Impact of hyperons on neutron star mergers: Gravitational waves, mass ejection and black hole formation

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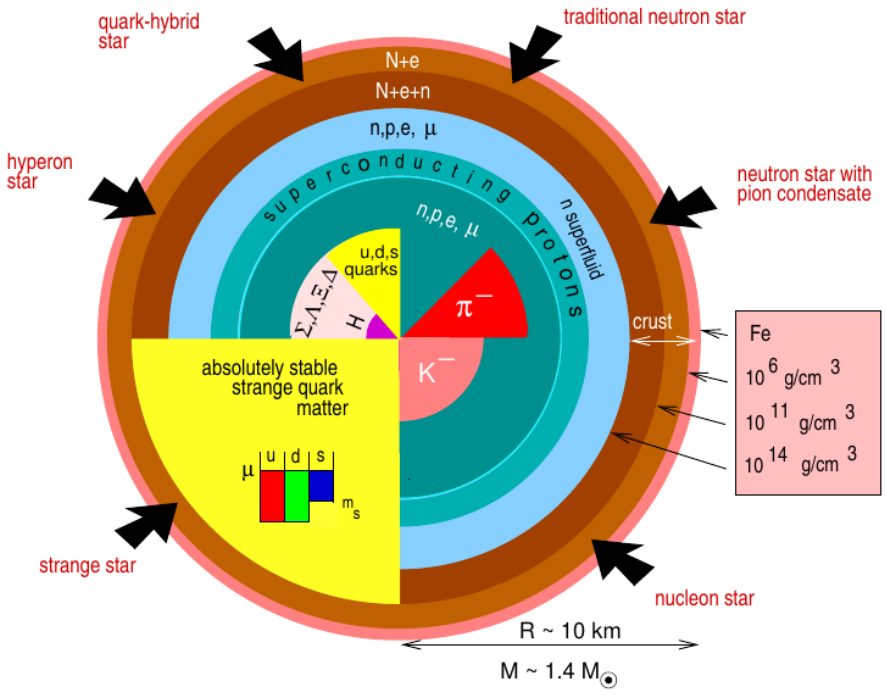
Neutron stars

- Masses: ~1-3 $M_\odot$
- Radii: ~10-15 km
- Central density a few times nuclear saturation density $\rho_{sat} = 2.7 \times 10^{14}$ g cm^{-3}
  → high density equation of state (EoS) partially unknown hence we rely on different models for the EoS

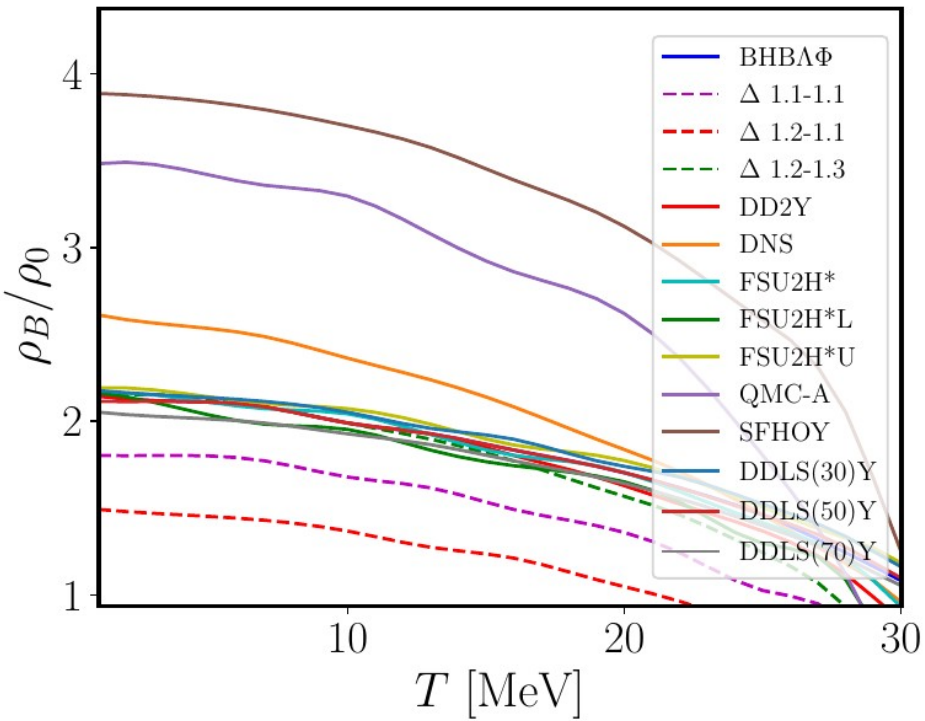
- Very compact: General relativity needed



Weber 2001 (JPG)

