Nuclear phase diagram: from heavy ions to neutron stars

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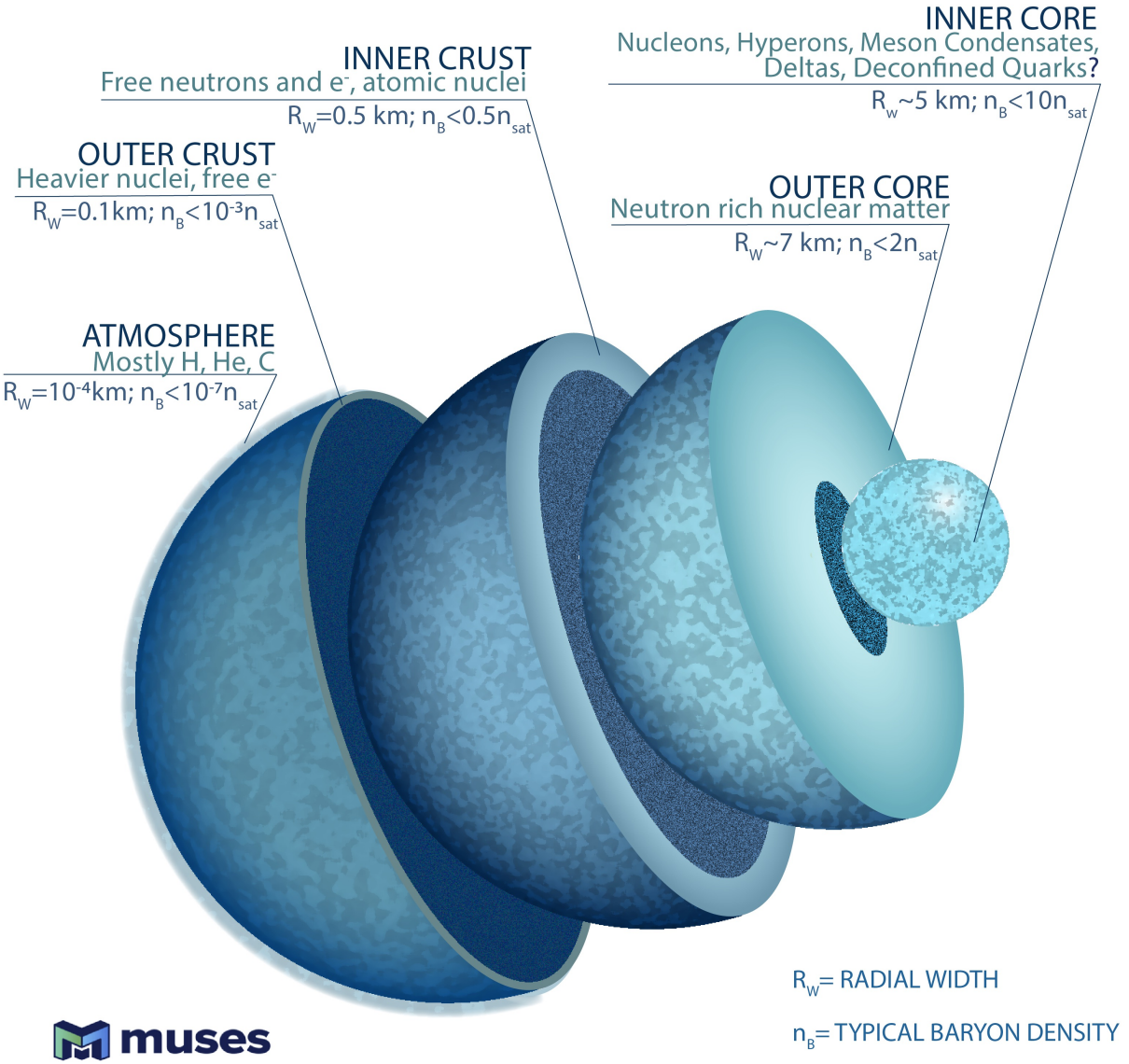
Neutron Stars

- Mostly made up of dense matter (beyond saturation density)
- With inner core (beyond 2x saturation density) containing exotic matter

