

# Strangeness in astrophysics: Theoretical developments



Veronica Dexheimer



# Neutron Star (NS) strangeness modeling

- ★ Hyperons included in NS modeling by Glendenning generating  $M_{\max} = 1.82 M_{\text{sun}}$

*Phys.Lett.B* 114 (1982) 392-396

- ★ Idea of strange quark stars introduced by Witten

R(km)	10.5	12.0	12.3	11.2	11.1
$M/M_{\odot}$	1.11	1.58	1.89	1.98	2.00

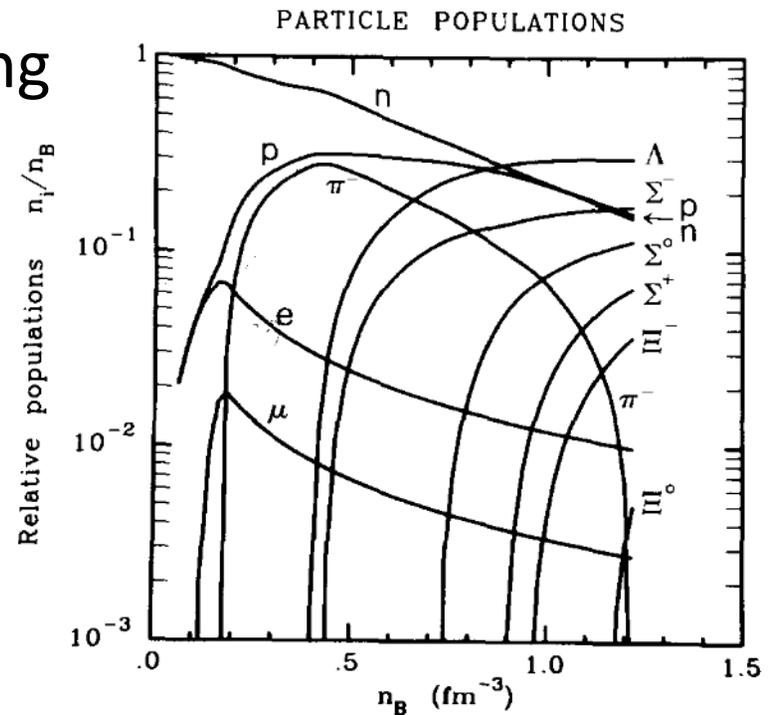
*Phys.Rev.D* 30 (1984) 272-285

- ★ Modeling of kaon condensation in neutron stars by Thorsson, Prakash, and Lattimer

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- ★ Negative parity strange states included in NS modeling by VD, Steinheimer and Schramm

*Phys.Rev.C* 87 (2013) 1, 015804



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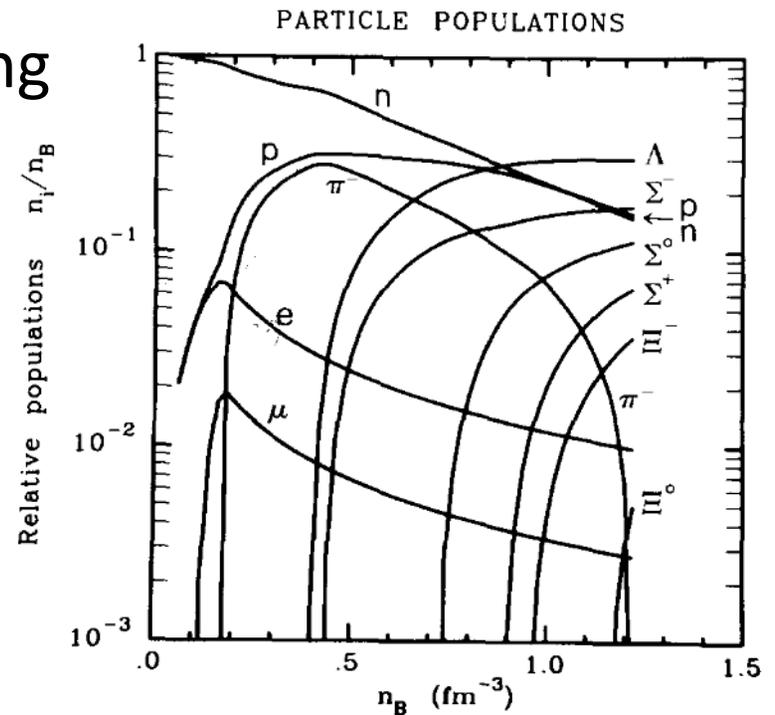
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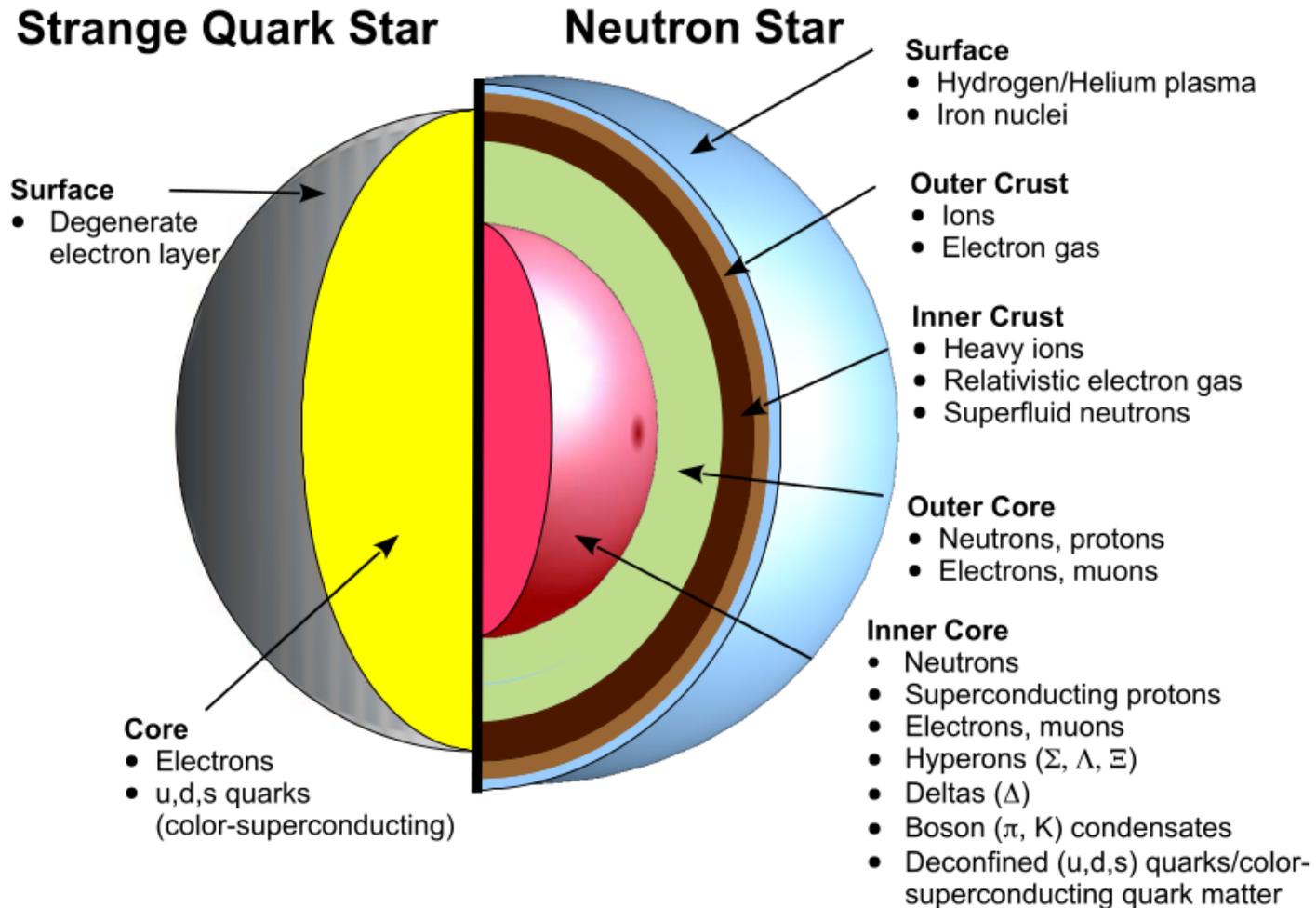
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# NS vs. Strange Quark Star structure