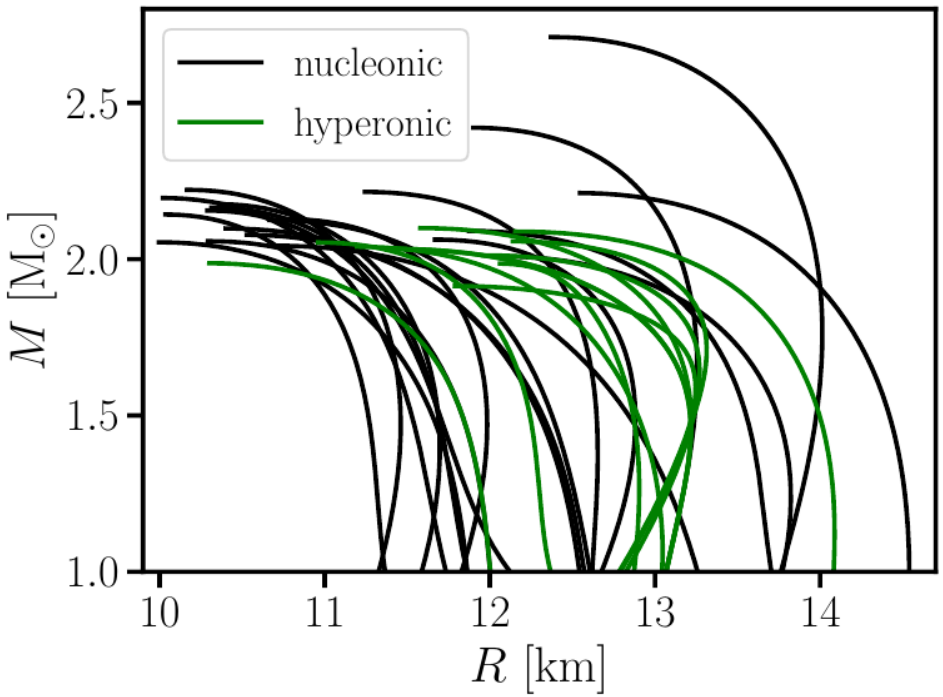
The hyperon problem

Hyperon onset density



Kochankovski et al 2025 (PRD)

Hyperonic and nucleonic EOSs produce similar cold static stars!

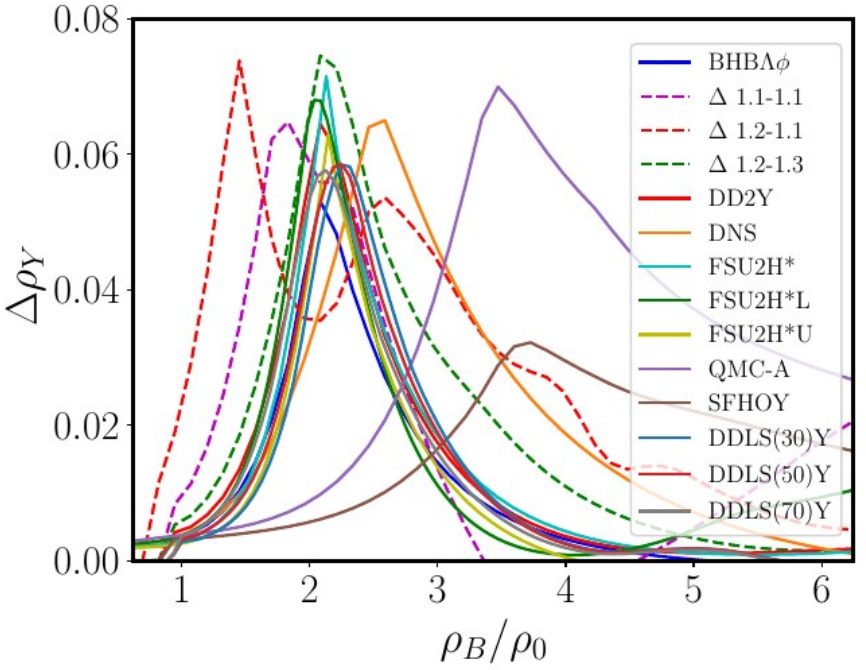


Blacker et al 2024 (PRD)

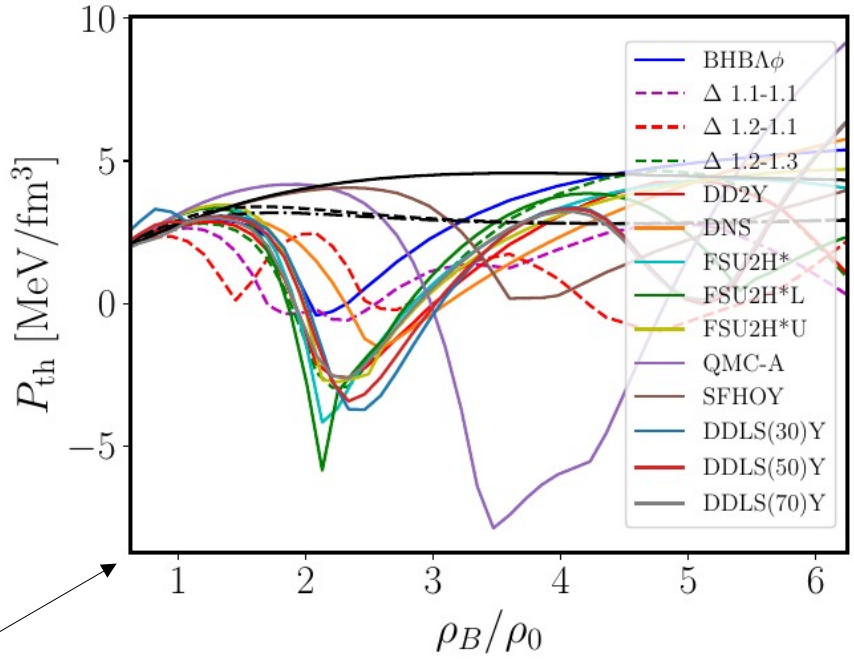
Hyperonic EOS properties

Hyperon abundance

$$\Delta\rho_Y = \frac{\sum_{Y_i}(\rho_{Y_i}(T,\rho_B,Y_Q) - \rho_{Y_i}(0,\rho_B,Y_Q))}{\rho_B}$$



