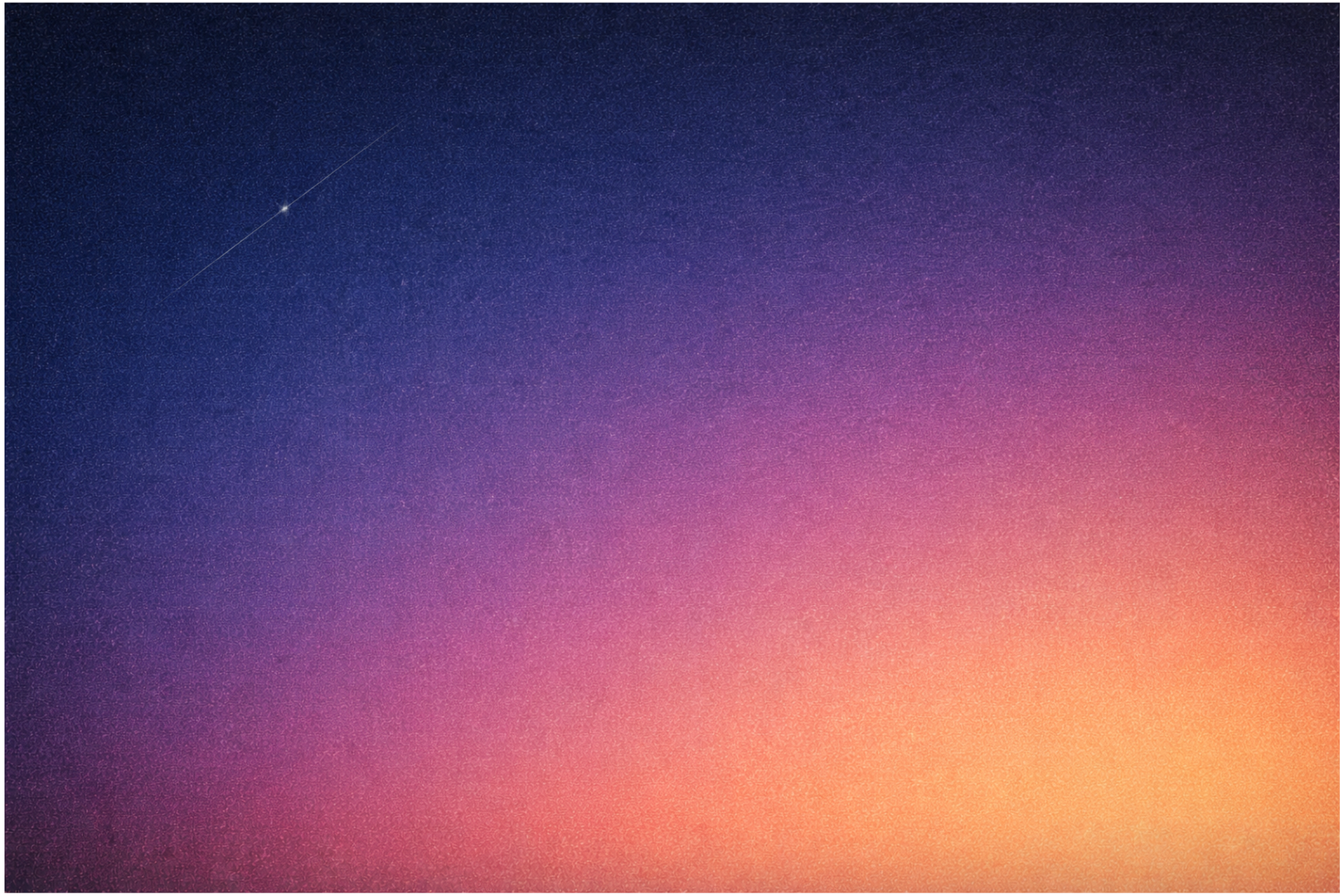
First-principles motivated prior for neutron-star equation-of-state inference



Oleg Komoltsev
[komoltsev.com]
New Frontiers in QCD
Kyoto · October 2026

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

UNTERSTÜTZT VON / SUPPORTED BY
Alexander von HUMBOLDT STIFTUNG

CRC-TR 211
Strong-interaction matter under extreme conditions

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OPEN ACCESS

Constrained Gaussian-process-bridge Prior for Neutron-star Equation-of-state Inference