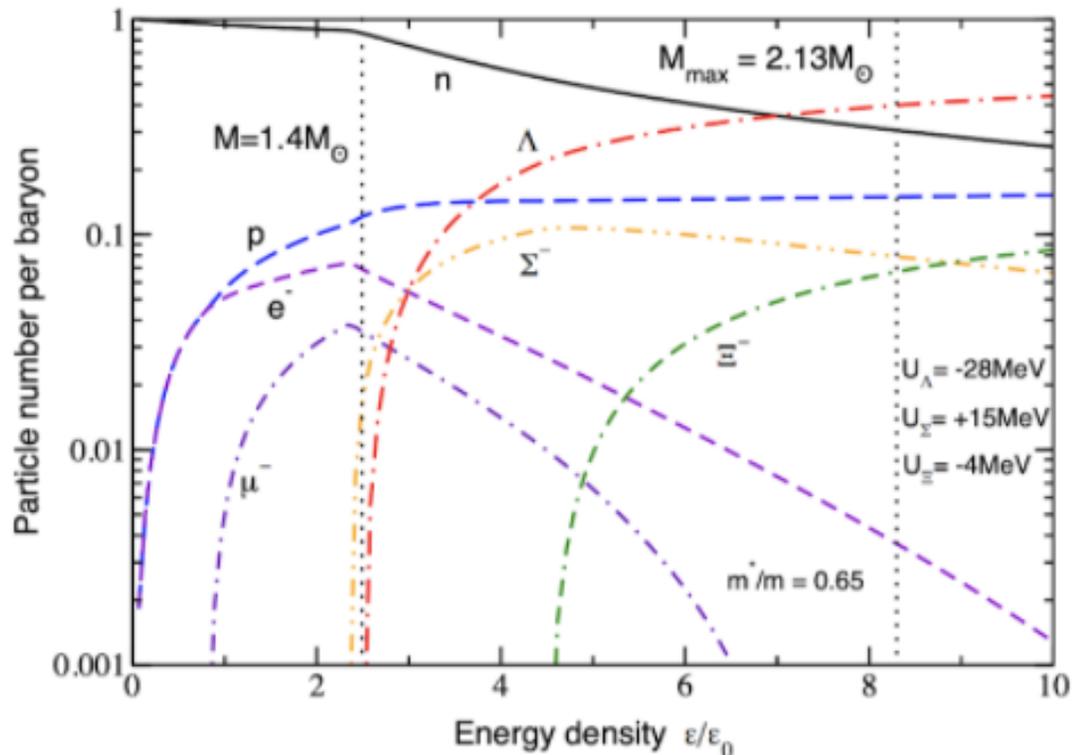


★ F. Weber, G. A. Contrera, M. G. Orsaria, W. Spinella, O. Zubairi

# Particle collision input

- ★ For the inner stellar core, hyperon potentials are the most important inputs
- ★ Using new Alice results from Fabbietti, Mantovani Sarti, and Vázquez Doce, Schaffner-Bielich [ArXiv:2012.09806](https://arxiv.org/abs/2012.09806) has shown that massive NS's are reproduced when isovector coupling is rescaled