Thermal pressure P_{th}

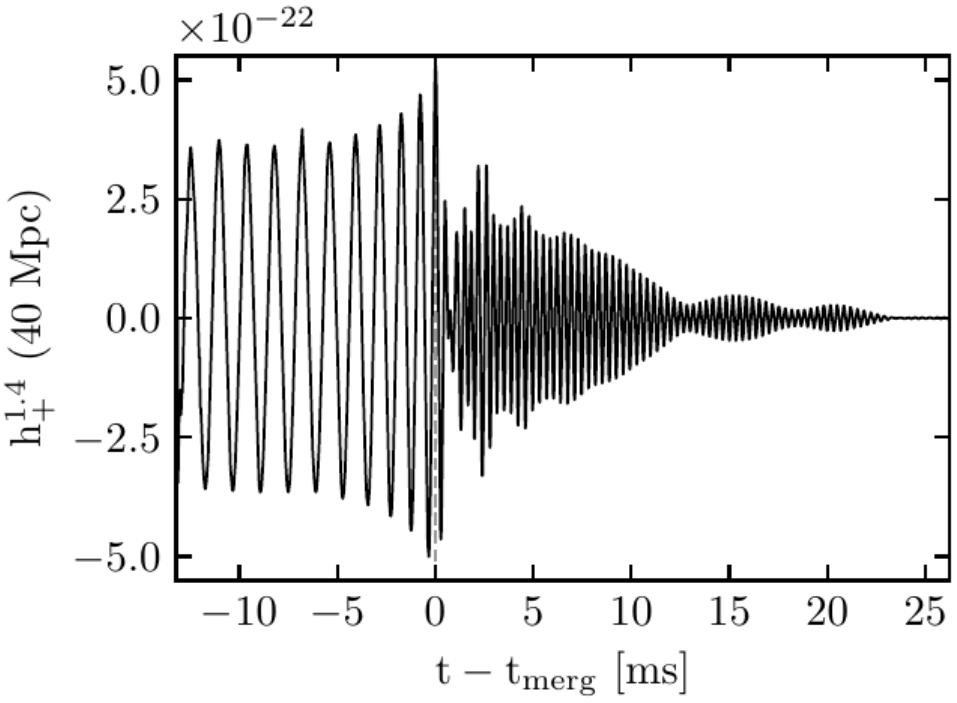


T=25 MeV, Y_Q=0.1

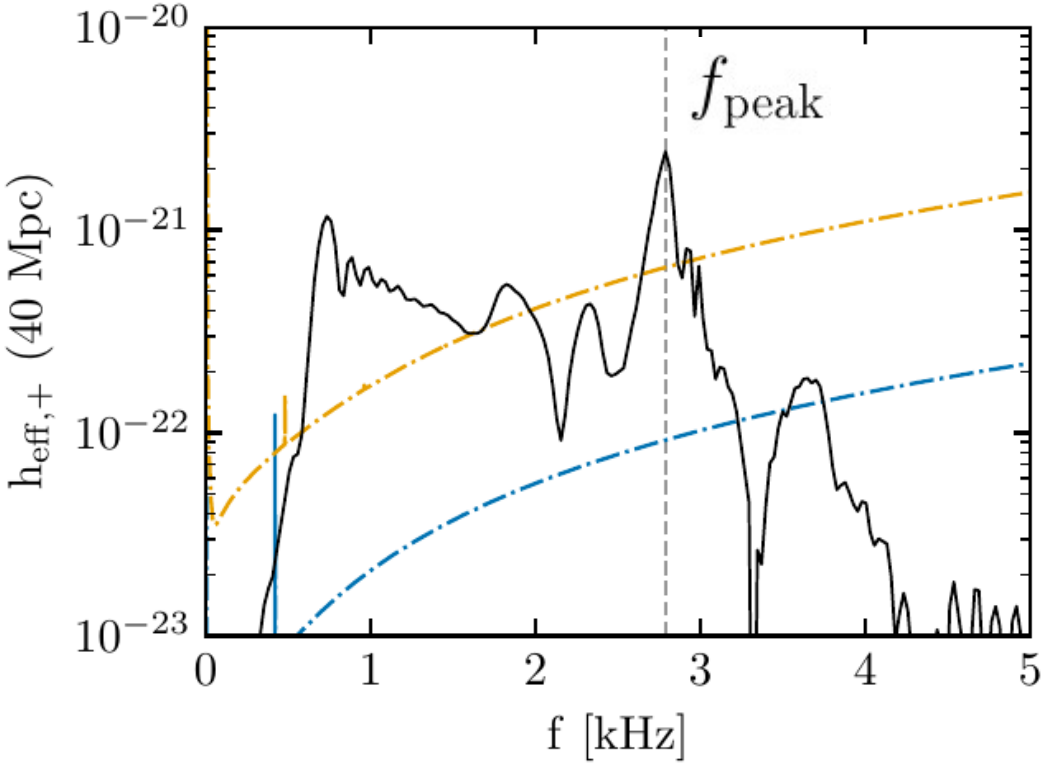
Kochankovski et al 2025 (PRD)

Gravitational waves (GWs)

