Functional Renormalization Group Study of Nuclear and Neutron Matter

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EUROPEAN CENTRE FOR THEORETICAL STUDIES
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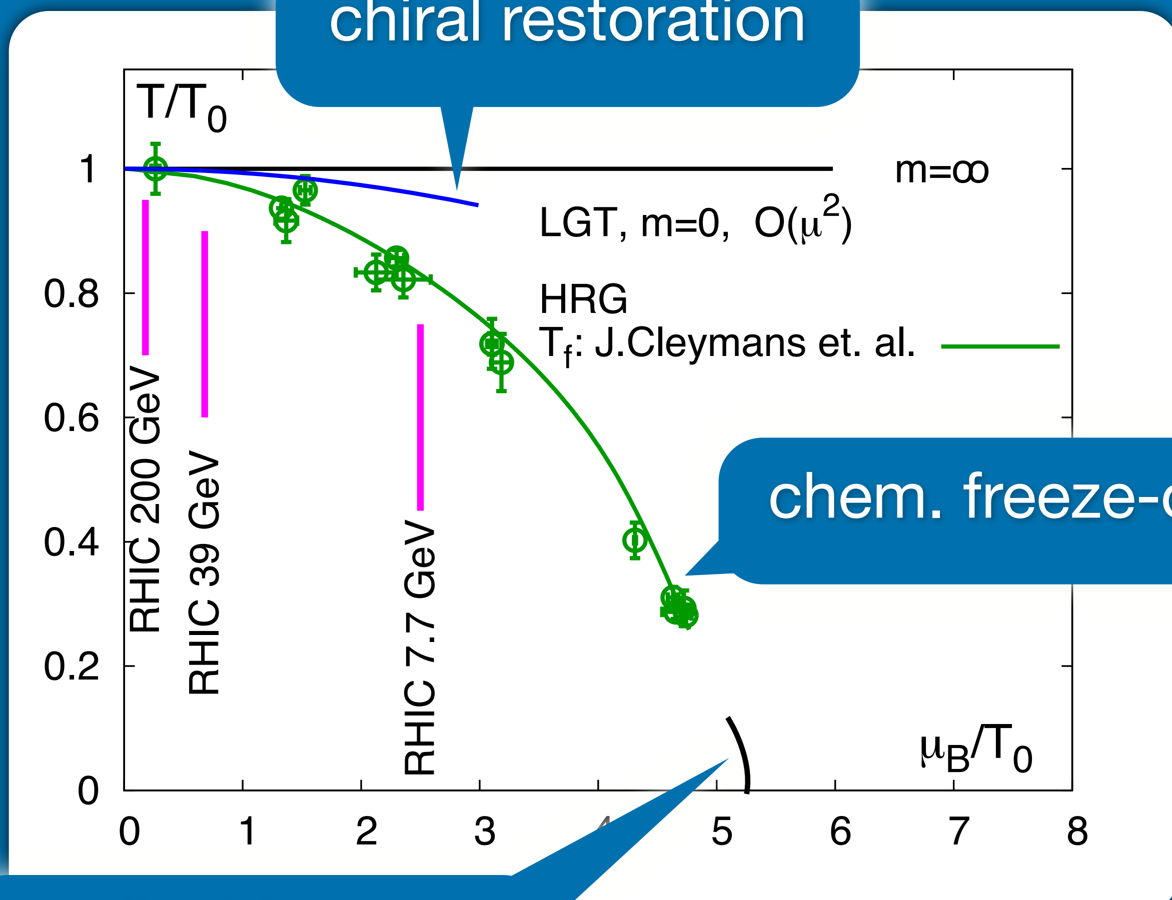
Motivation