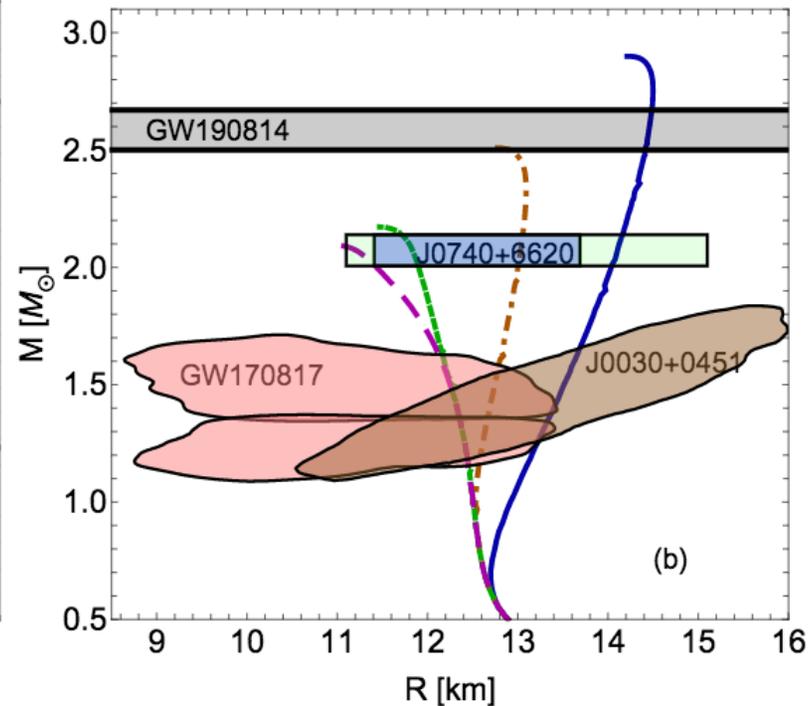
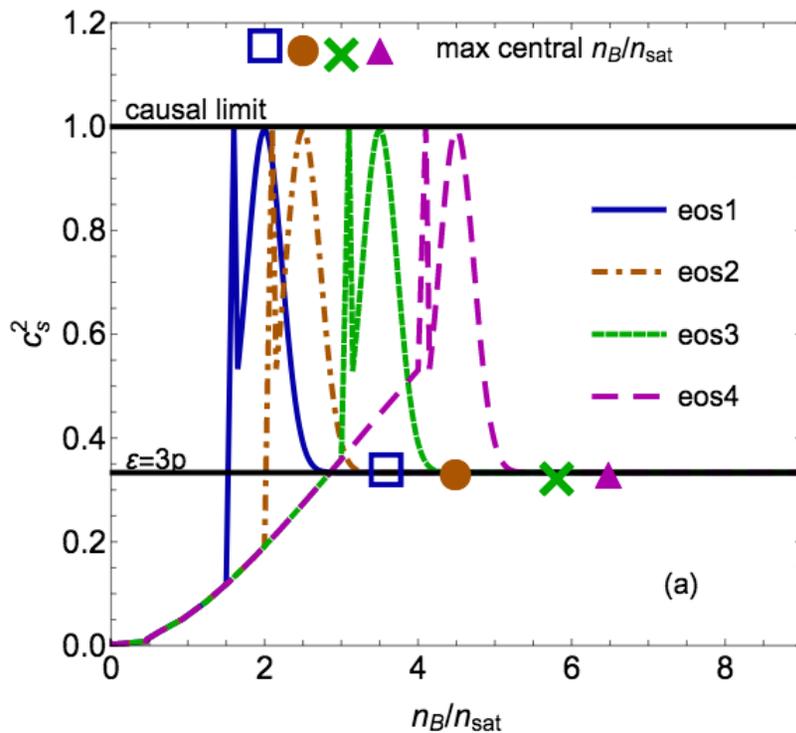
Phys.Rev.C 98 (2018) 6, 065804  
and  
Phys.Rev.C 85 (2012) 6, 065802



# Astrophysical input

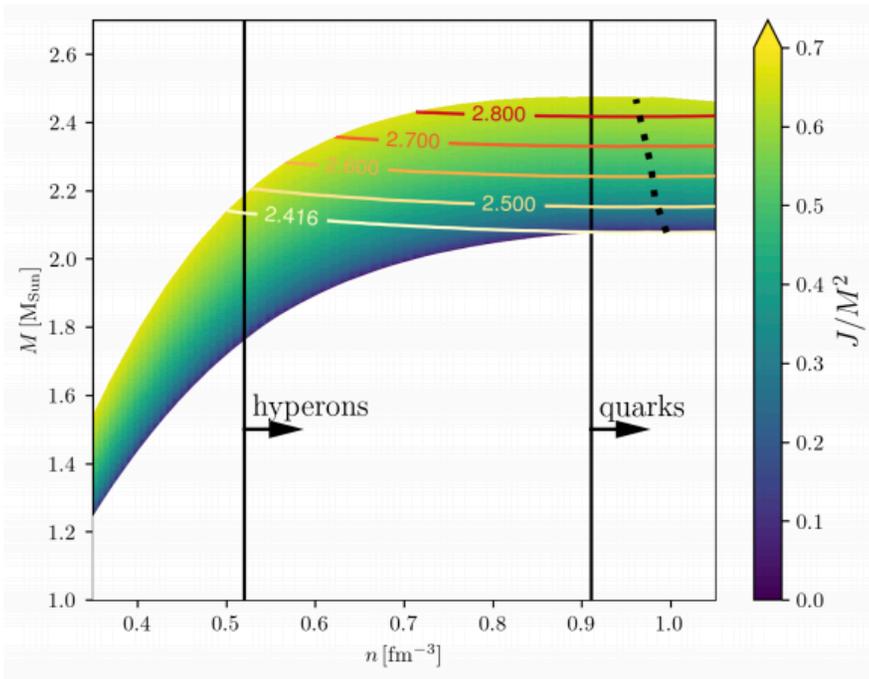
- ★ Lots of new NS data form NICER, LIGO/VIRGO, ...
- ★ But dips in the speed of sound (created when new degrees of freedom appear) are not excluded

