**Round Table Discussion 1**

# What can neutron star and heavy-ion physics learn from each other ?

(Convener: David Blaschke)

1) What do we know about the properties of nuclear matter at high density and temperatures from ab-initio nuclear physics calculations (chi EFT, many-body approaches) ?
Up to what temperature and densities the ab-initio calculations are applicable and how do we go beyond them ? (Ingo Tews)

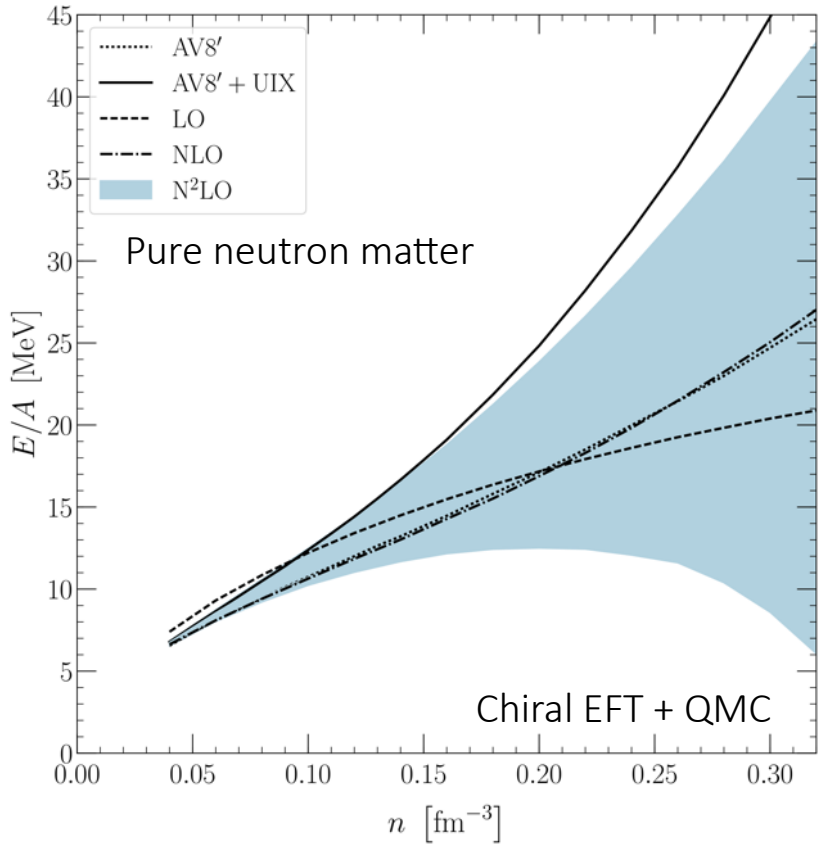
2) What is the minimal chemical potential, where the weak coupling QCD method might be applicable ? (Aleksi Vuorinen)

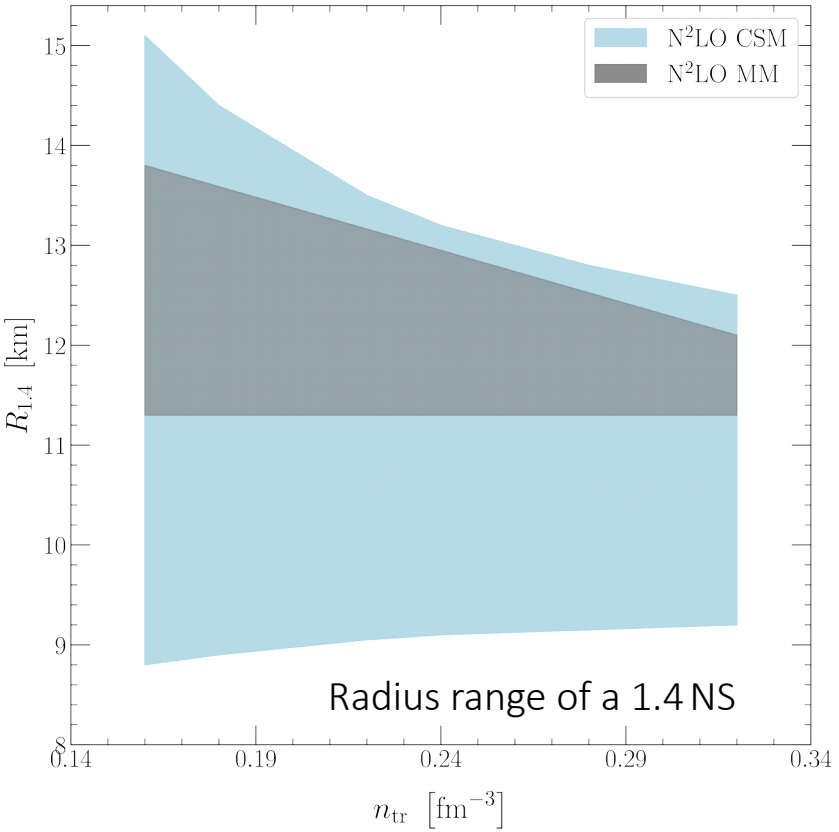
3) How important is modeling confinement in the EoS? Interpolation? Order of the phase transition at low temperatures (anomaly)? Impact of constraints for mass and radius of compact stars to rule out EoS (2 M_sun pulsar observations, binary merger GW170817, …)? (Mark Alford)

4) How to connect the EoS probed in HIC and in NS? Role of leptons and symmetry energy? (Pawel Danielewicz)

5) What is the role of strangeness in NS and HIC at high densities?
(Thomas Klähn)

[ 6) What happens to the chiral symmetry breaking in nuclear matter ? ]



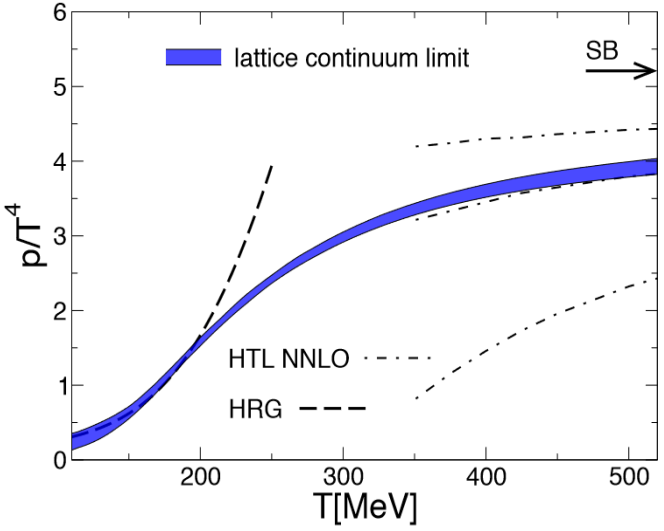

- **Chiral EFT**: Systematic expansion of nuclear forces, including many-body forces, in powers of $(Q/\Lambda_b)^n$, $\Lambda_b$=500-600 MeV. The unknown coupling constants are fit to experimental data (NN scattering, light nuclei).
- **Systematic error estimates** possible, and interaction uncertainties dominate. Large community effort to reduce uncertainties!
- **Consistent approach** to nuclei and matter.