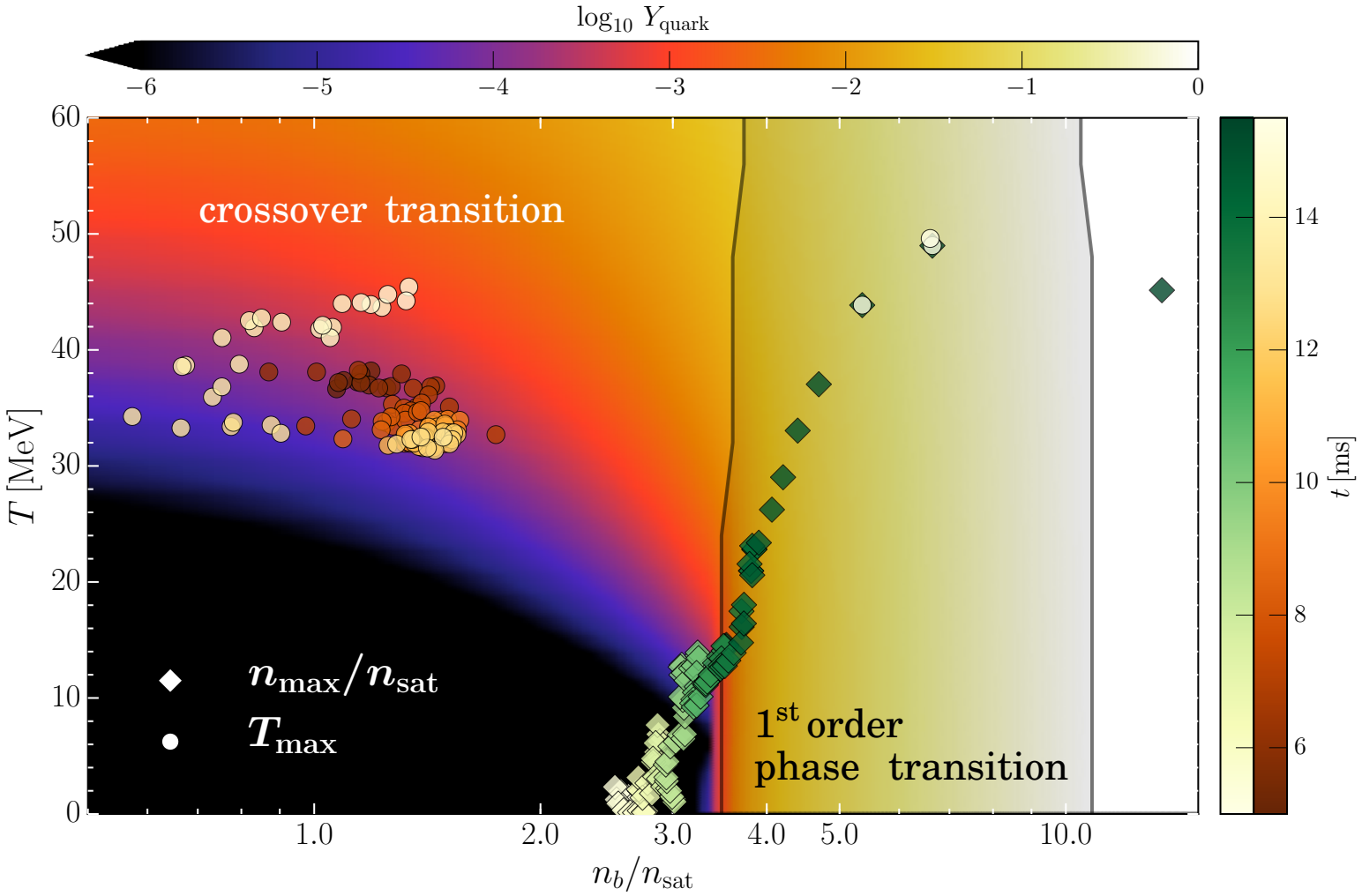
e-Print: [2303.17021]



Neutron-Star Mergers

- Dense matter reaching temperatures of many tens of MeV

Phys.Rev.Lett. 122 (2019) 6, 061101 e-Print: 1807.03684



QCD Phase Diagram

- Current input from different (first-principle and effective) theories and experiments