Tan et. al in preparation

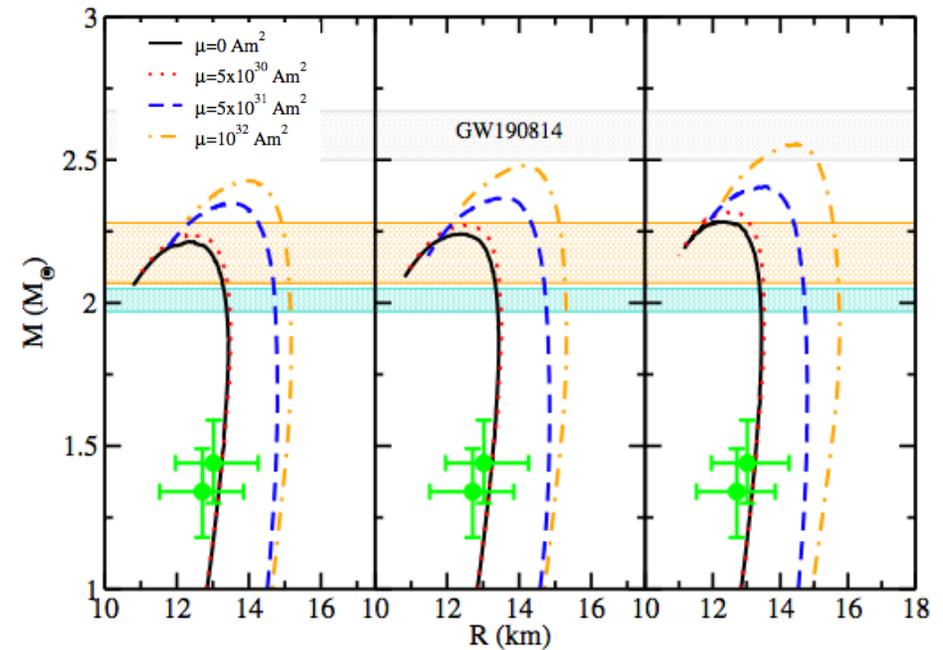


# GW 190814

- ★ Possibly most massive NS observed *Astrophys.J.Lett.* 896 (2020) 2, L44
- ★ Reproduced by nucleonic models and models with strangeness when rotation or magnetic fields are accounted for *Phys. Rev. C* 102, 065805 (2020)



*Phys.Rev.C* 103 (2021) 2, 025808



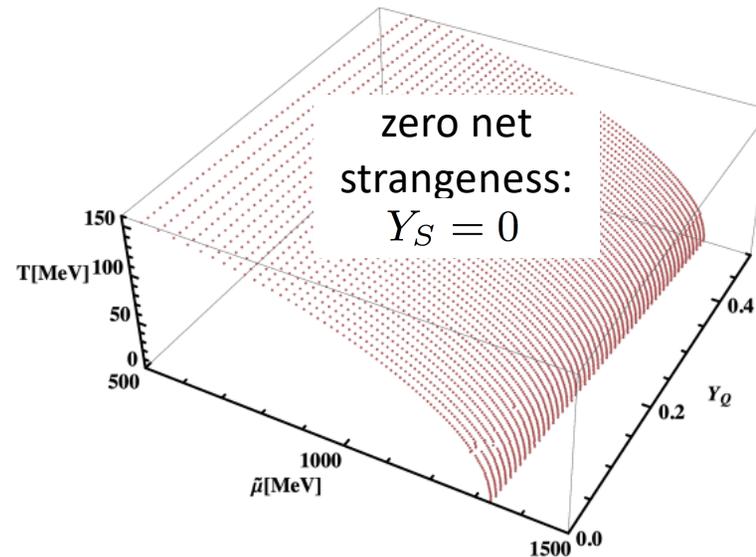
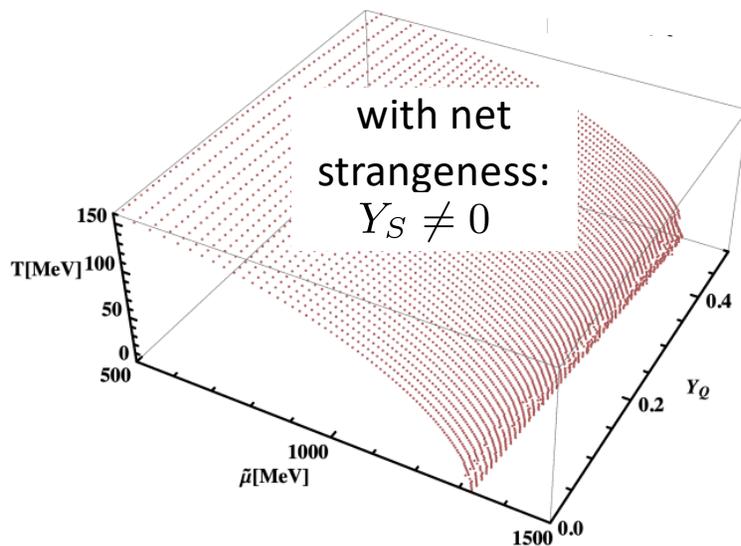
ArXiv: 2104.05950

# 3D QCD Phase Diagrams

- \*  $T, \tilde{\mu}, Y_Q$  with charge fraction  $Y_Q = Q/B = 0 \rightarrow 0.5$  and  
Gibbs free energy per baryon  $\tilde{\mu} = \frac{\partial P}{\partial B/V} = \mu_B + Y_Q \mu_Q$   
in CMF model