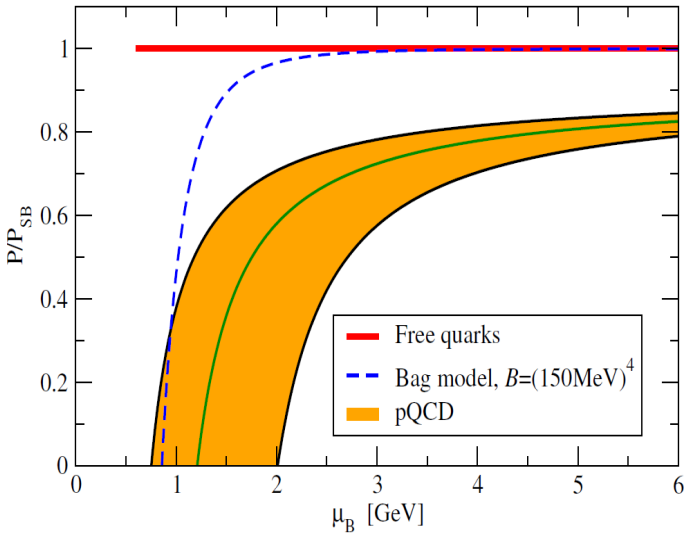
- Uncertainties & breakdown of chiral EFT calculations estimated from **order-by-order calculations** which show convergence pattern.
- Extension to higher densities above a certain $n_{tr}$ using **very general expansion schemes**:
  - Polytropic expansion,
  - Speed-of-sound expansion,
  - Meta-modelling
- **Density range 1-2 $n_{sat}$ of great importance**, tight experimental constraints needed.

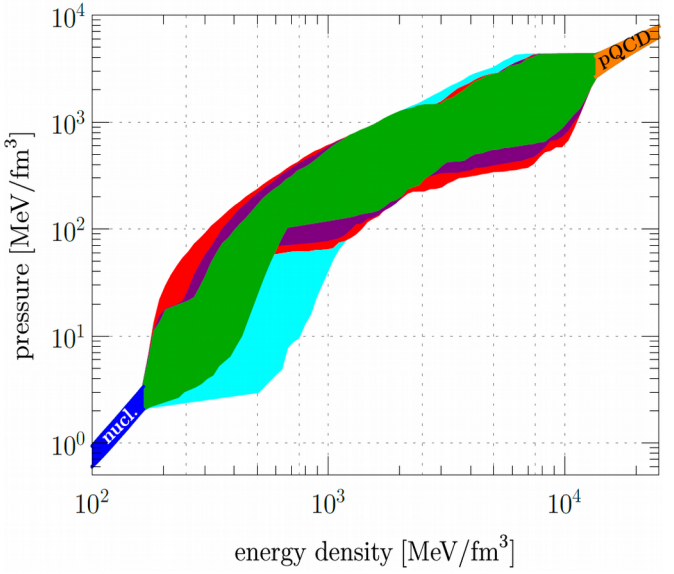
High $T$: [Borsanyi et al. 1309.5258; Strickland, AV, unpublished]

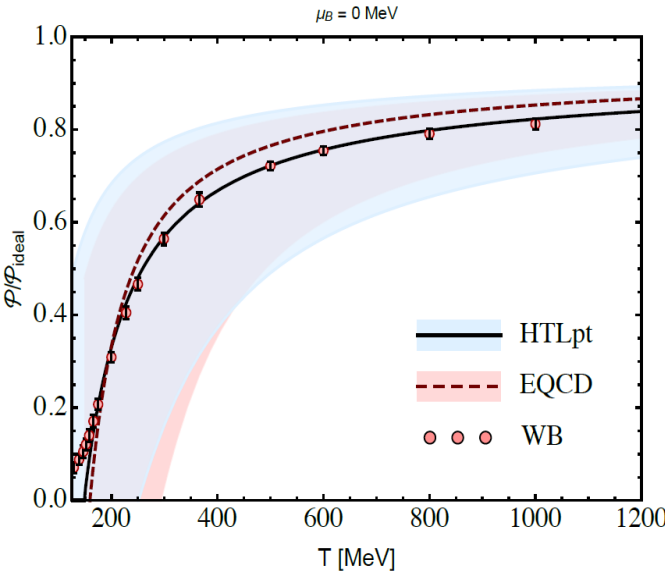
Zero $T$: [Fraga, Kurkela, AV, 1311.5154; Gorda et al, 1807.04120 ]

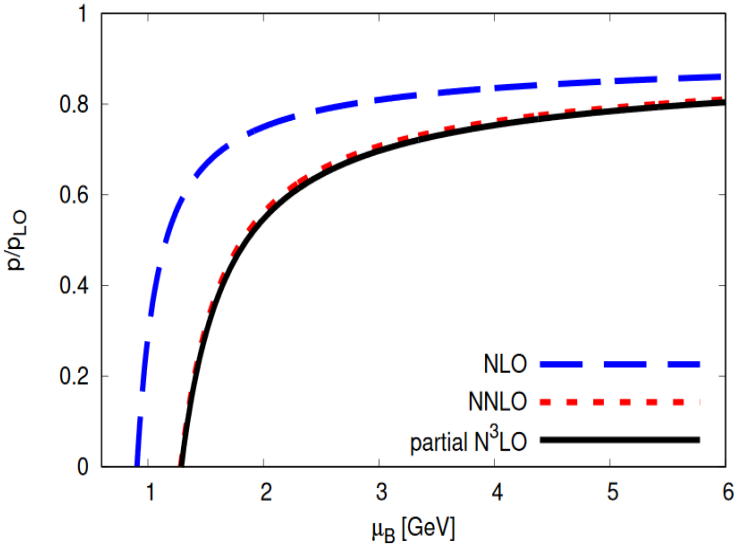
Interpolation at $T=0$: [Annala, Gorda, Kurkela, AV, 1711.02644]

