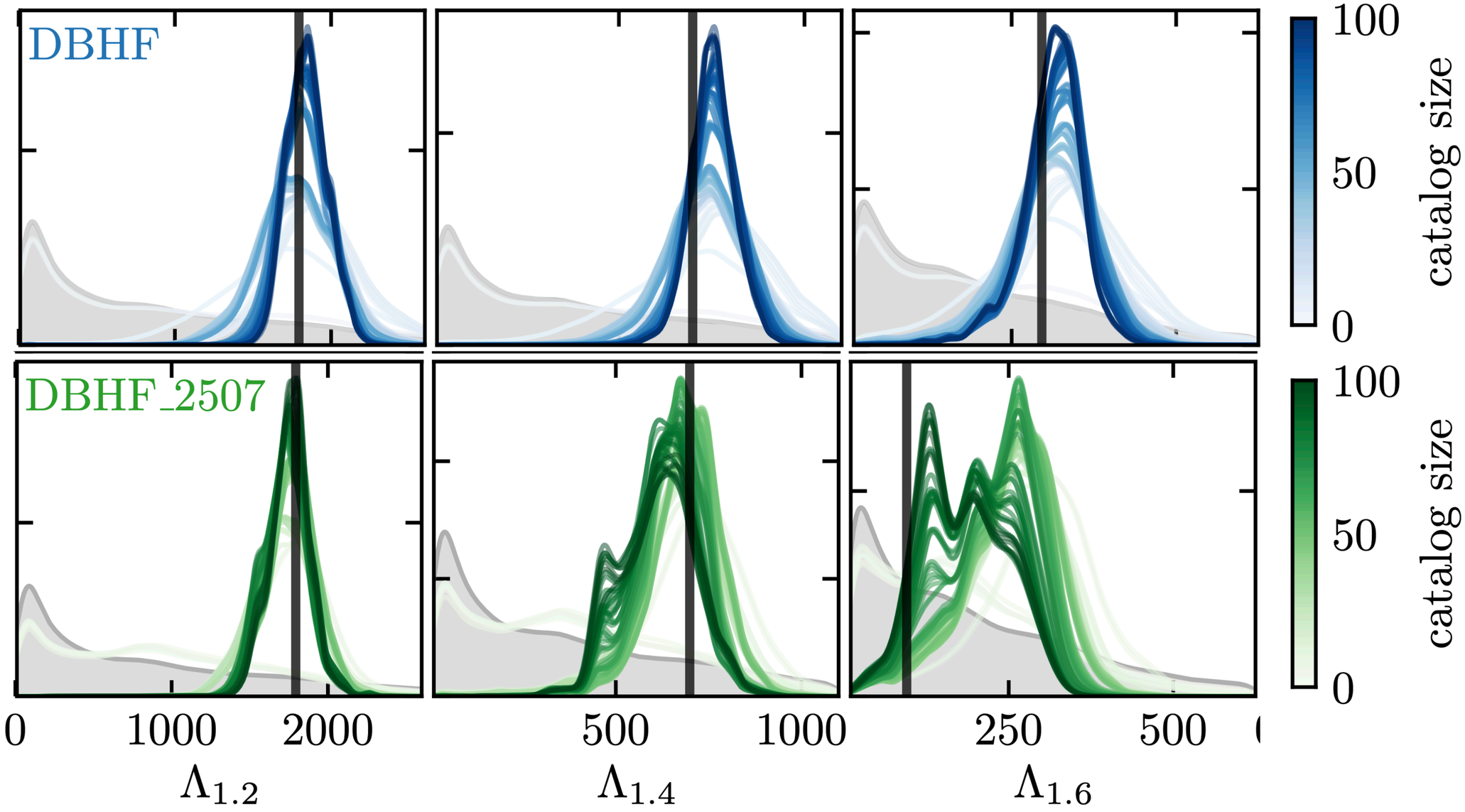
Distribution on PT parameters

Characterization (Injections)



Painfully slow convergence!

What can we measure?



Conclusions:

- We have developed a phenomenoligical scheme to extract PTs from arbitrary EoSs
- We can use this to constrain the parameters of a real PT inside neutron stars
- GWs will be effective probe of tidal parameters at A+ senstivity
- LIGO GWs likely not informative enough to settle PT question
- Future work includes better prior specification