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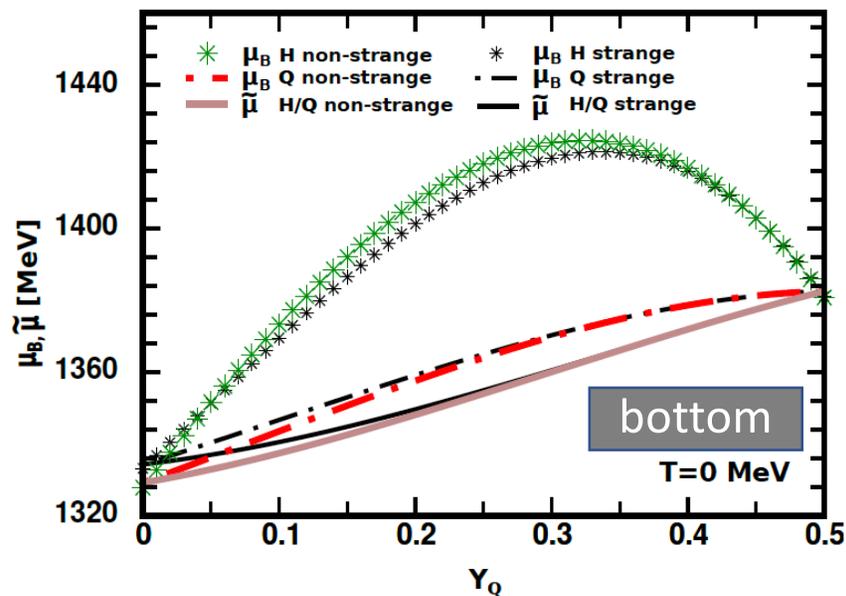
- \* In both cases larger  $Y_Q$  (at fixed  $T$ ) pushes the phase transition to larger  $\tilde{\mu}, \mu_B$
- \* Changes due to effects on particle population on each side

*Phys.Rev.D* 102 (2020) 7, 076016 and  
*J.Phys.Conf.Ser.* 1602 (2020) 1, 012013

# Slices of 3D QCD Phase Diagrams

( $Y_S=S/B=0$  in color,  $Y_S \neq 0$  in black)

- ★ For finite net strangeness  $Y_S \neq 0$ , deconfinement takes place at larger  $\tilde{\mu}, \mu_B$



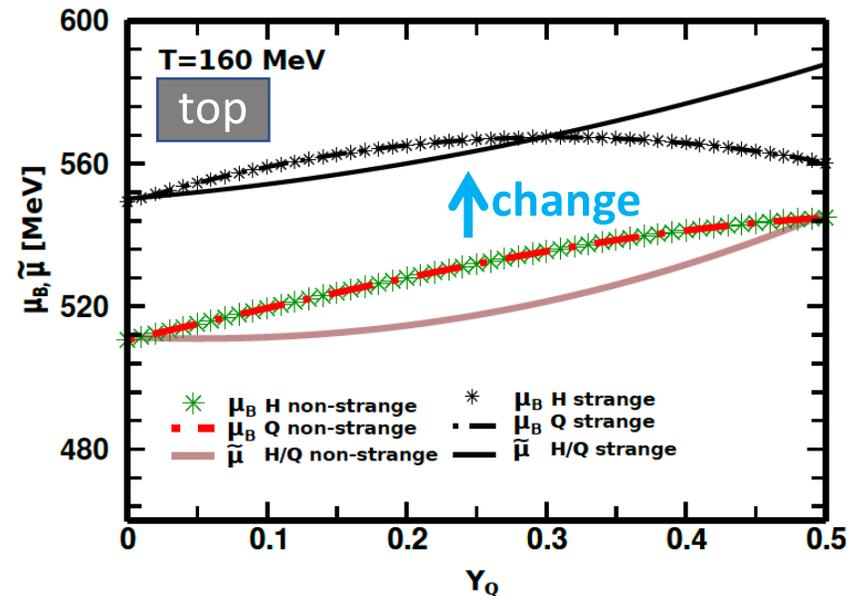
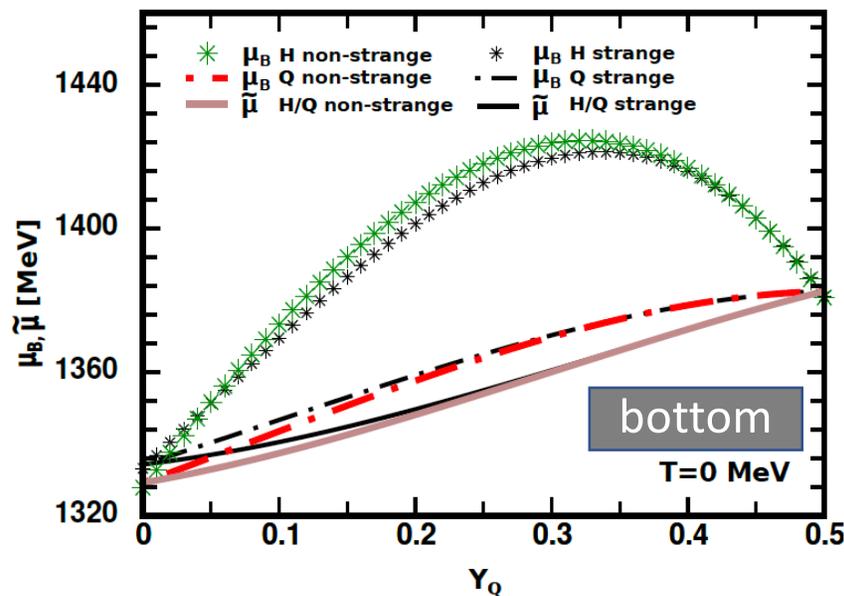
$$\tilde{\mu} = \mu_B + Y_Q \mu_Q$$