GW signal

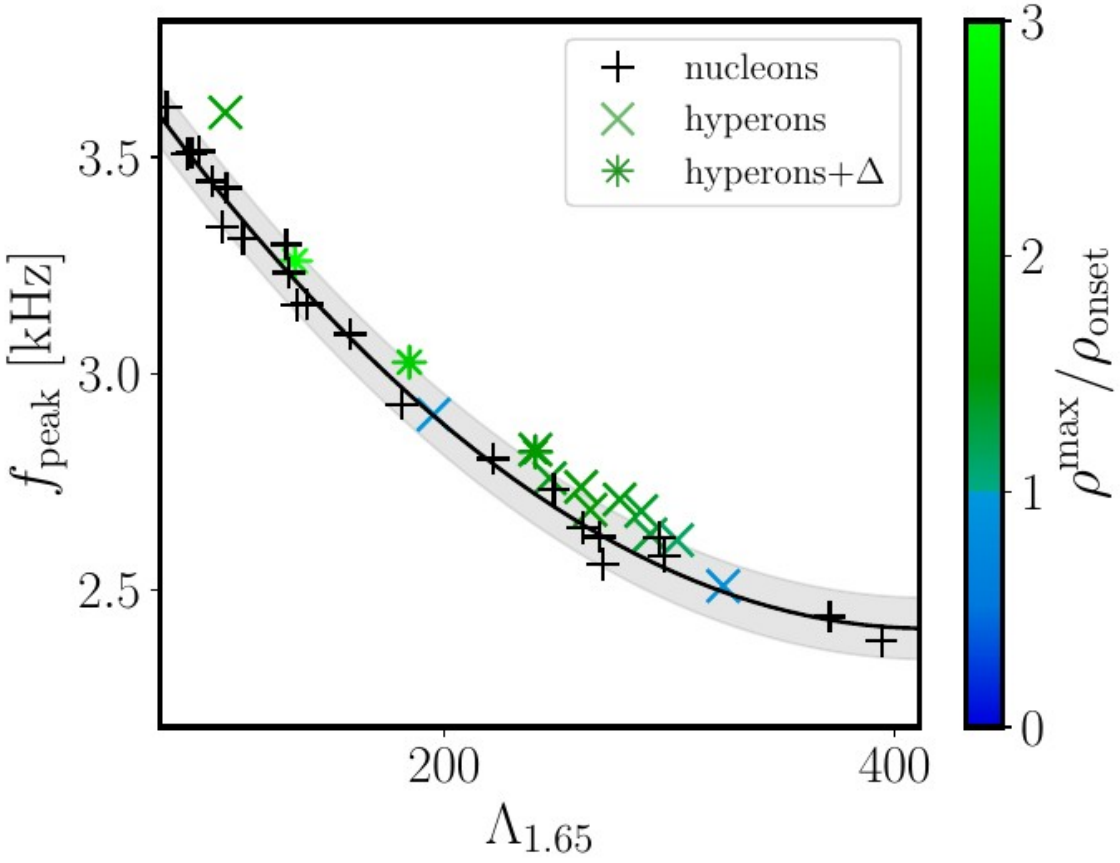


GW spectrum



Scenario 1: How to find hyperons through GWs

1.4-1.4 $M_\odot$ BNS systems



Kochankovski et al 2025 (PRD)

$f_{\rm peak}(\Lambda_M)$ based on nucleonic models, but differently sensitive to hyperons

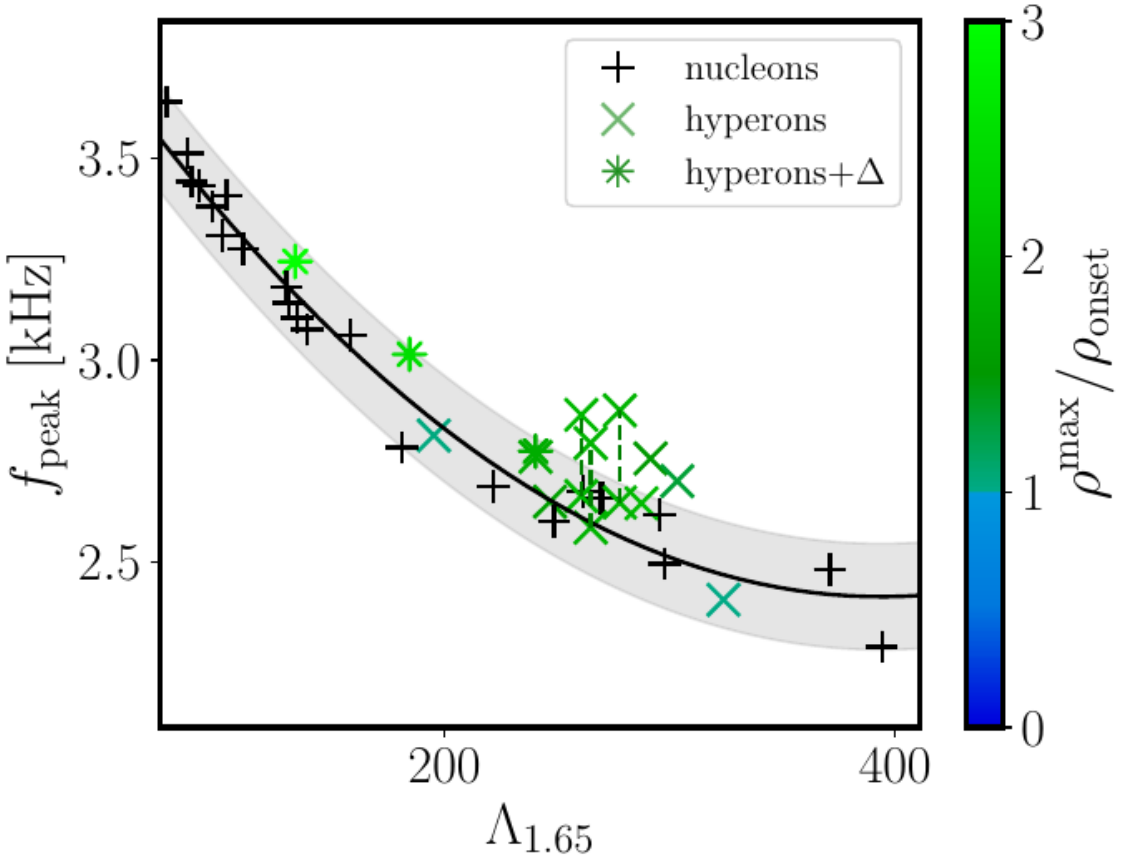
Grey band wrt frequencies:

- Maximum deviation (yes)
- Simulation effects (~yes)
- Observation accuracy (no)

Observation outside of band as indication of hyperons

Note: Potentially difficult to measure, not necessarily unique hyperon signature

Unequal mass binaries



Kochankovski et al 2025 (PRD)

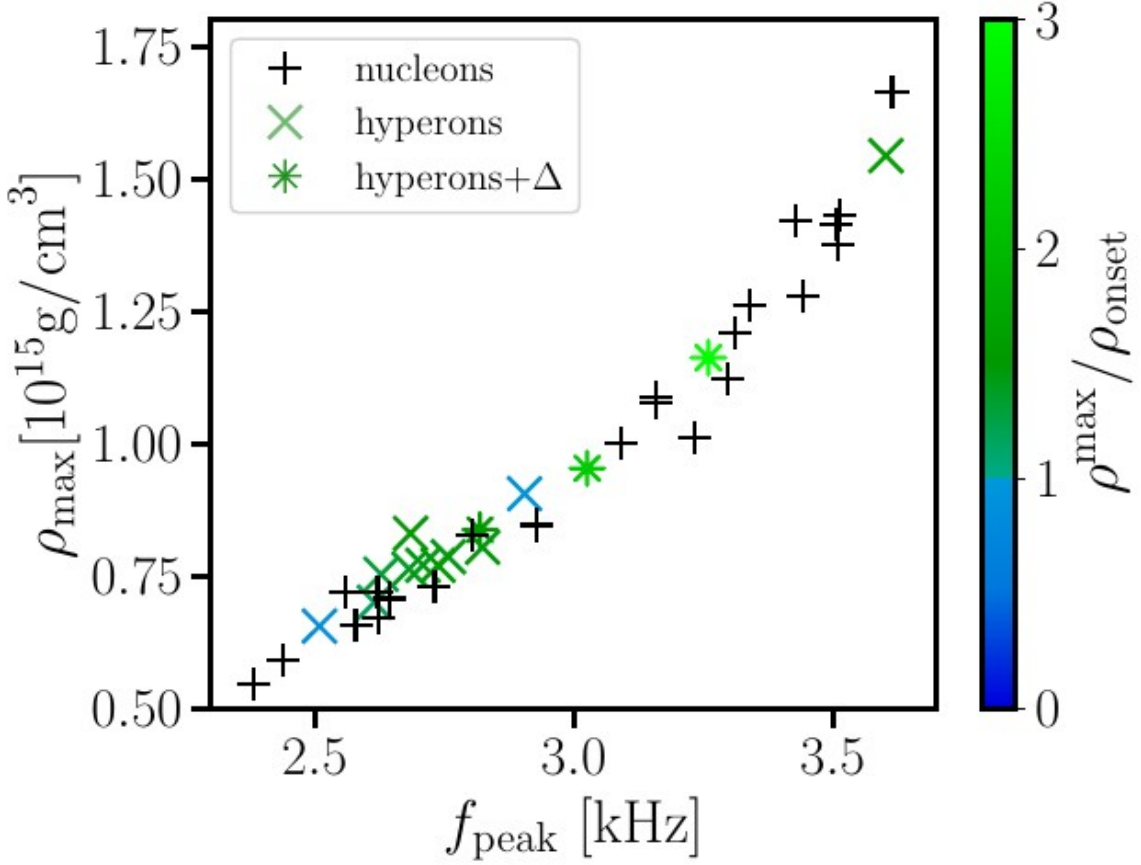
Binary systems with unequal mass companion stars:

- $q = M_1/M_2 = 0.8$
- $M_{\rm tot} = M_1 + M_2 = 2.8\ M_\odot$

More pronounced effect due to higher hyperonic content

Similar effect for more massive binary systems

Constraints on onset density



Kochankovski et al 2025 (PRD)