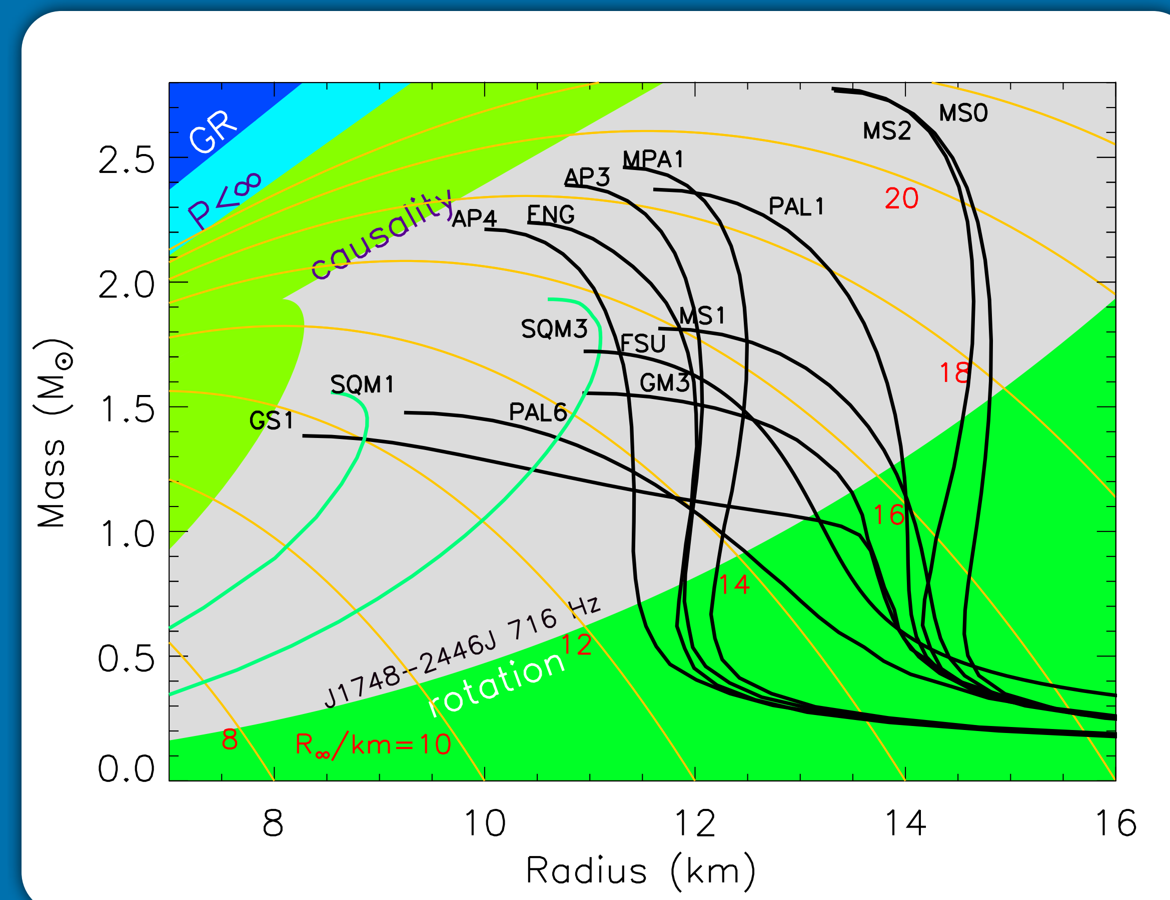


chiral restoration

chem. freeze-out

liquid-gas transition

Kaczmarek *et al.* Phys. Rev. D **83**, 2011



Lattimer, Annu. Rev. Nucl. Part. Sci. 62, 2012

Nucleon-meson model

scalar-isoscalar boson

pions

protons & neutrons

Lagrangian

$$\mathcal{L} = \bar{\psi}\Big(i\gamma^\mu\partial_\mu - g_s(\sigma + i\gamma^5\boldsymbol{\pi}\cdot\boldsymbol{\tau}) - g_\omega\gamma_\mu\omega^\mu - g_\rho\gamma_\mu\boldsymbol{\rho}^\mu\cdot\boldsymbol{\tau}\Big)\psi$$
$$+ \frac{1}{2}\partial_\mu\sigma\,\partial^\mu\sigma + \frac{1}{2}\partial_\mu\boldsymbol{\pi}\,\partial^\mu\boldsymbol{\pi} - U_{\mathrm{mic}}(\sigma,\boldsymbol{\pi})$$
$$- \frac{1}{4}F^{(\omega)}_{\mu\nu}F^{\mu\nu}_{(\omega)} + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu - \frac{1}{4}\boldsymbol{F}^{(\rho)}_{\mu\nu}\boldsymbol{F}^{\mu\nu}_{(\rho)} + \frac{1}{2}m_\rho^2\boldsymbol{\rho}_\mu\boldsymbol{\rho}^\mu$$

vector-isoscalar boson

vector-isovector boson

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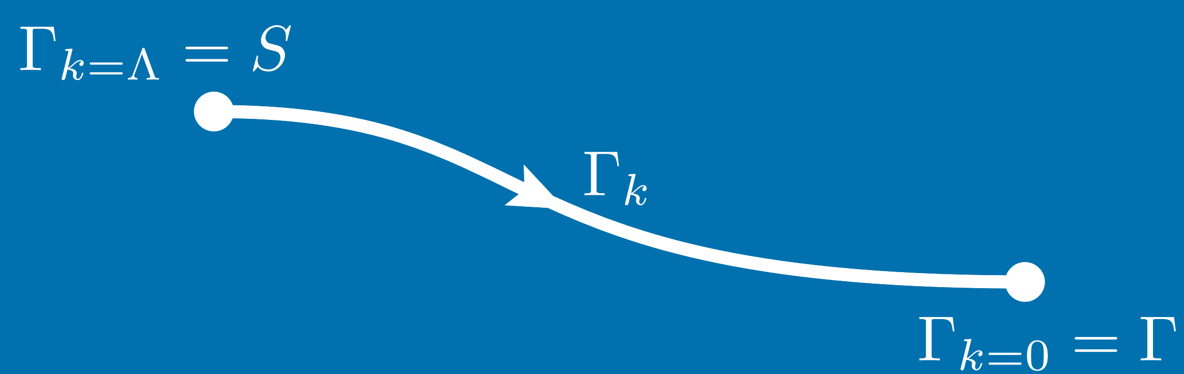
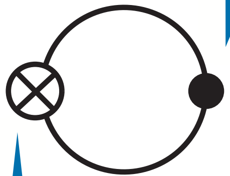