*Phys.Rev.D* 102 (2020) 7, 076016

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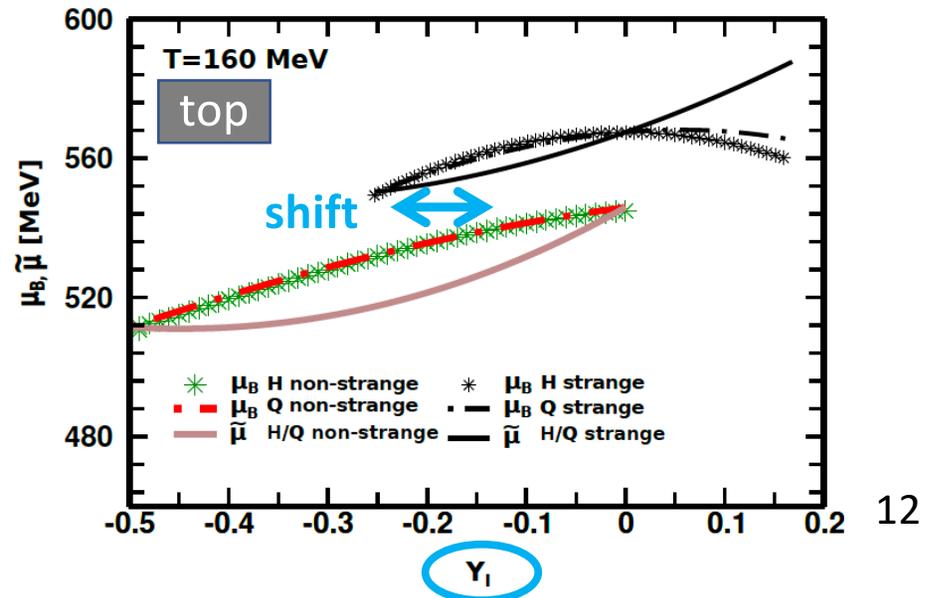
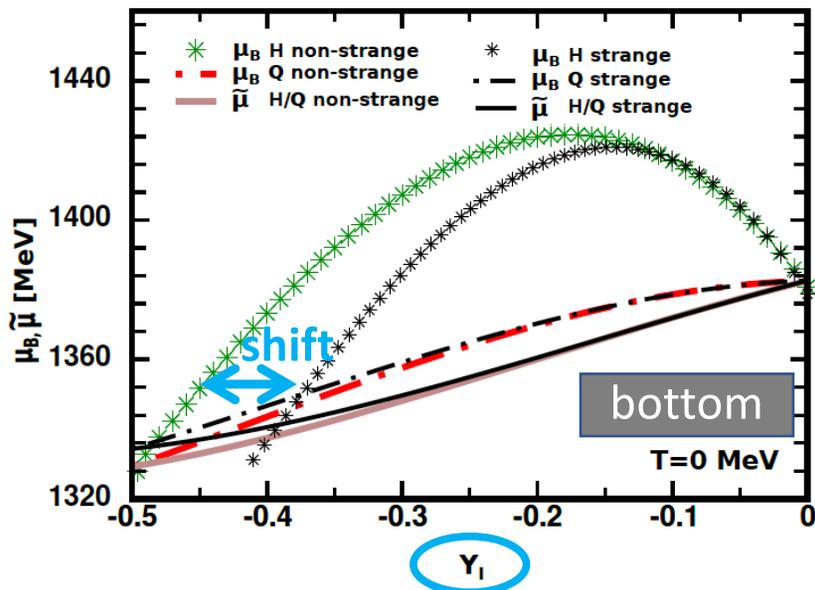
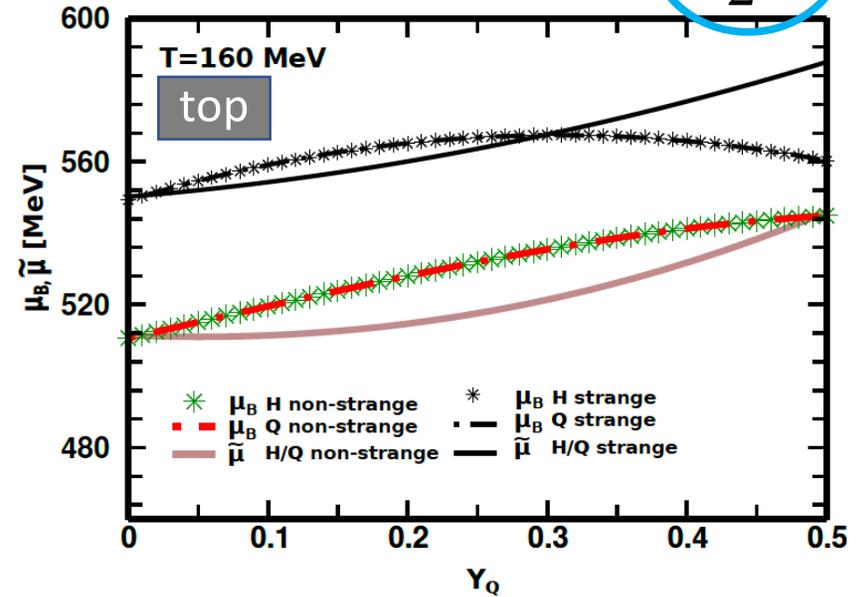
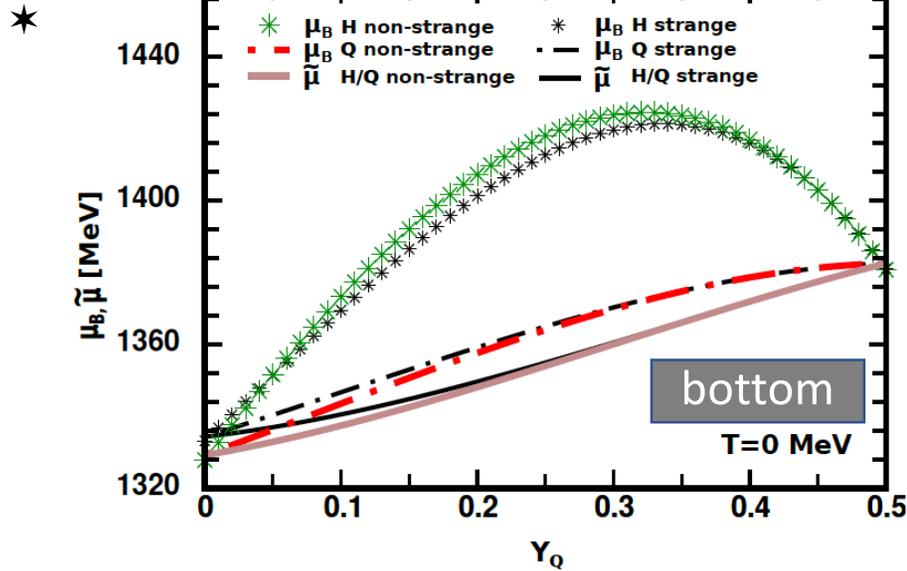
- ★ For finite net strangeness  $Y_S \neq 0$ , deconfinement takes place at larger  $\tilde{\mu}, \mu_B$