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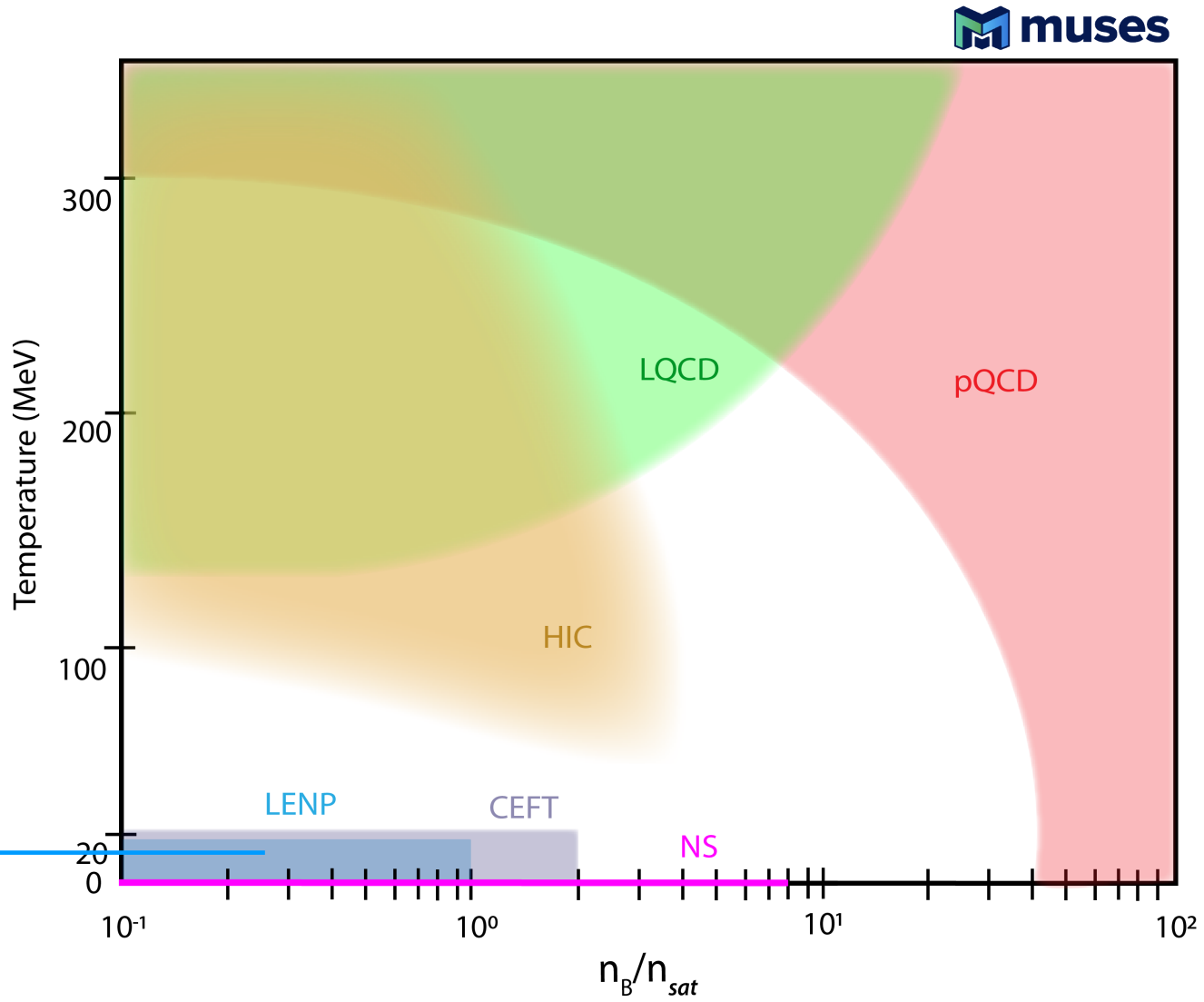
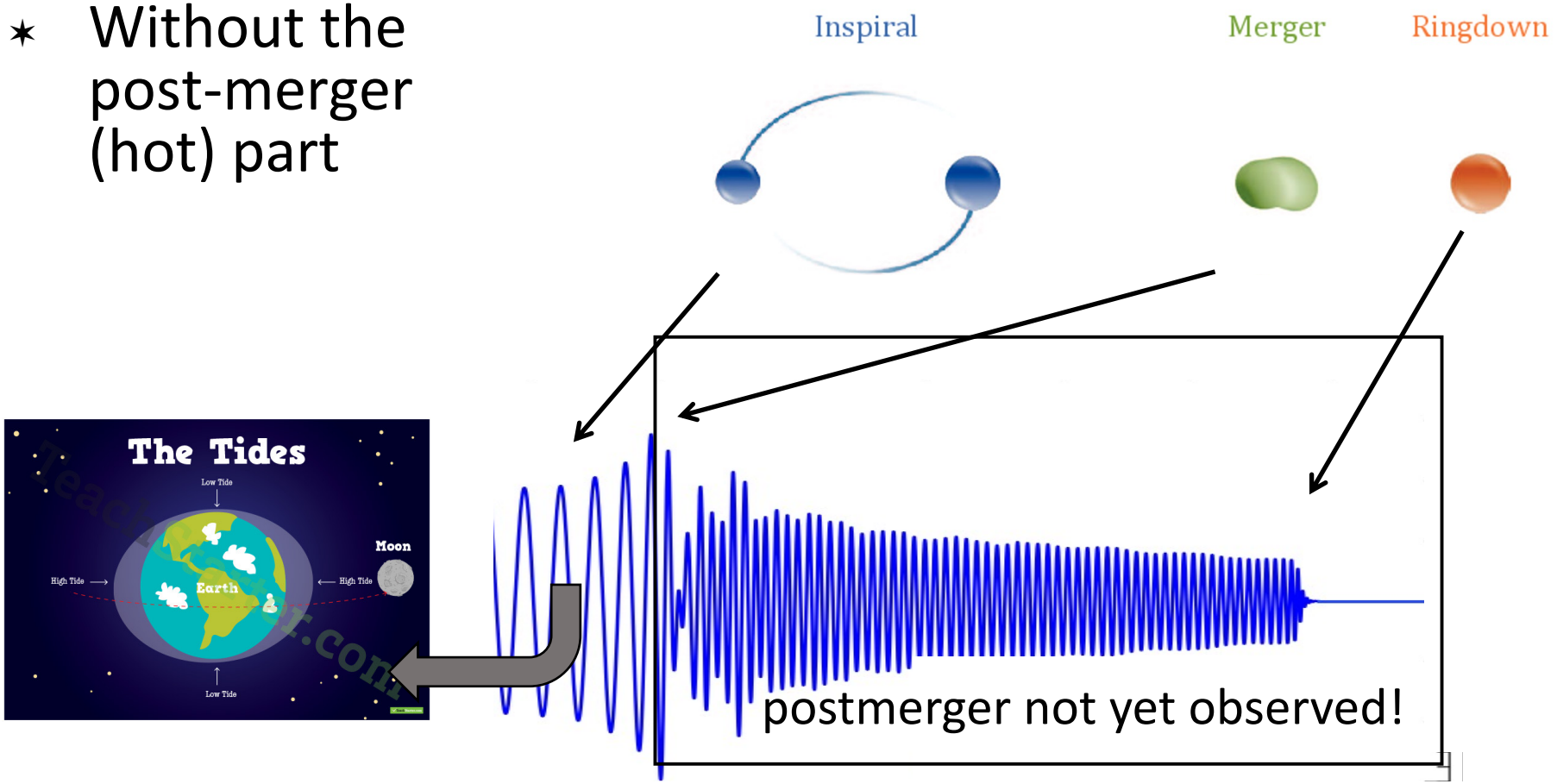