Wetterich's flow equation

$$k\partial_k \Gamma_k[\Phi] = \frac{1}{2}\,\mathrm{Tr}\,k\partial_k R_k \left(\Gamma_k^{(2)}[\Phi] + R_k\right)^{-1} =$$



full propagator

renormalization scale

k-dependent effective action

regulator

Wetterich, Phys.Lett. **B301**, 1993

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Flow equation

$$\partial_k U_k = \frac{k^4}{12\pi^2}\left[\frac{3}{E_\pi}\left(1+2\frac{1}{e^{\beta E_\pi}-1}\right)+\frac{1}{E_\sigma}\left(1+2\frac{1}{e^{\beta E_\sigma}-1}\right)- \right.$$
$$\left. - \sum_{i=n,p}\frac{4}{E_N}\left(1-\frac{1}{e^{\beta(E_N-\mu_{i,\mathrm{eff}})}+1}-\frac{1}{e^{\beta(E_N+\mu_{i,\mathrm{eff}})}+1}\right)\right]$$

pion loop

sigma loop

nucleon loop

anti-nucleon loop

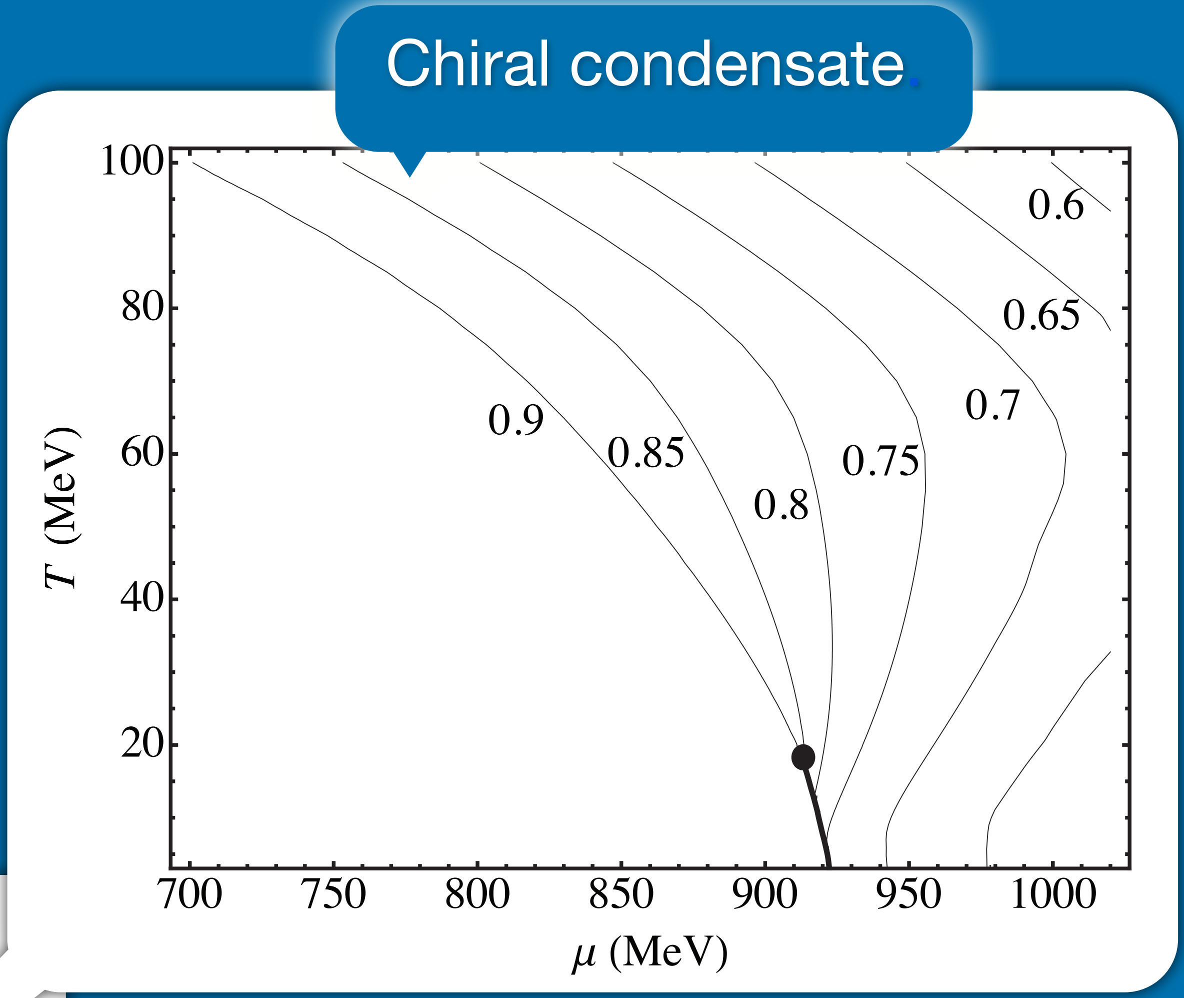
$$E_\pi^2 = k^2 + \frac{\partial U_k}{\partial \chi}, \quad E_\sigma^2 = k^2 + \frac{\partial U_k}{\partial \chi} + 2\chi\frac{\partial^2 U_k}{\partial \chi^2}, \quad E_N^2 = k^2 + 2g_s^2\chi,$$