$\rho_{\rm max}(f_{\rm peak})$ relation based on simulations

Use:
Observational indication of hyperons

↓

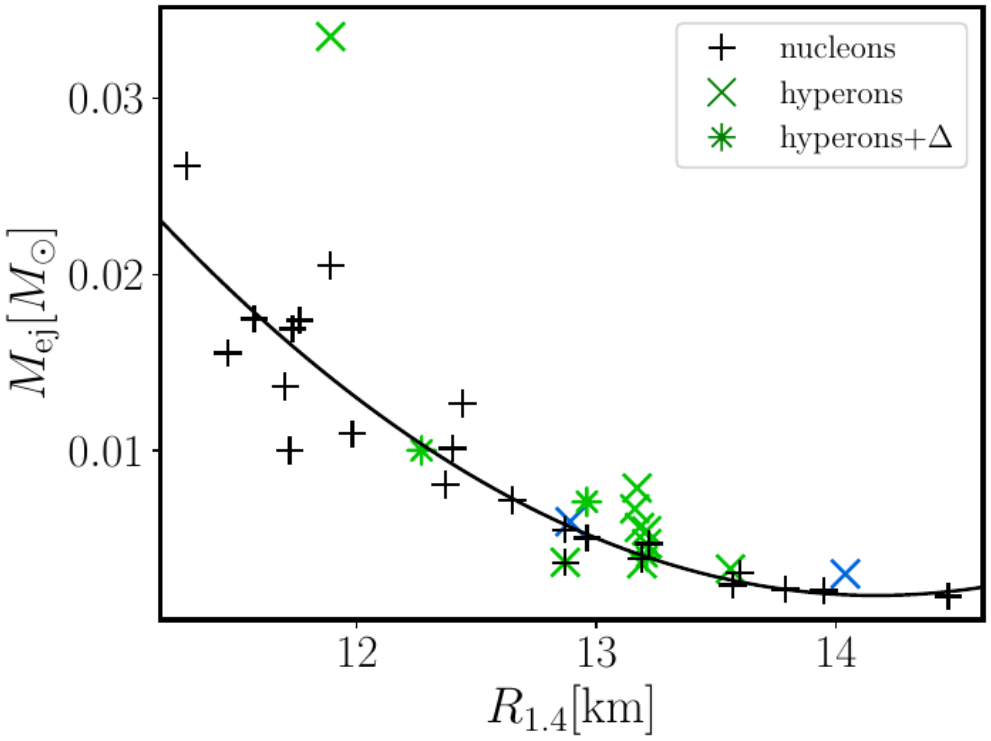
$\rho_{\rm max}$ upper limit on $\rho_{\rm onset}$

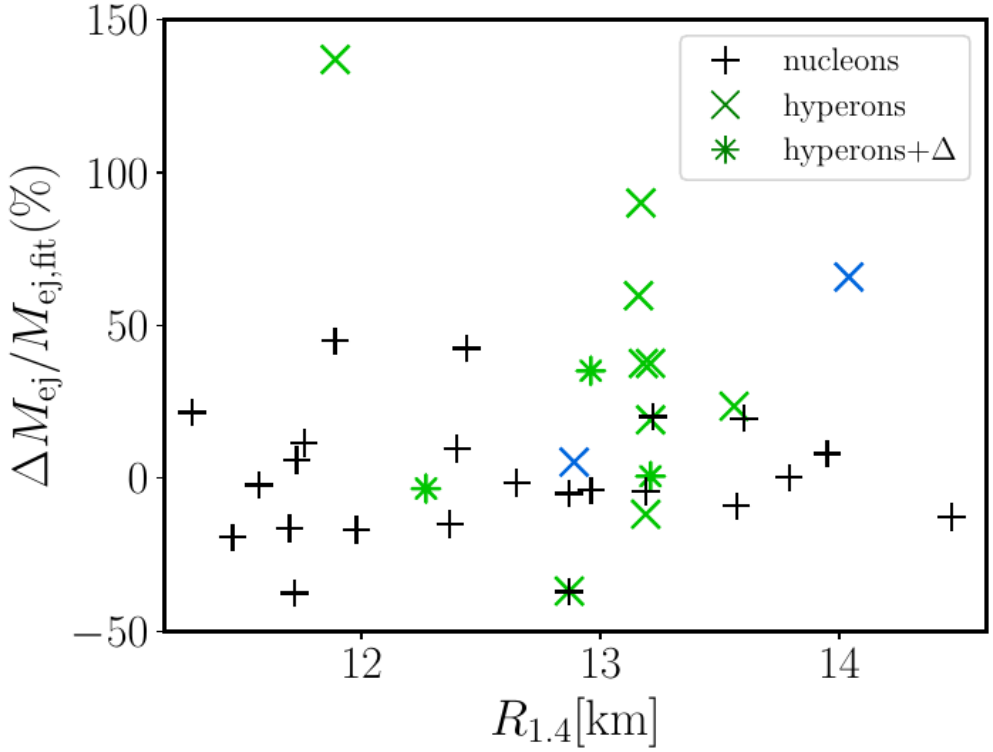
Note:
Shown 1.4-$1.4\ M_\odot$ systems, but the relation is insensitive to total mass