Gravitational Wave Data

- Several measurements from neutron-star mergers but only GW170817 provided electromagnetic counterparts and a relevant measurement of the tidal deformability
- Without the post-merger (hot) part

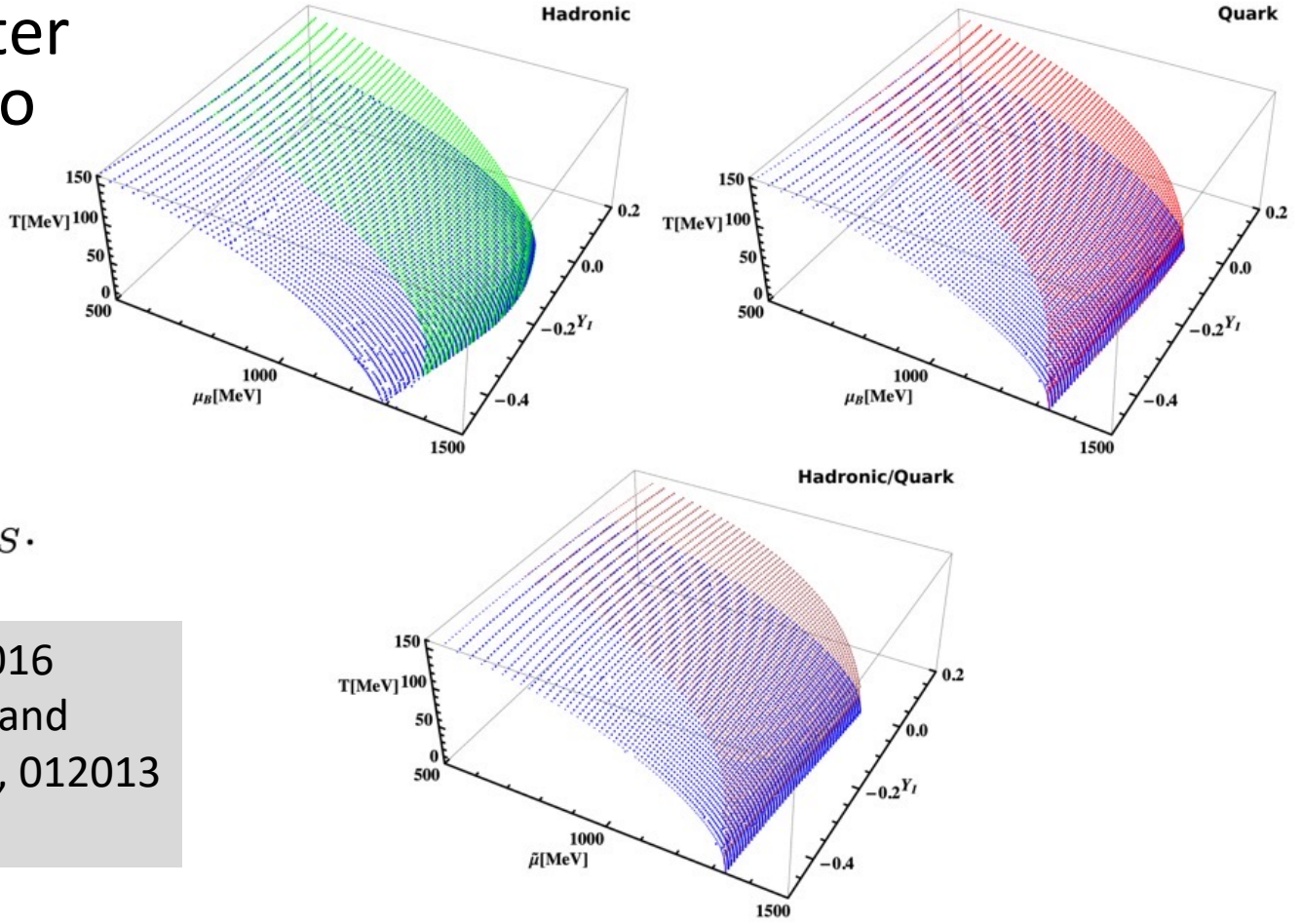


Isospin and Strangeness

- Deconfinement to quark matter and phase diagrams also depend on strangeness fraction $\mathbf{Y_S}$ and isospin fraction $\mathbf{Y_I}$ (or hadronic/quark charge $\mathbf{Y_Q}$)
- For strange matter ($\mathbf{Y_S} \neq 0$) there is no simple relation between fractions