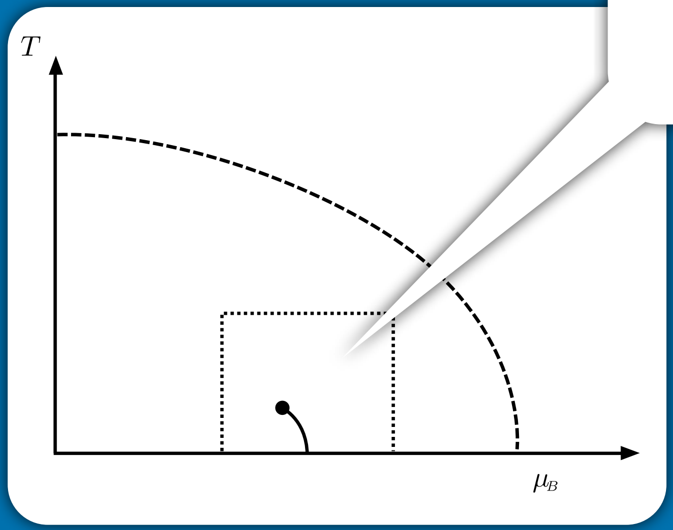
$$\chi = \frac{1}{2}(\sigma^2 + \boldsymbol{\pi}^2) \qquad \Gamma_k = \beta V \cdot U_k$$

full inverse propagators

Chiral restoration

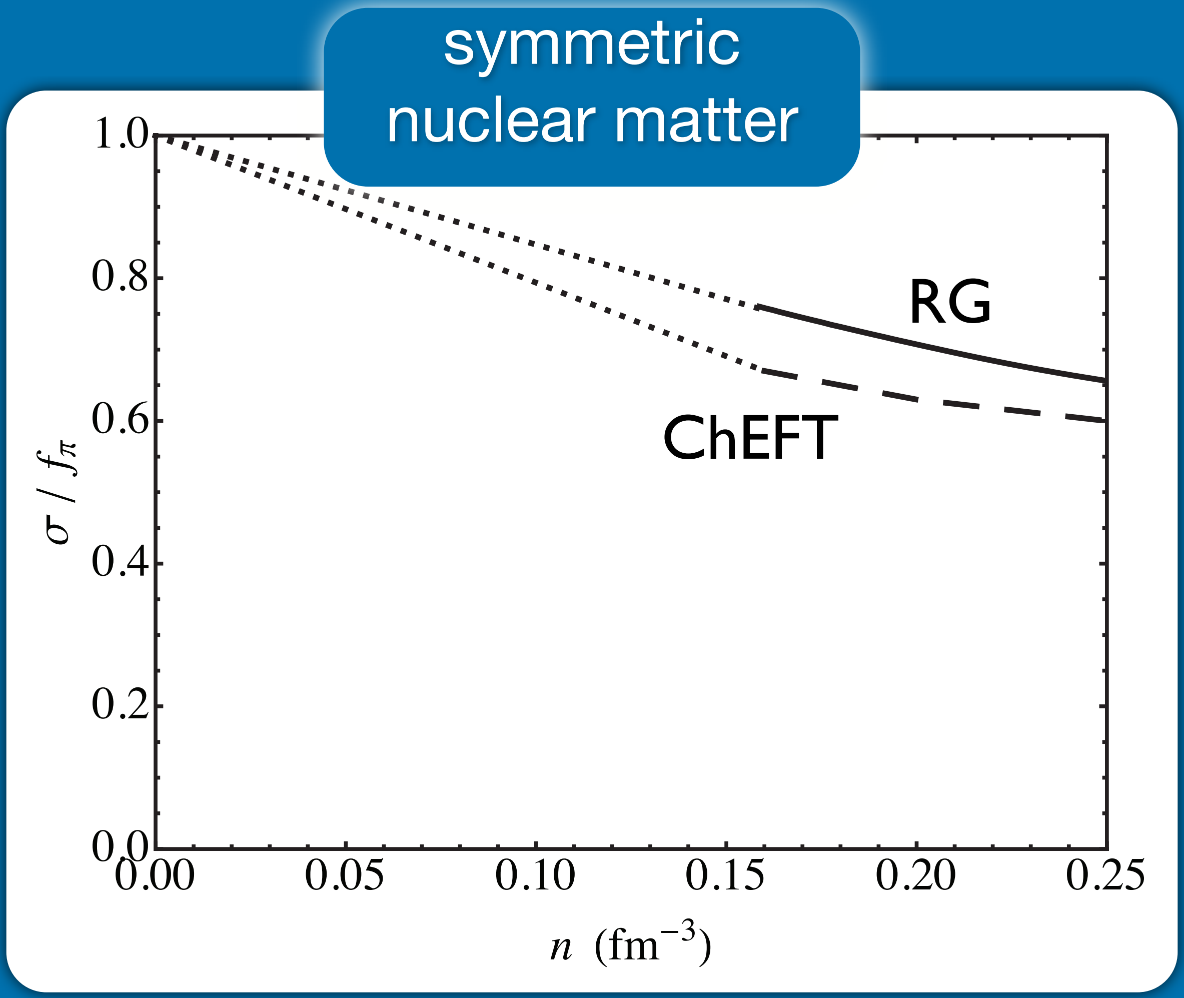
Drews, Hell, Klein, Weise, Phys.Rev. D **88**, 2013