Effect of hyperons on amount of ejecta

Increase of early dynamical ejecta up to ~2x w.r.t. purely nucleonic models

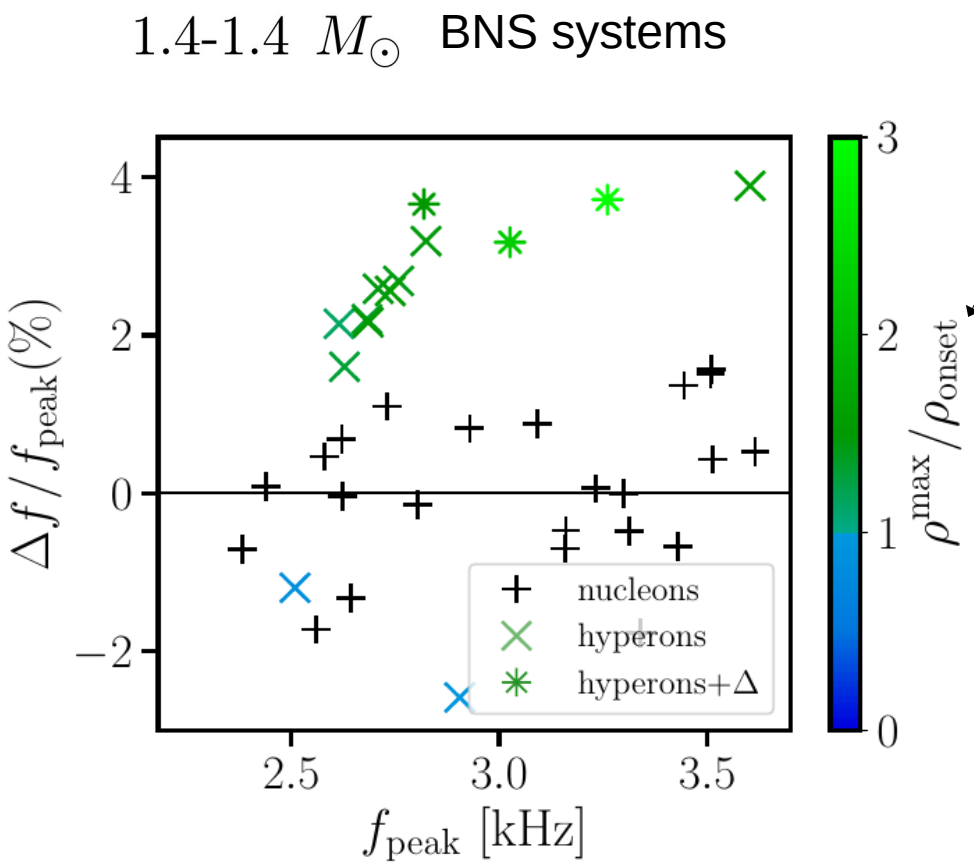
Relevance: Matter that becomes gravitationally unbound; relevant for heavy element nucleosynthesis; shapes EM emission





Kochankovski et al 2025 (PRD)

Scenario 2: Gravitational wave frequency shift



T=0.1 MeV

Different thermal treatments:

-Recipe 1: $p = p(\rho, T, Y_q)$

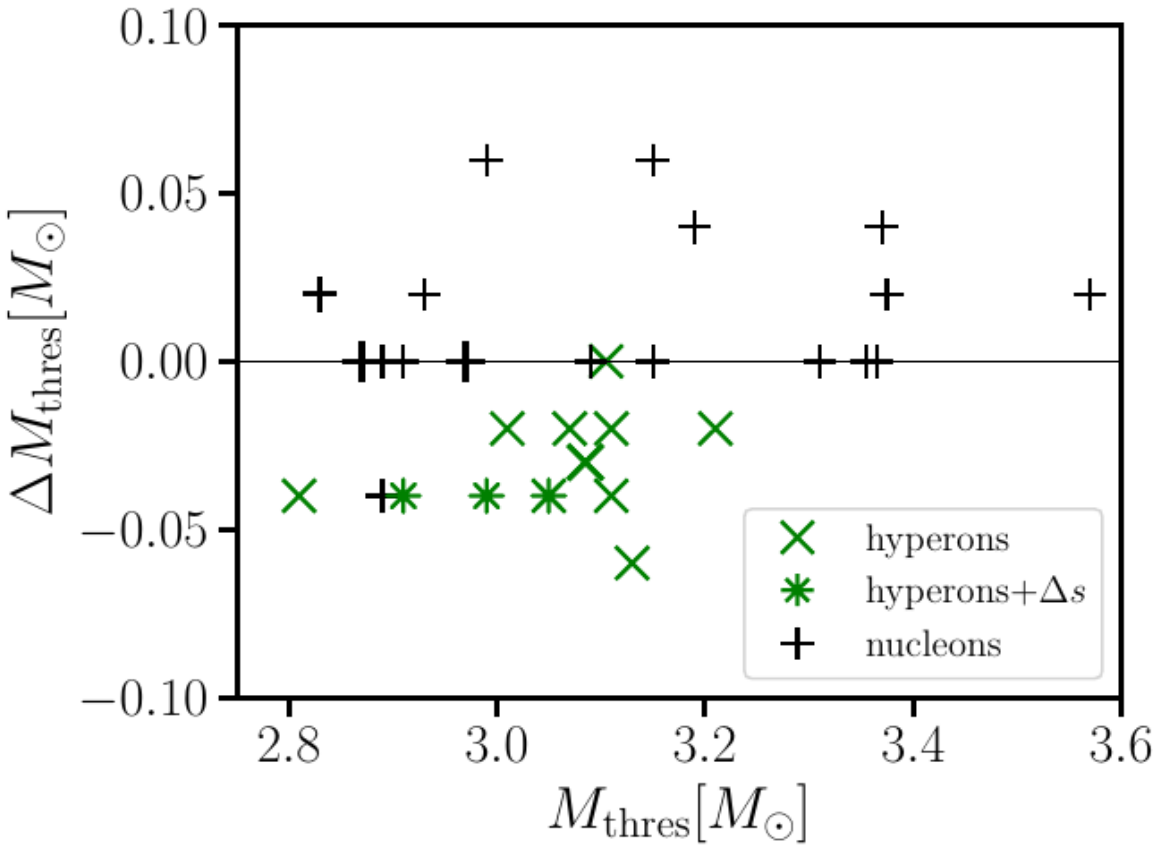
-Recipe 2: $p = p_{COLD}(\rho) + (\Gamma_{th}-1) \times \rho \times [\epsilon-\epsilon_{COLD}(\rho)]$

Γ_{th}=1.75 emulates nucleonic thermal behavior

$\Delta f = f_{\rm peak} - f_{\rm peak}^{1.75}$ as indicator of hyperons

Kochankovski et al 2025 (PRD)