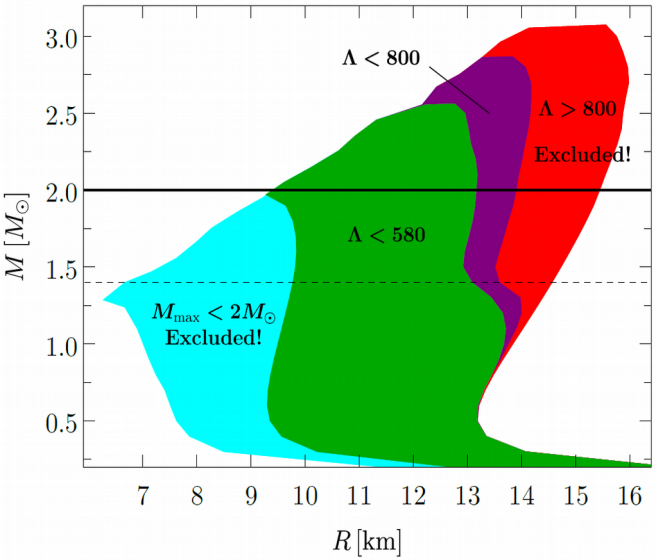


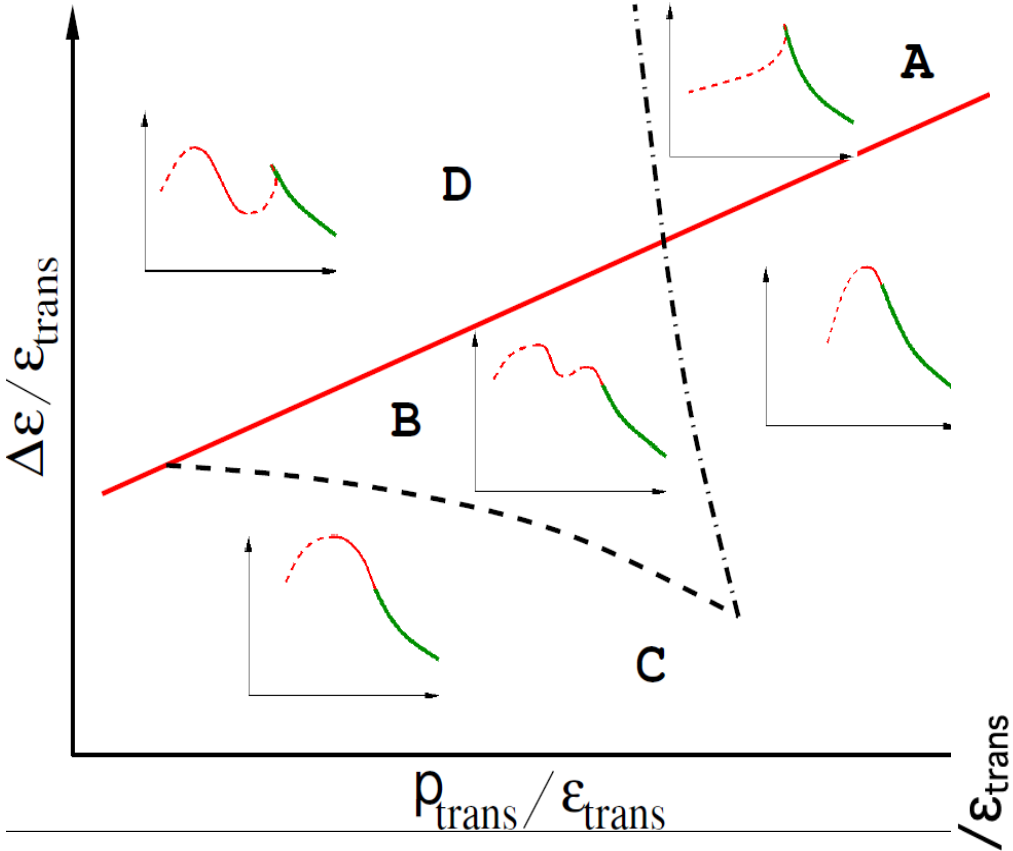



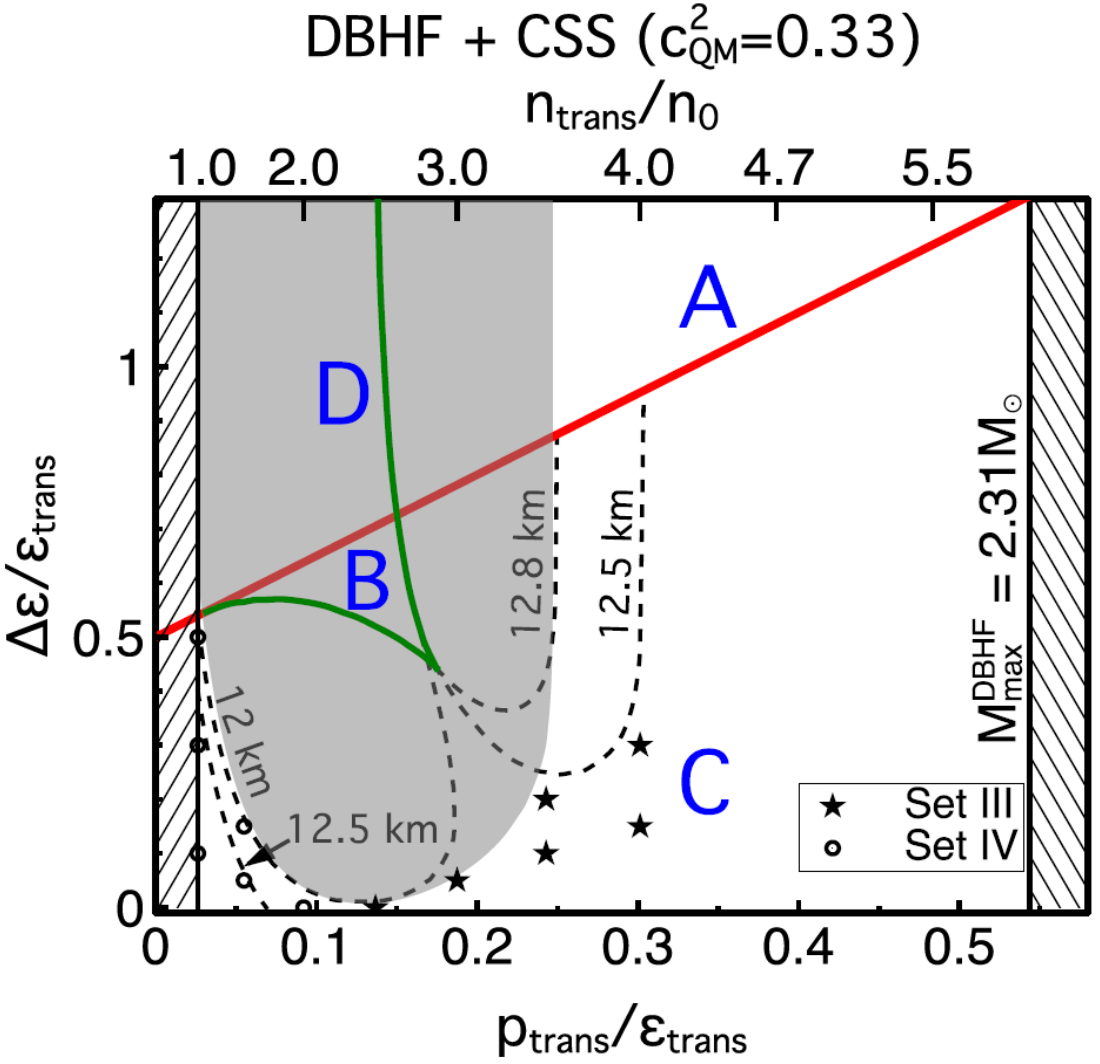



# EoS with 1st order phase transition and phase diagram of hybrid compact stars

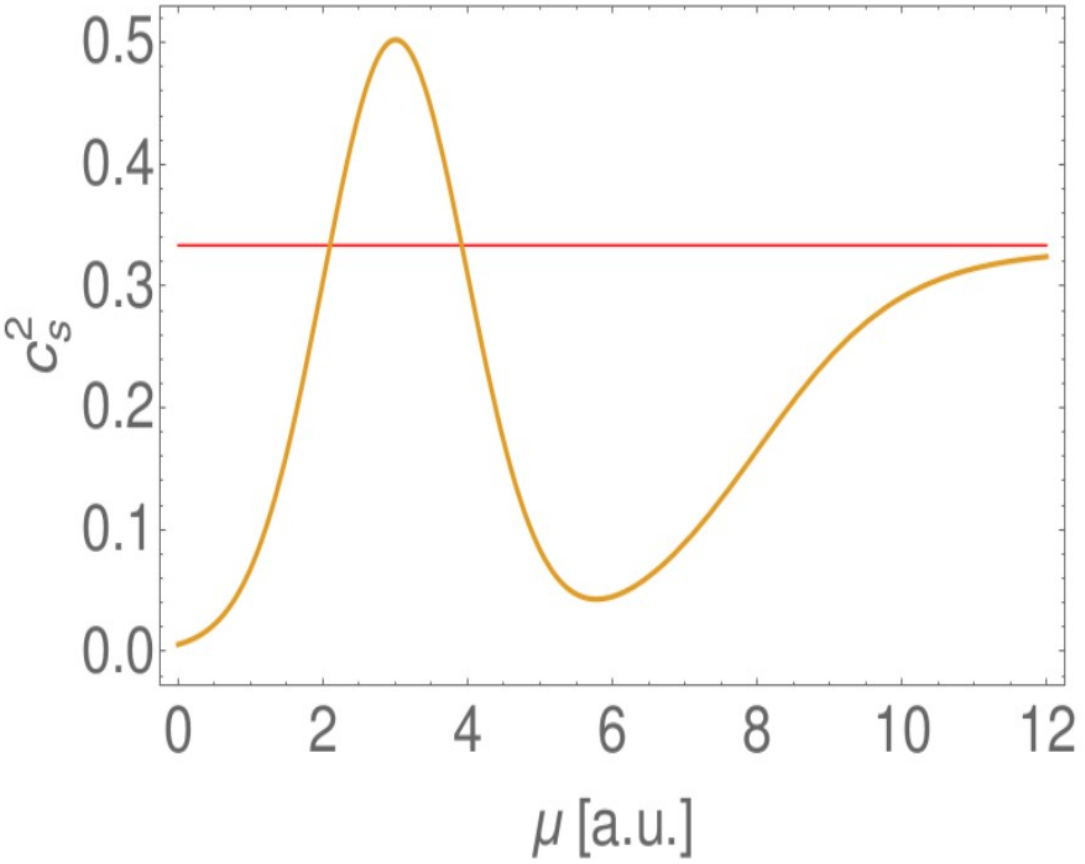


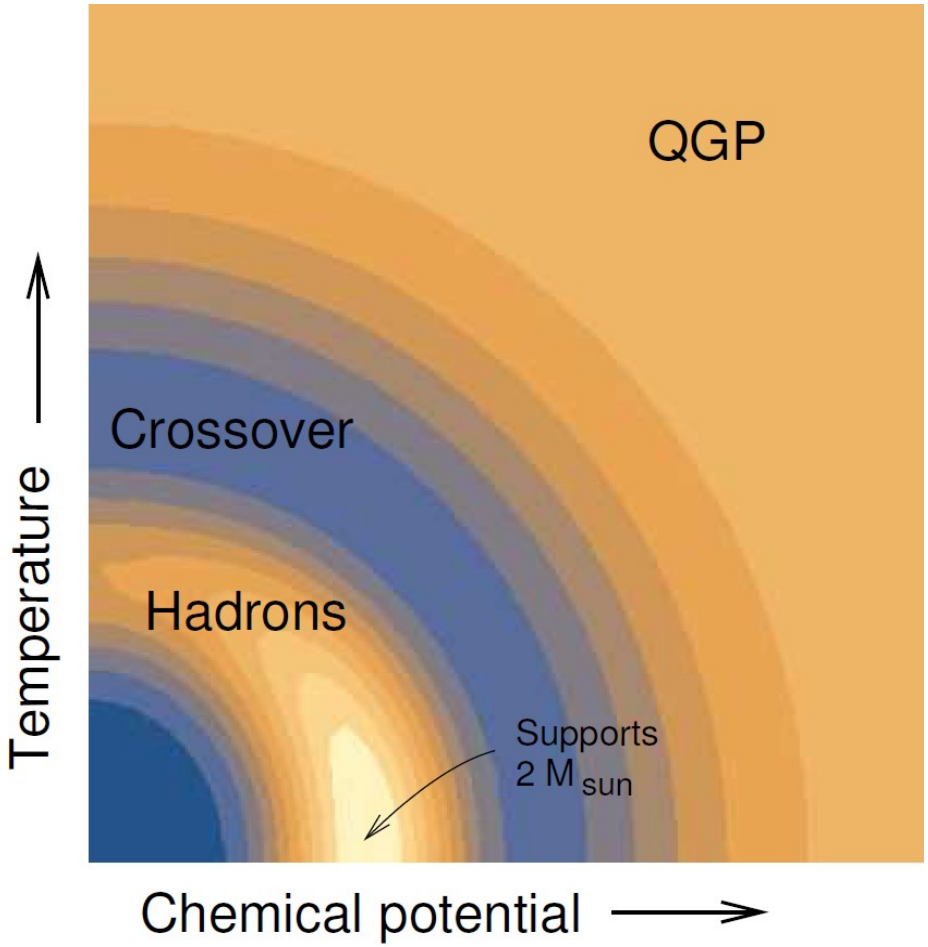

M. Alford, S. Han, M. Prakash,