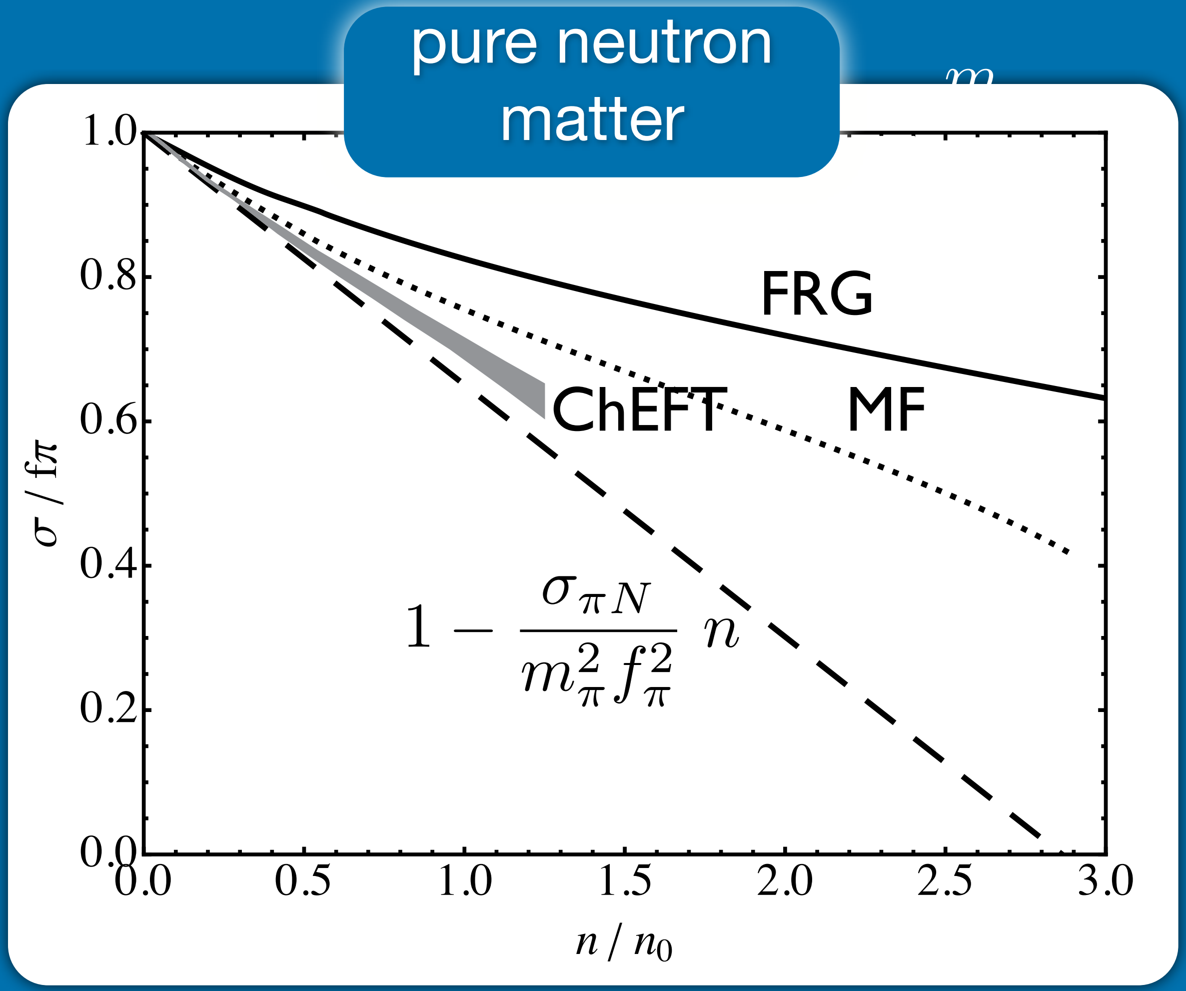


Chiral condensate

Drews, Hell, Klein, Weise, Phys.Rev. D **88**, 2013