Threshold mass



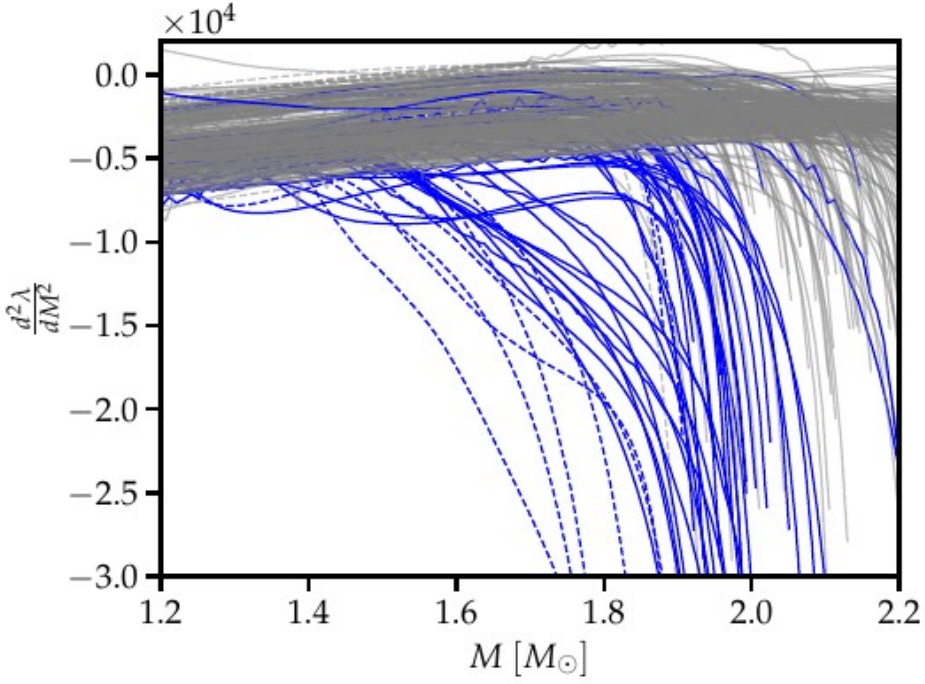
$$\Delta M_{\rm thres} = M_{\rm thres} - M_{\rm thres}^{1.75}$$

- Threshold mass to prompt collapse to black hole
- Comparison to Γ_{th} recipe for thermal effects
- Can help identify hyperons compared to a nucleonic EOS with similar cold behavior

Kochankovski et al 2025 (PRD)

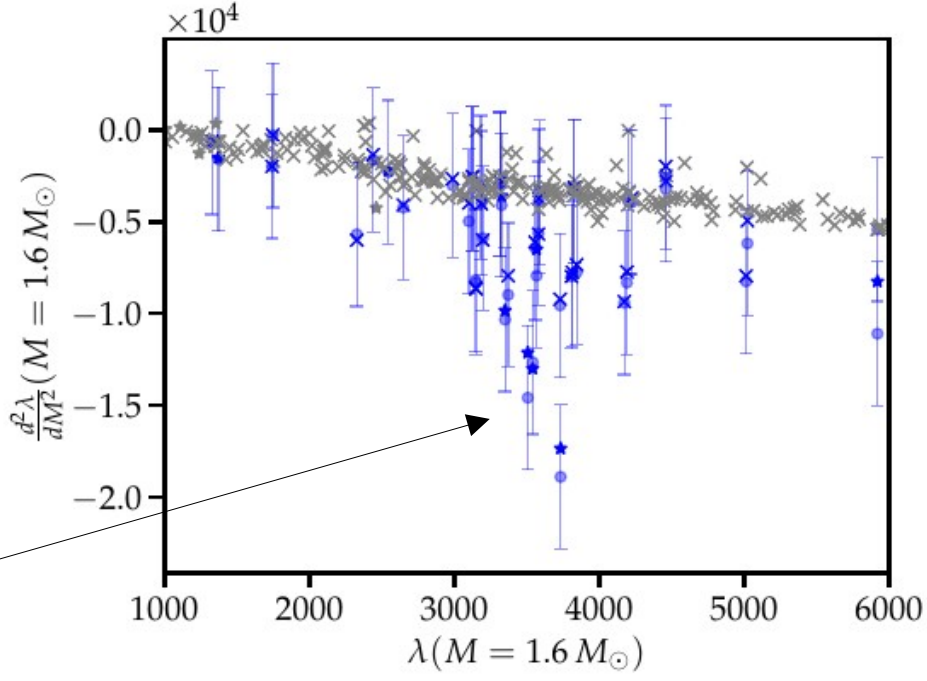
What about single NS measurements?

Tidal deformability $\lambda = \frac{2}{3} k_2 R^5$



Bauswein et al 2025 (Arxiv)

Values computed based on 3 (λ,M) observations, with ΔM=0.25 and δλ=100



For roughly half hyperonic EoSs (all available) no overlap with nucleonic models

Summary

Neutron star merger remnants

- The thermal production of hyperons induces potentially measurable increase in the GW frequencies and ejecta masses and decrease in the threshold mass.
- The observed effects are not easy to detect and not necessarily unique to the occurrence of hyperons.
- More pronounced effects in higher total binary masses and unequal mass systems
- Stronger impact on secondary GW spectrum features ($f_{2\text{-}0}$) [not discussed]

Isolated neutron stars

- Softening of cold hyperonic EoS leaves imprint that can potentially be identified with 3 tidal deformability measurements at different masses

Thank you for your attention!