Phys. Rev. D 88, 083013 (2013)

M. Alford, F. Burgio, et al.,
Phys. Rev. D 92, 083002 (2015)

# Role of 2M_sun constraint from pulsar mass for QCD EoS and phase diagram




Discussion at INT Seattle:
"The Phases of Dense Matter"
INT-16-2b, July 11 – August 12 (2016)

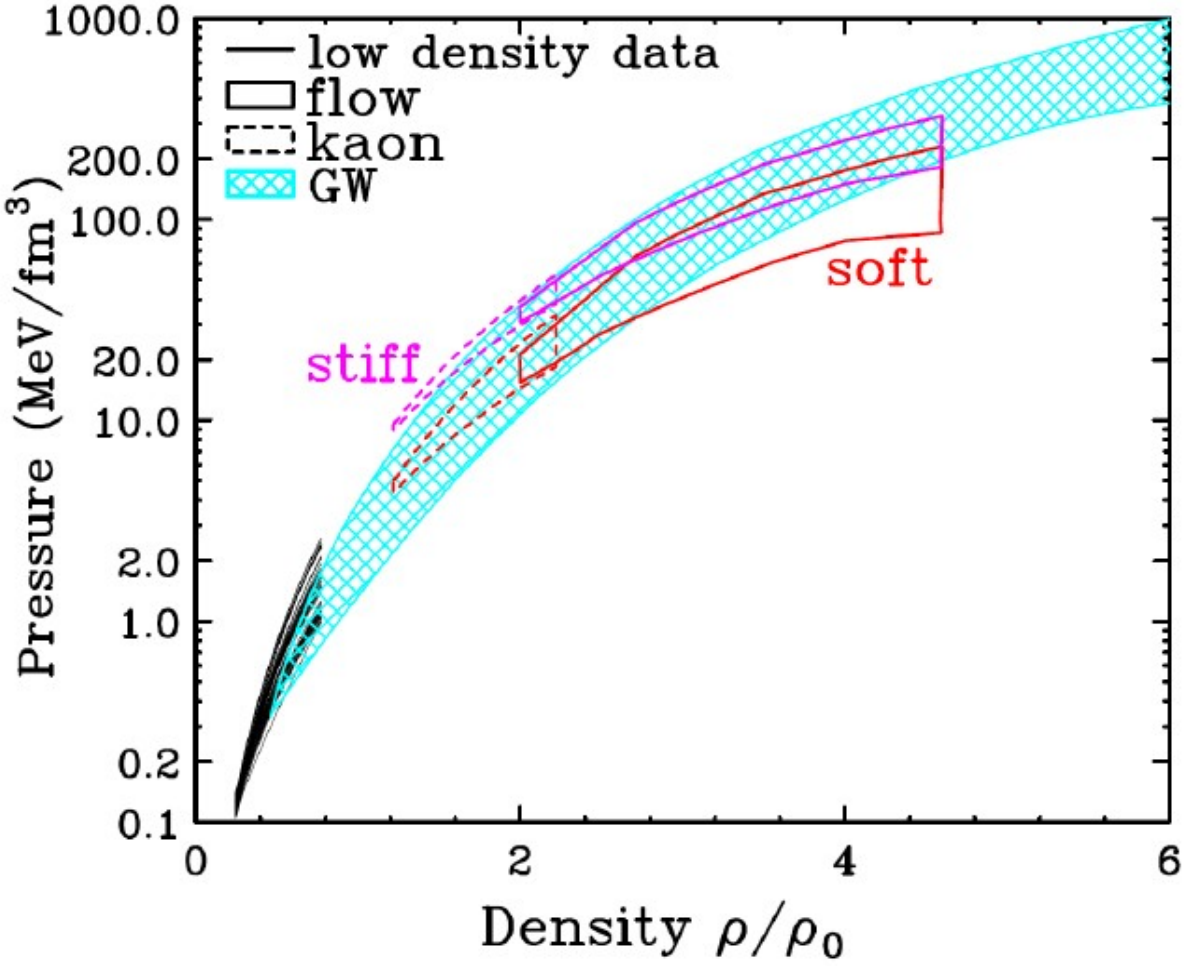



See also:

I. Tews, J. Carlson, S. Gandolfi, S. Reddy,
Astrophys. J 860, 149 (2018) [arxiv:1801.01923]

# Heavy-Ion Collisions & n-Star Mergers

Equation of State (EOS) from nuclear collisions and from neutron-star merger




Collision observables testing

$E(\rho_n, \rho_p) = E_0(\rho) + S(\rho)\left((\rho_n - \rho_p)/\rho\right)^2 + \ldots$ :