$$\tilde{\mu} = \mu_B + Y_Q \mu_Q$$

*Phys.Rev.D* 102 (2020) 7, 076016

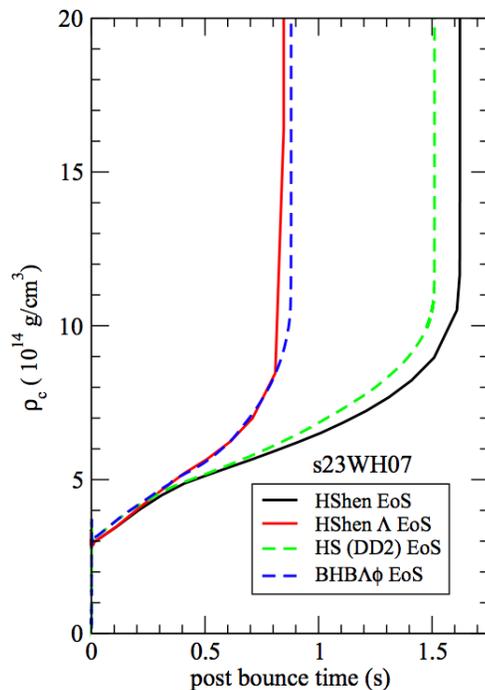
- ★ For finite net strangeness  $Y_S \neq 0$ , isospin and charge fraction relation is not trivial  $Y_I = Y_Q - 0.5 + \frac{1}{2}Y_S$



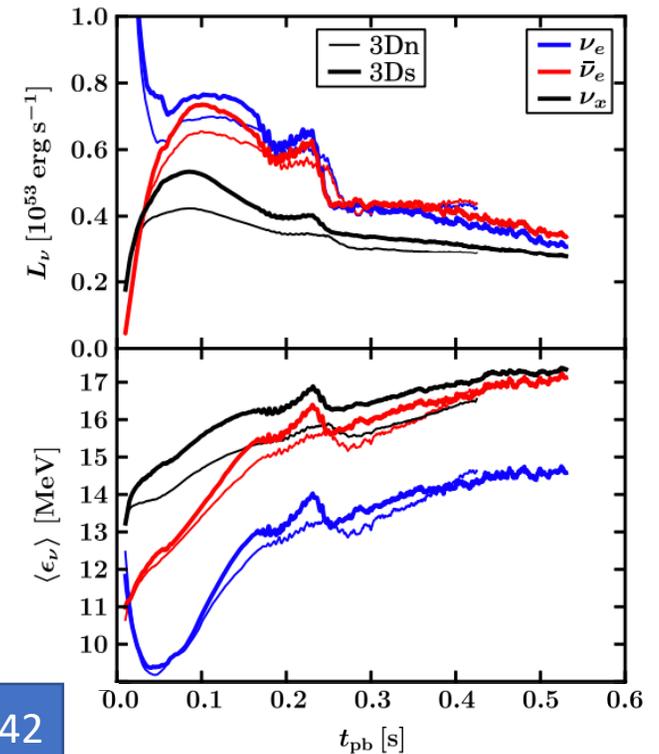
# Strangeness in supernovae

- ★ s-quarks can turn non-explosive massive-star 3D simulations into successful ones
- ★ Strangeness affects neutrino interactions, reducing neutrino opacity generating higher

luminosities and mean energies of neutrino emission



*Astrophys.J.Lett.* 808 (2015) 2, L42

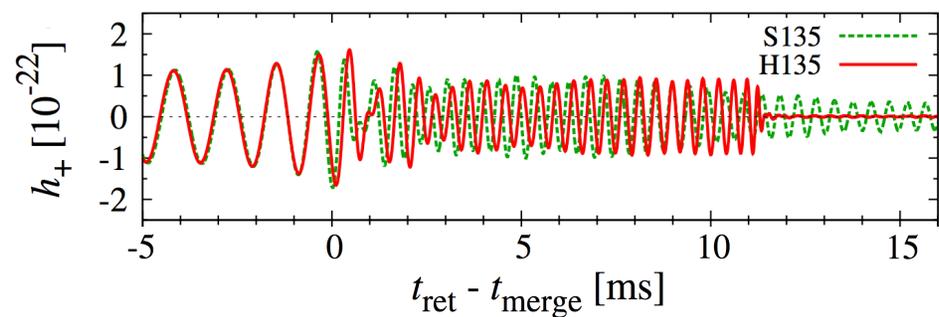
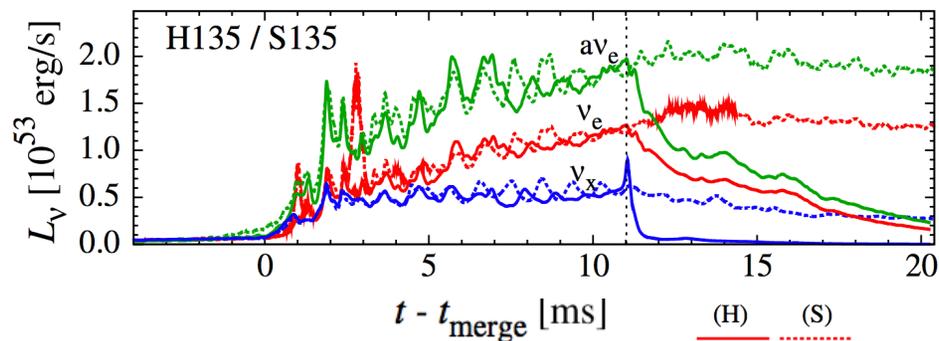