Tyler Gorda, Oleg Komoltsev, Aleksi Kurkela, and Eirik Sunde

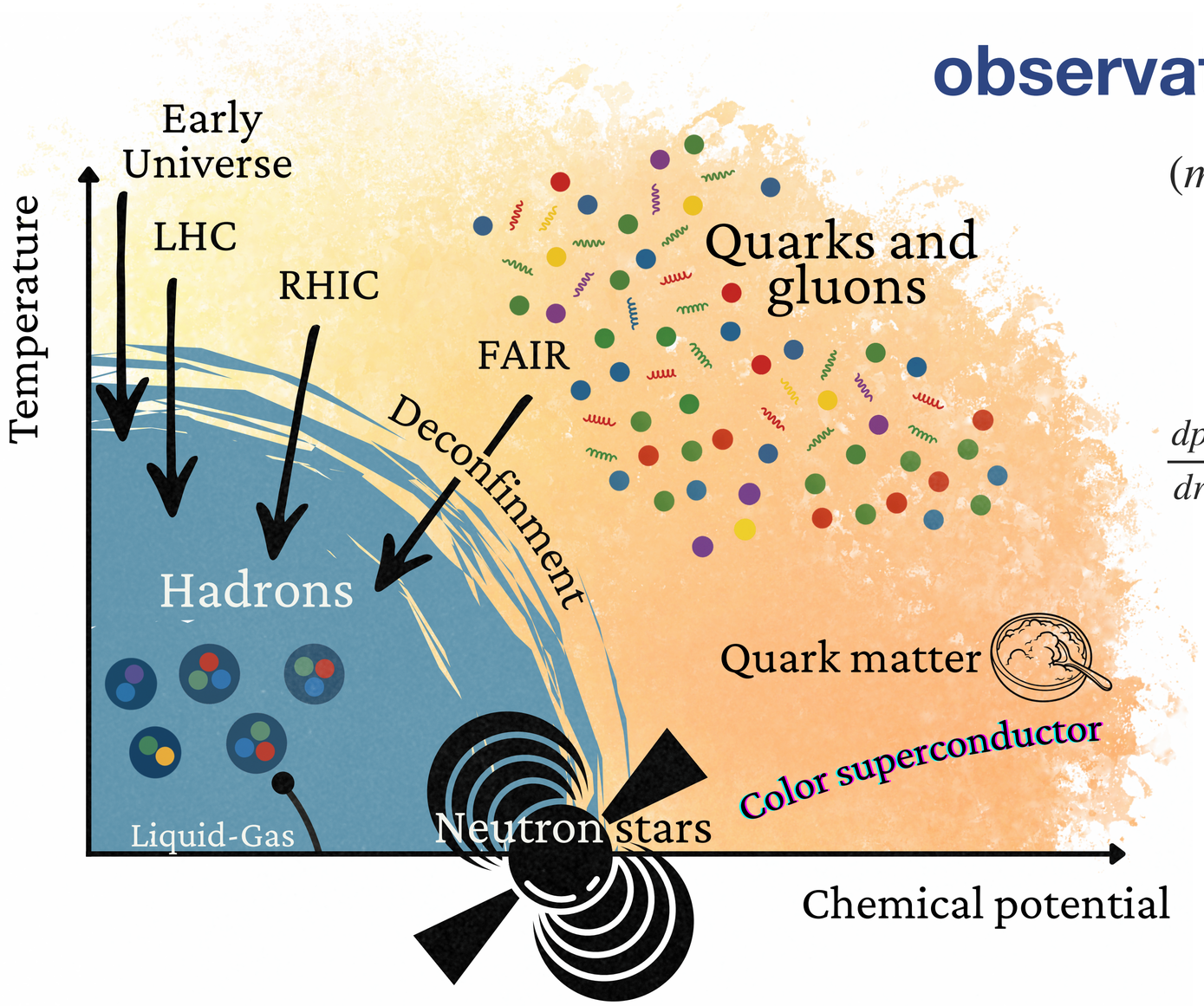
Published 2026 April 23 • © 2026. The Author(s). Published by the American Astronomical Society.