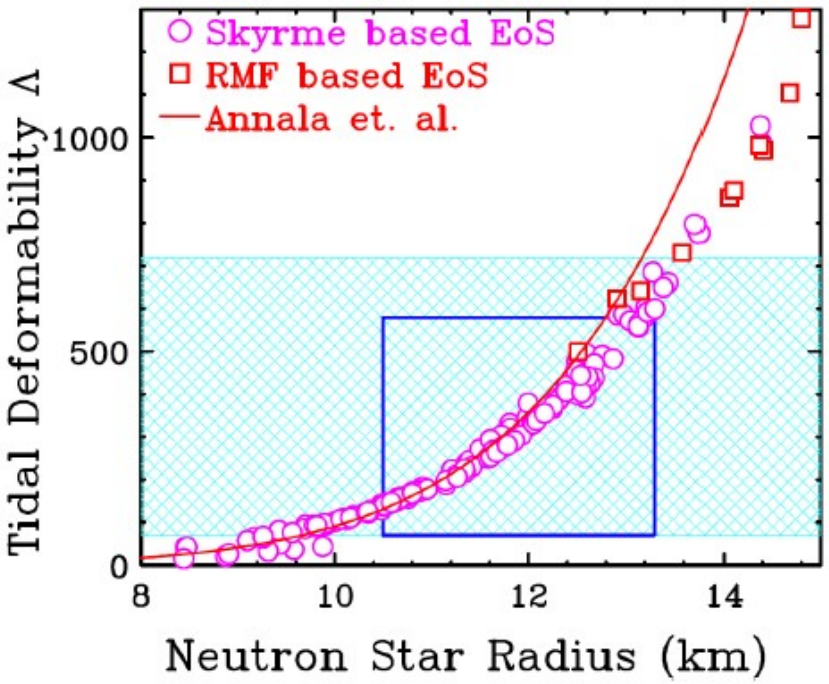
flow asymmetries, $\pi$ and $K$ yields, spectra of isospin partners