- ★ Hyperons affect density and temperature profiles inside massive exploding stars

*Astrophys.J.* 809 (2015) 2, 116

# Strangeness in NS mergers

- ★ Change in neutrino luminosity not distinguishable before high temperature regions are swallowed into the blackhole
- ★ But change in gravitational wave frequency and amplitude before and after merger can signal hyperons

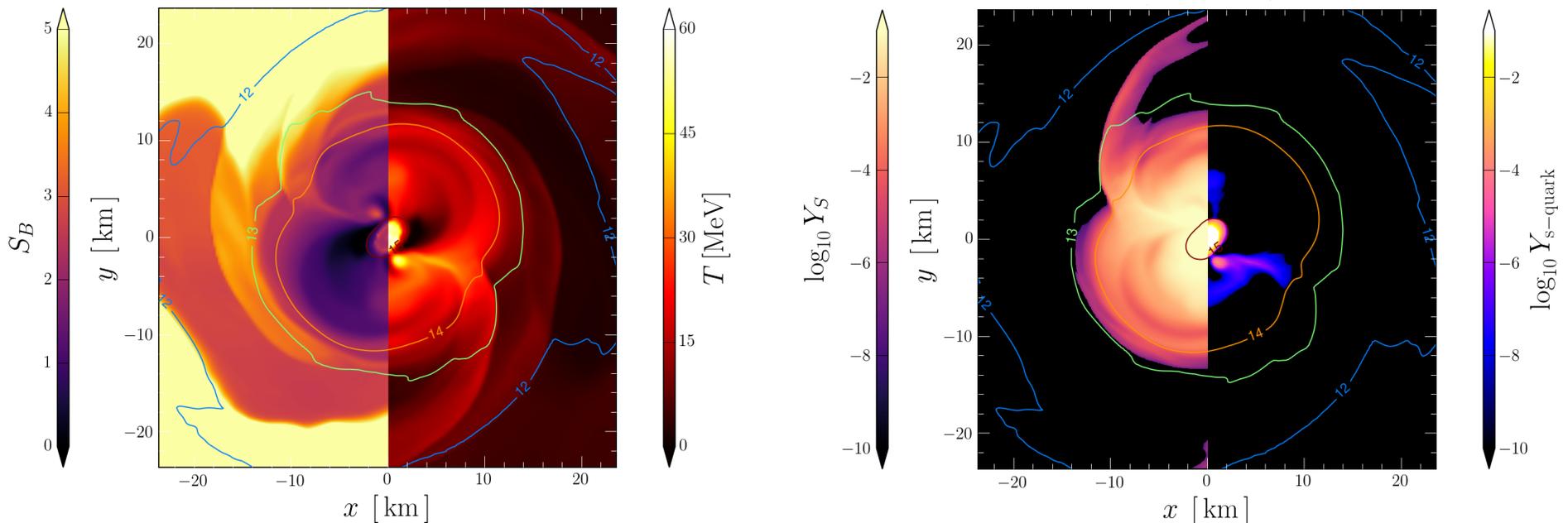


*Phys.Rev.Lett.* **107** (2011) 21, 211101

# Strangeness in NS mergers

(in hadronic and quark phases – 5 ms after merger)

- ★ Using 3D CMF EoS in Frankfurt/Illinois GRMHD code

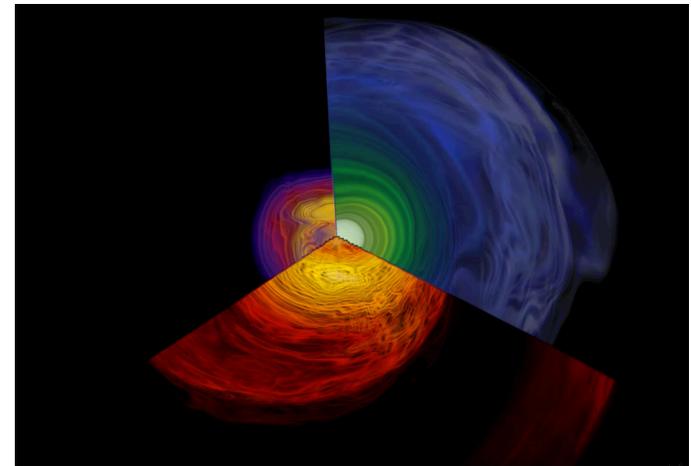


- ★ Increase of temperature/entropy per baryon at PT
- ★ Reaching heavy-ion entropies but with lots of net strangeness

*Phys.Rev.Lett.* 122 (2019) 6, 061101  
and *Eur.Phys.J.A* 56 (2020) 2, 59

# Conclusions and outlook

- ★ **Strangeness in neutron stars is definitely not ruled out**
- ★ Strangeness affects significantly low charge fraction matter at  $T=0$  and all kinds of matter at large temperatures
- ★ Comparisons among HI collisions and astrophysics must be performed with care ( $T$ ,  $S_B$ ,  $Y_Q$ ,  $Y_S$ , leptons, ...)
- ★ Neutron-star mergers create unique ideal conditions to achieve deconfinement
- ★ Finite temperature NS modelling is improving and observations are slowly constraining EoS so, soon we will be able to start quantifying strangeness in astrophysics



[Simulation and visualization by Most, Papenfort, Weih, and Rezzolla](#)