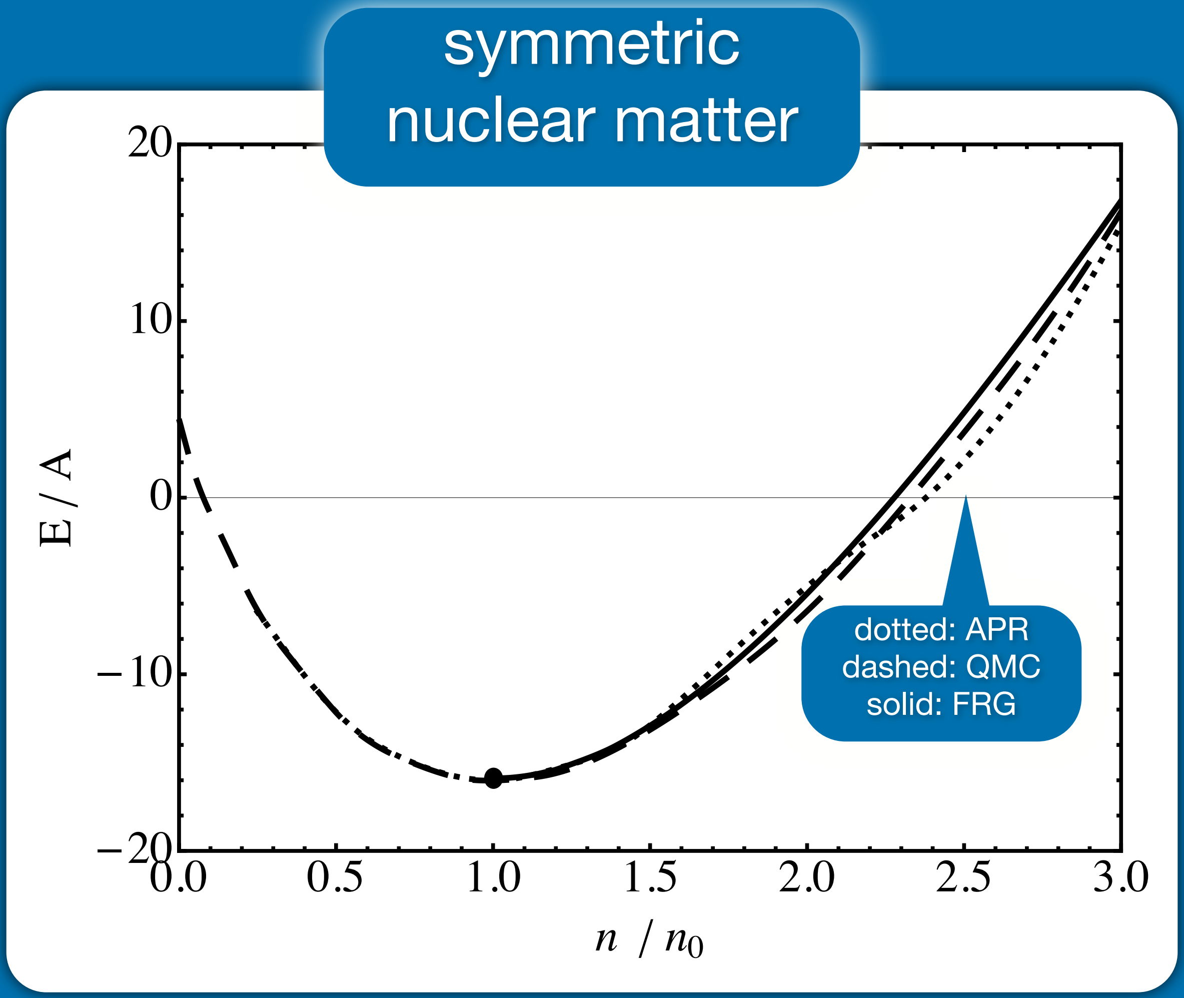
ChEFT: Fiorilla, Kaiser, Weise, Nucl. Phys. **A 880**, 2012
Fiorilla, Kaiser, Weise, Phys. Lett. **B 714**, 2012