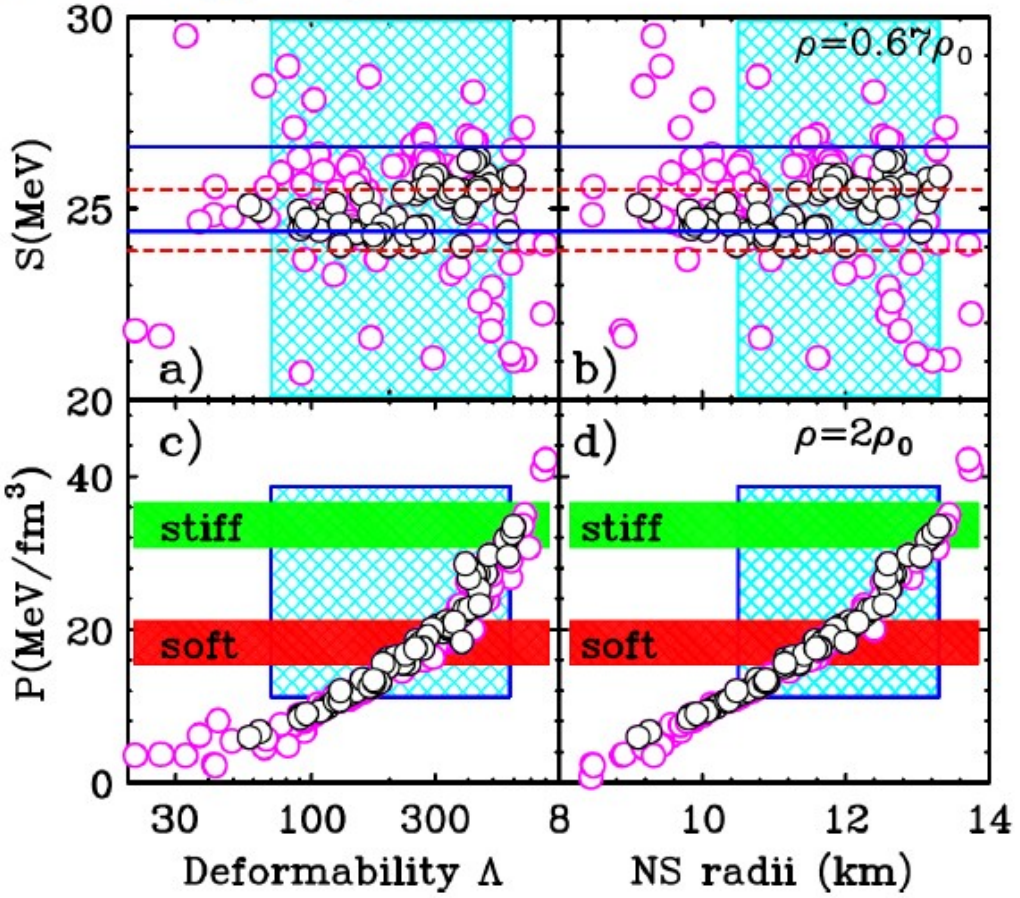
NSCL

# Accessible Features of EOS

## Different info from different beam-energy regions

higher-$\rho$ more relevant$\rightarrow$




$E_n \simeq E_0 + S$

$S$ tested at lower energies, $\lesssim 0.5$ GeV/nucl, FRIB/RIKEN/FAIR

$E_0$ tested up to $\sim 10$ GeV/nucleon, FAIR/NICA/SPS

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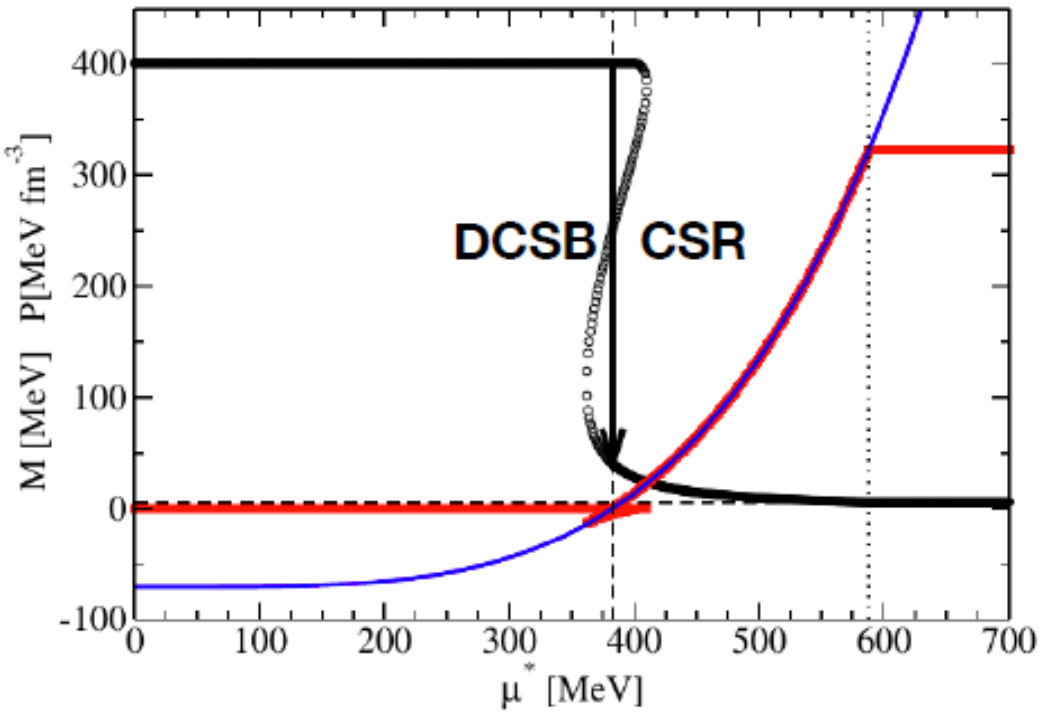
# Consistent Nuclear and Quark Matter Models?




differences between NJL and Bag:
DCSB, confinement, vector interaction
(TK, T.Fischer, ApJ , 2015)

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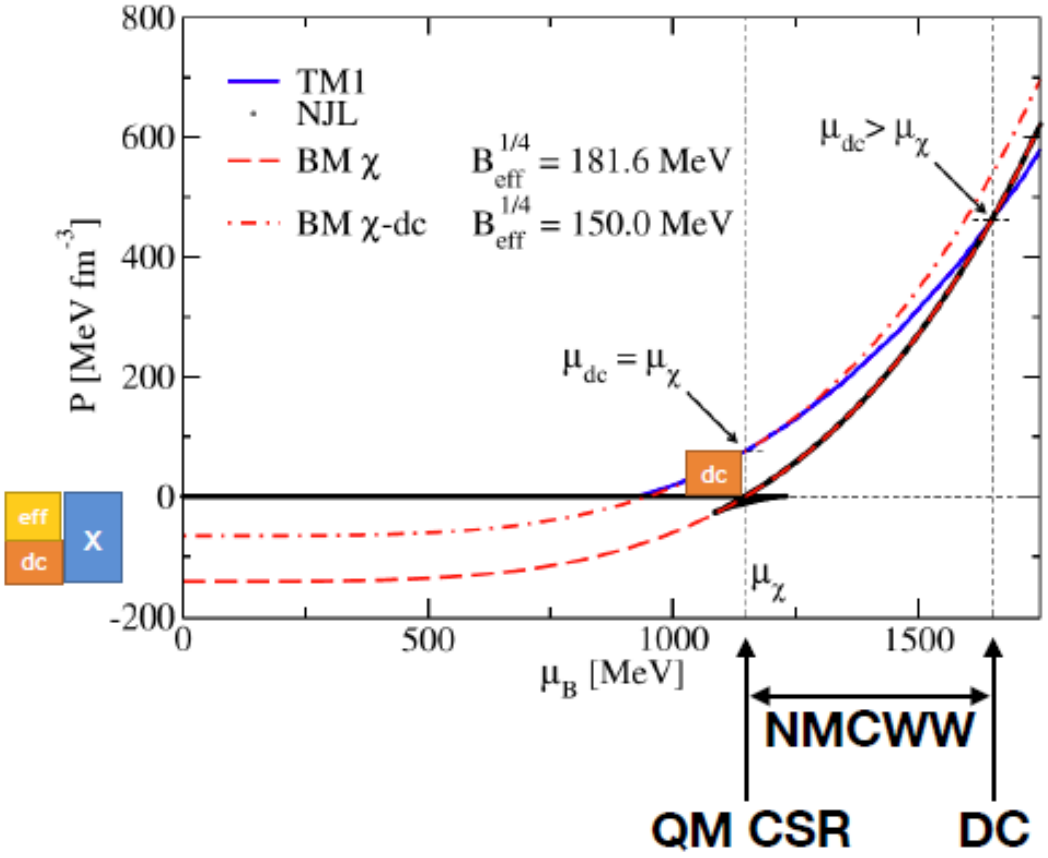


differences between NJL and Bag:
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## Problems

- de/confinement at finite chem. potential
- DCSB on quark level in nuclear matter
- QCD 'near' phase transition is non-perturbative