$$Y_Q = Y_I + \frac{1}{2} - \frac{1}{2} Y_S,$$

$$\tilde{\mu} = \mu_B + Y_Q \mu_Q + Y_S \mu_S.$$

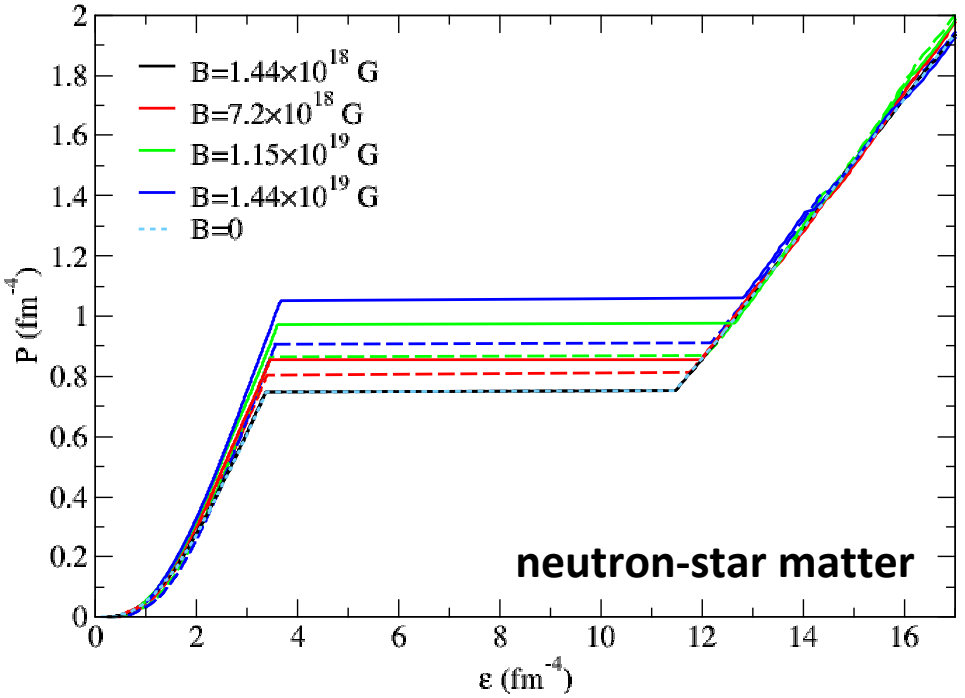


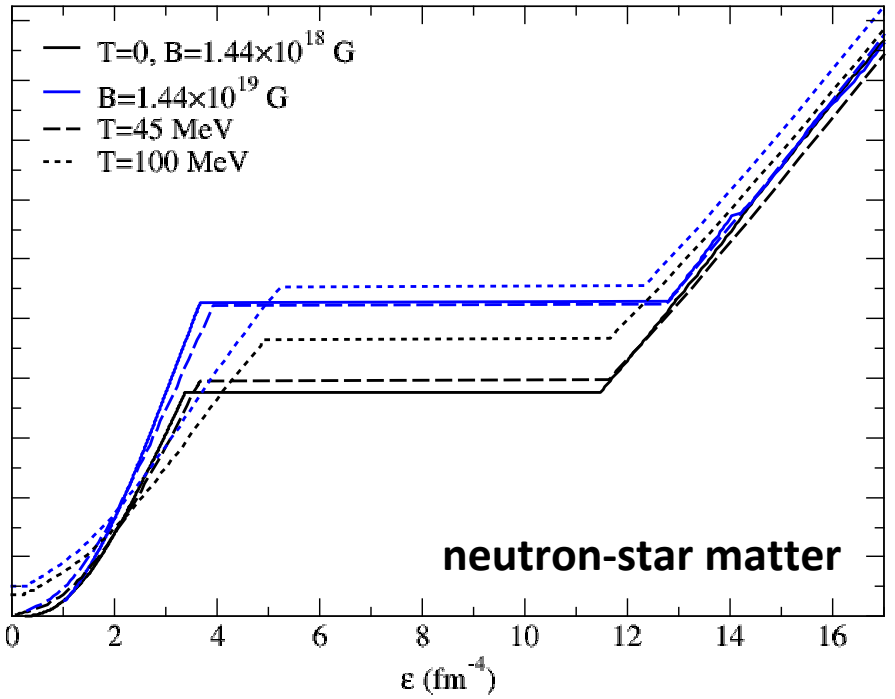
Phys.Rev.D 102 (2020) 7, 076016
e-Print: 2004.03039 [nucl-th] and
J.Phys.Conf.Ser. 1602 (2020) 1, 012013
e-Print: 2010.00996 [nucl-th]

Magnetic Fields

- Deconfinement to quark matter and phase diagrams also depend on magnetic field **B**

e-Print: 2304.02454 [nucl-th]