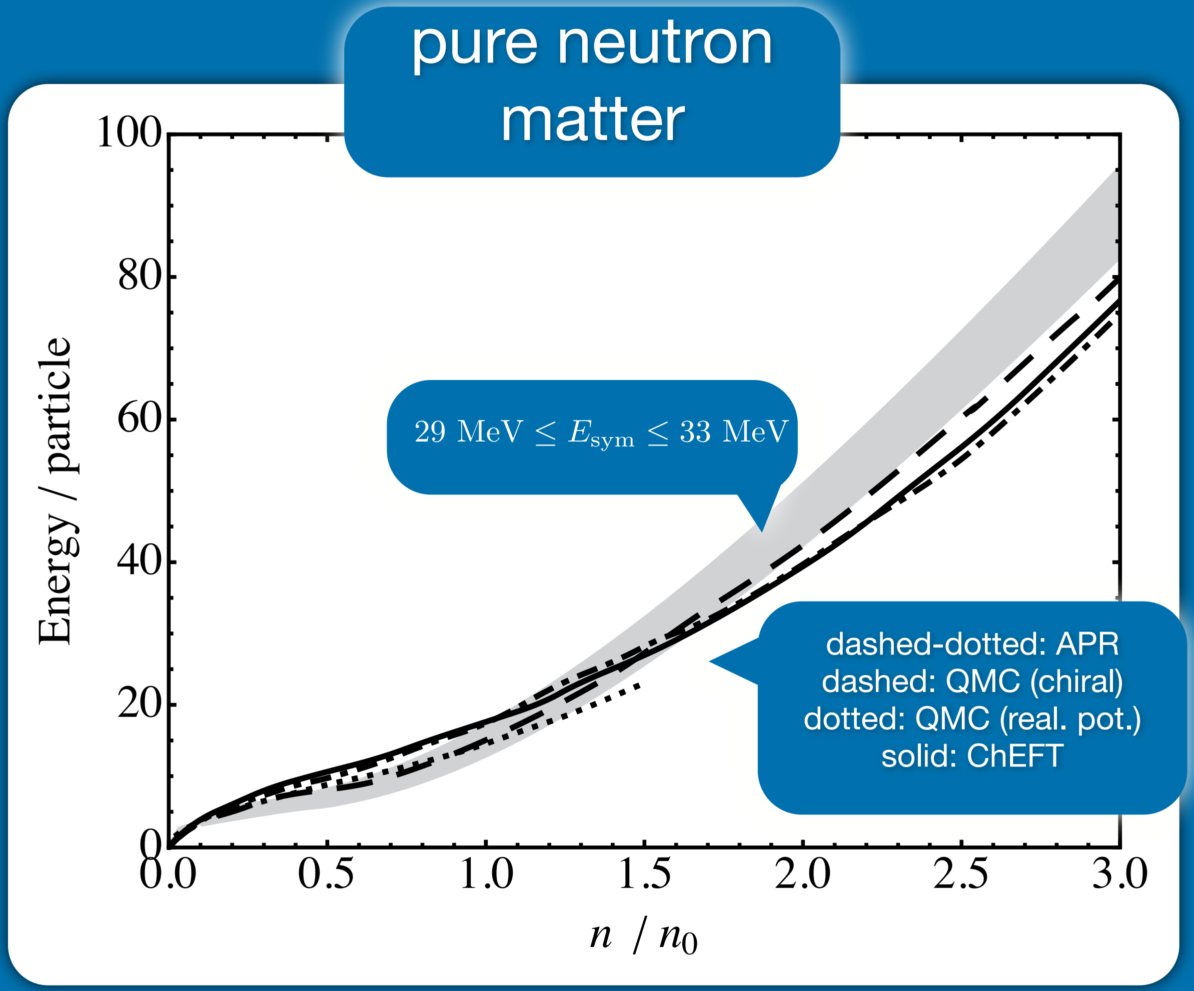


ChEFT: Krüger *et al.*, Phys. Lett. **B 726** (2013)

Equations of State

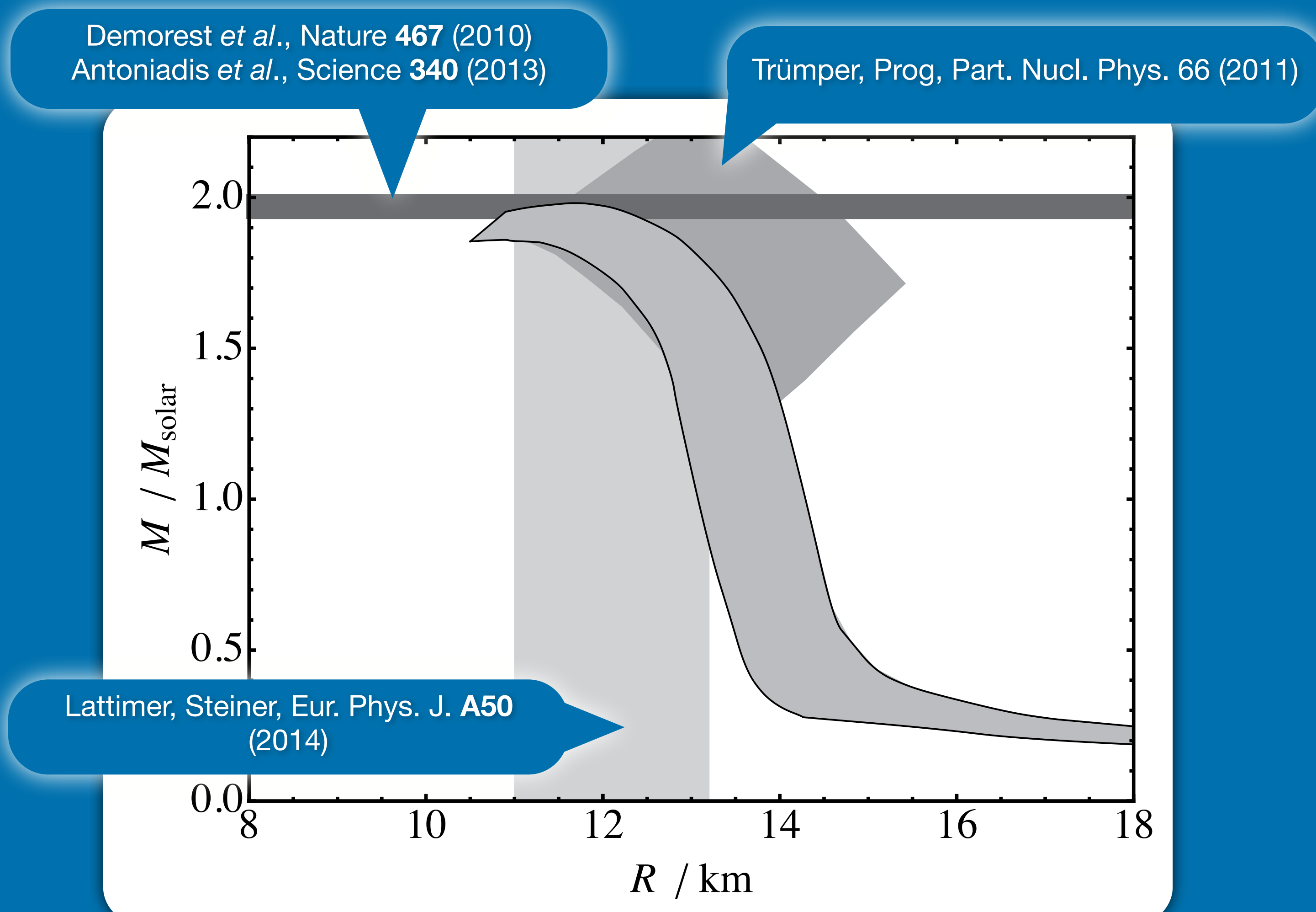
Drews, Hell, Klein, Weise, Phys.Rev. D **88**, 2013
Drews, Weise, arXiv:1404.0882