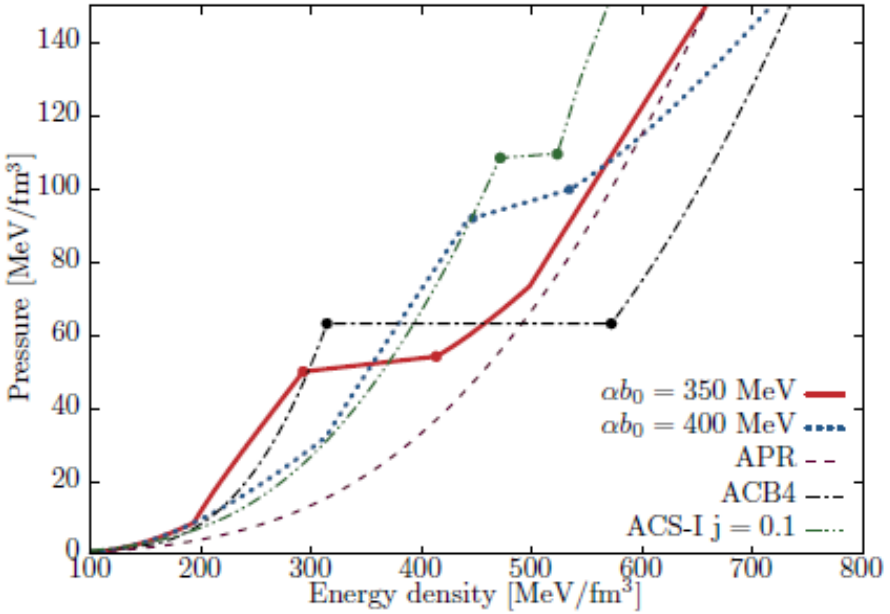
## Workarounds

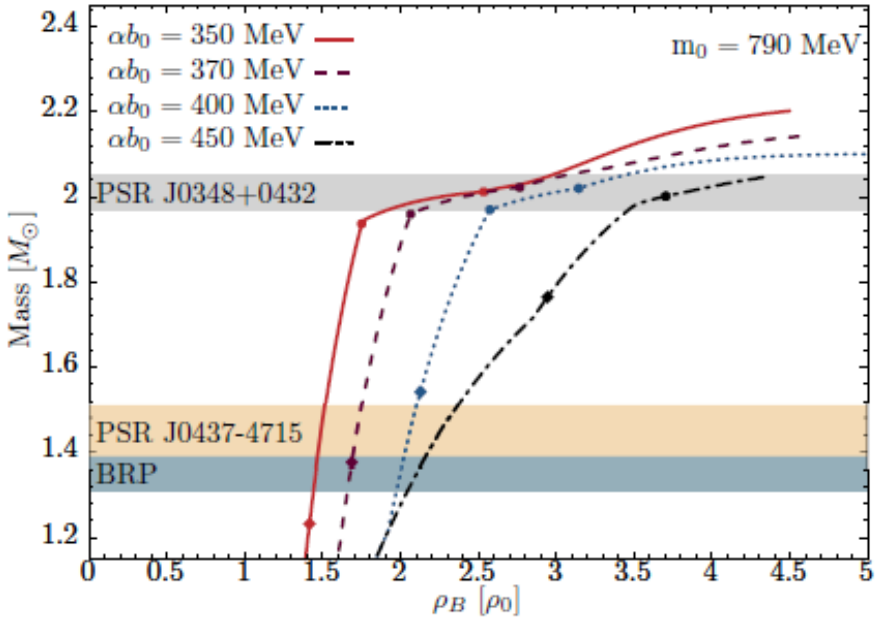
- Effective models
  (quark-meson-nucleon coupling)
- Two-phase approach
- nature of phase transition
  (Maxwell type 1st order vs. mixed phases)

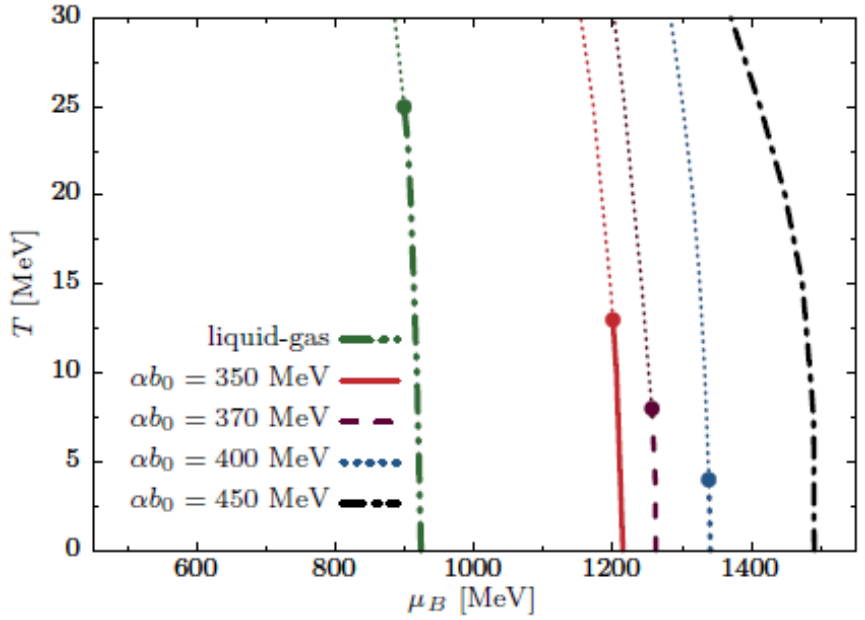
LOTS of room for ambiguities
(nature of effective models)

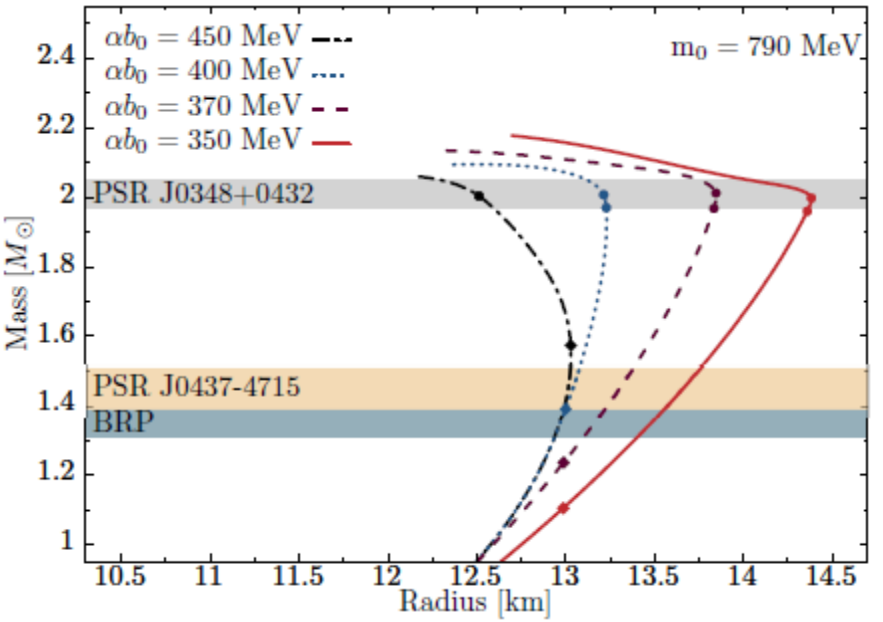
Majority of effective QM models exploit
quasi-particle picture -> dispersion/propagator poles
More problematic at finite T, but issue is fundamental:
(QM thresholds in effective models put in 'by hand':
supression, IR-regularization, 'QM-waiver')

# Chiral symmetry restoration by parity doubling in NM and structure of neutron stars




M. Marczenko et al., arxiv:1805.06886 (talk in session F on Sunday)