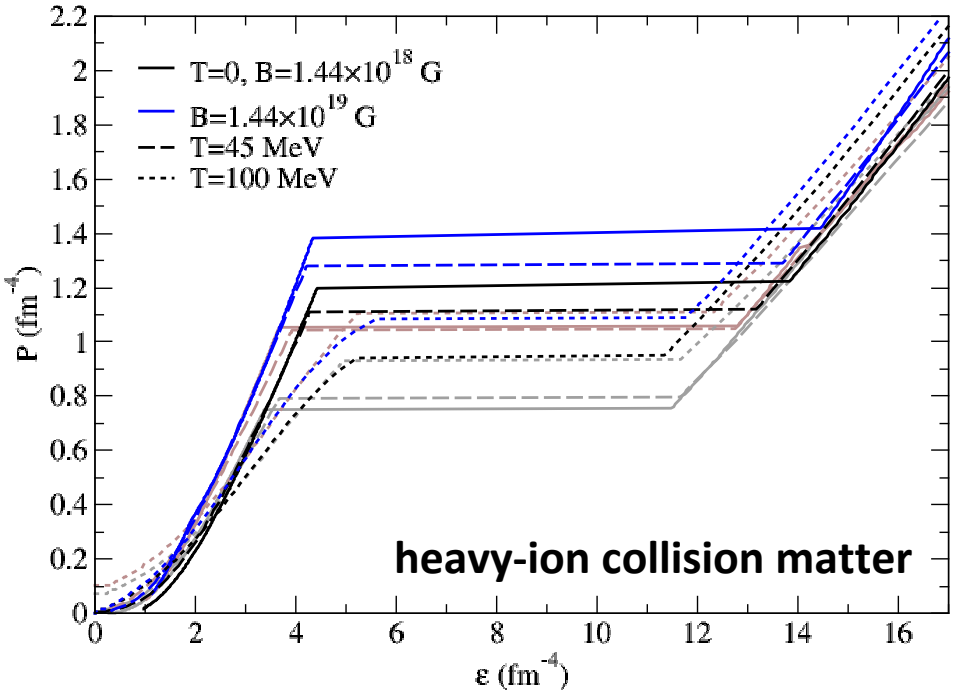


- (Stronger) phase transition takes place at larger ε and μ_B for larger B in CMF model
- (Weaker) phase transition takes place at lower μ_B for larger T

Magnetic Fields

- Neutron-star vs. heavy-ion collision matter also change dependence on **B**

e-Print: 2304.02454 [nucl-th]



- Neutron-star matter also shown for comparison in different colors

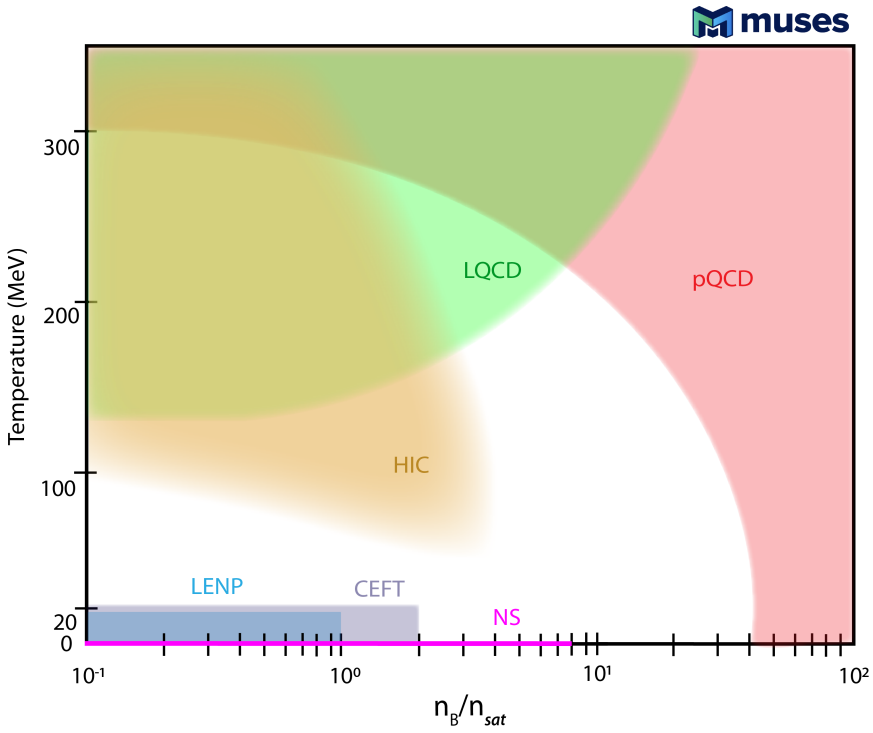
B=1.44x10^{18} G for neutron-star matter

B=1.44x10^{19} G for neutron-star matter

- Phase transition takes place at larger μ_B and is stronger for heavy-ion collision matter (for any **T** and **B**) in CMF model

Conclusions and Outlook

- Neutron-star matter allows access to strange and highly isospin-asymmetric matter at large densities
- Neutron-star mergers will very soon also inform us about dense and hot matter (while also strange and highly isospin asymmetric)



- The multidimensional QCD phase diagram is slowly becoming constrained ➤ MUSES cyberinfrastructure https://muses.physics.illinois.edu/