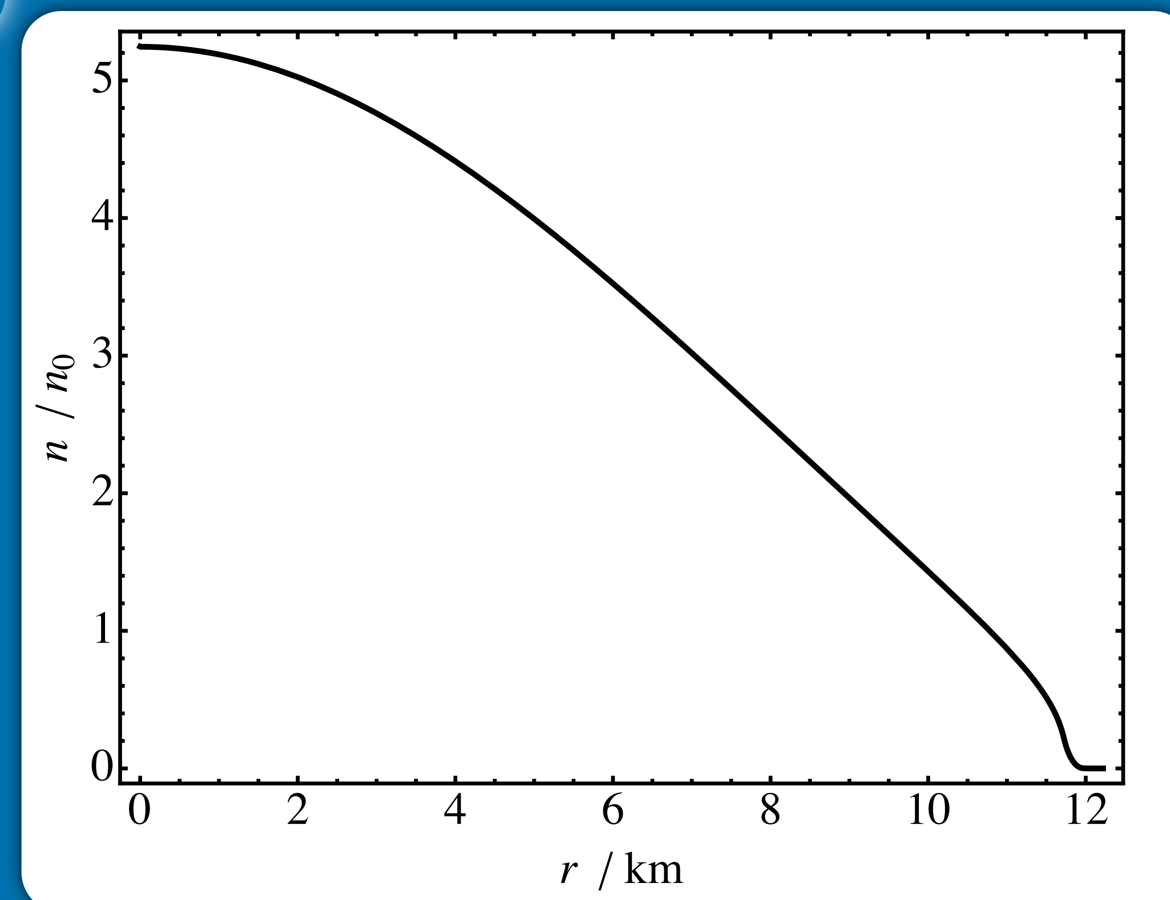




Neutron Stars

Drews, Weise, arXiv:1404.0882





mass $M = 1.97\ M_\odot$

radius $R = 12.2$ km

Summary

- chiral restoration and chemical freeze out
- symmetric and asymmetric matter
- neutron stars