The Astrophysical Journal, Volume 1002, Number 1

Citation Tyler Gorda *et al* 2026 *ApJ* **1002** 40

DOI 10.3847/1538-4357/ae552a

QCD phase diagram



observations

$$(m, r, \Lambda)$$

tov & love

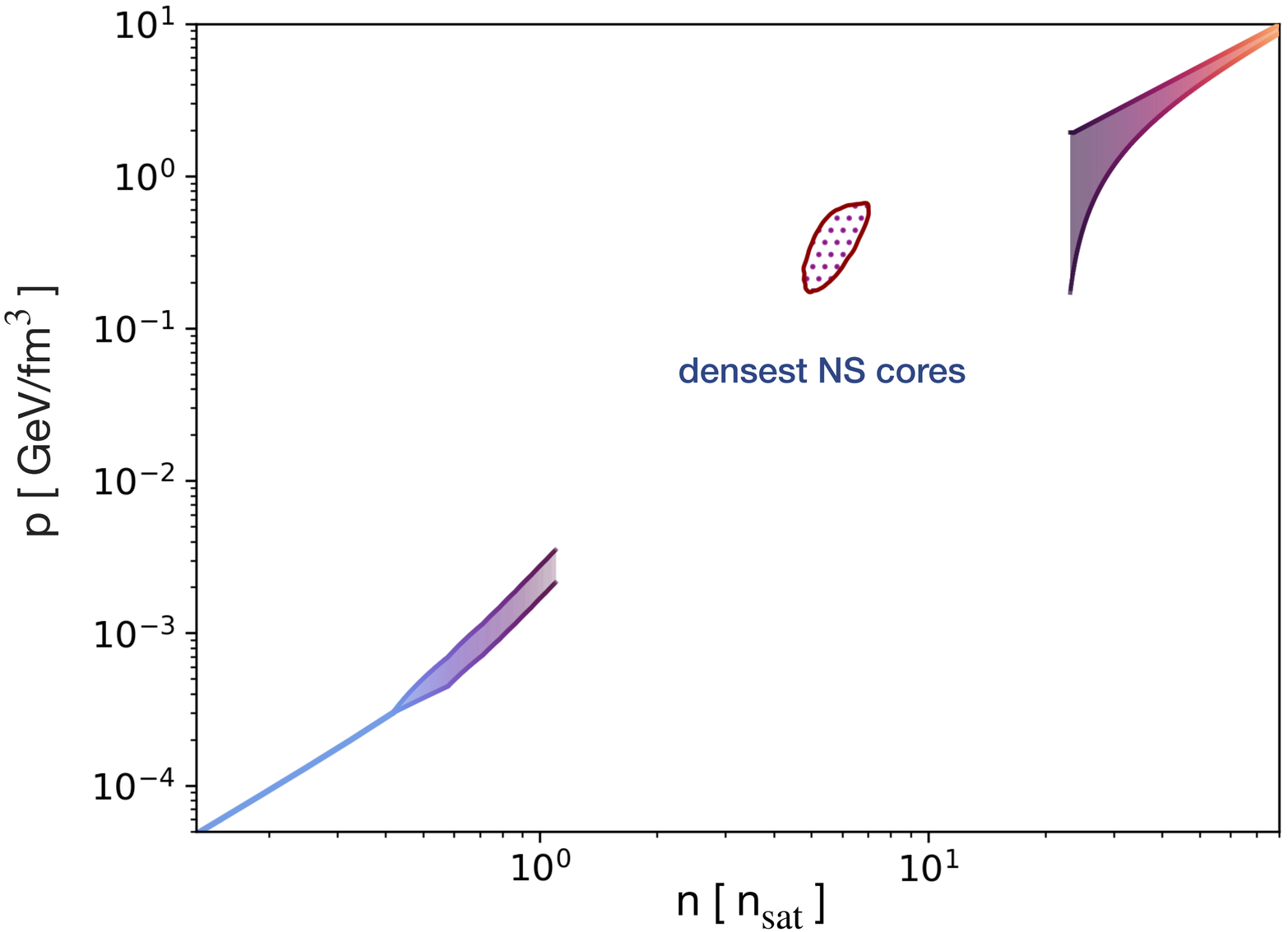
$$\frac{dp}{dr} = -\frac{Gm}{r^2}\varepsilon\left(1+\frac{p}{\varepsilon}\right)\left(1+\frac{4\pi r^3\varepsilon}{m}\right)\left(1-\frac{2Gm}{r}\right)^{-1}$$

$$\frac{dm}{dr} = 4\pi r^2\varepsilon \qquad \frac{d\Lambda}{dr} = f(r,\varepsilon,p)$$

equation of state

$$p(\varepsilon)$$

EoS from the first principles



perturbative QCD (pQCD)

Gorda, Kurkela et.al.
Phys. Rev. Lett. 127, 162003

chiral effective field theory (cEFT)

Hebeler, Lattimer et.al.
ApJ 773 11

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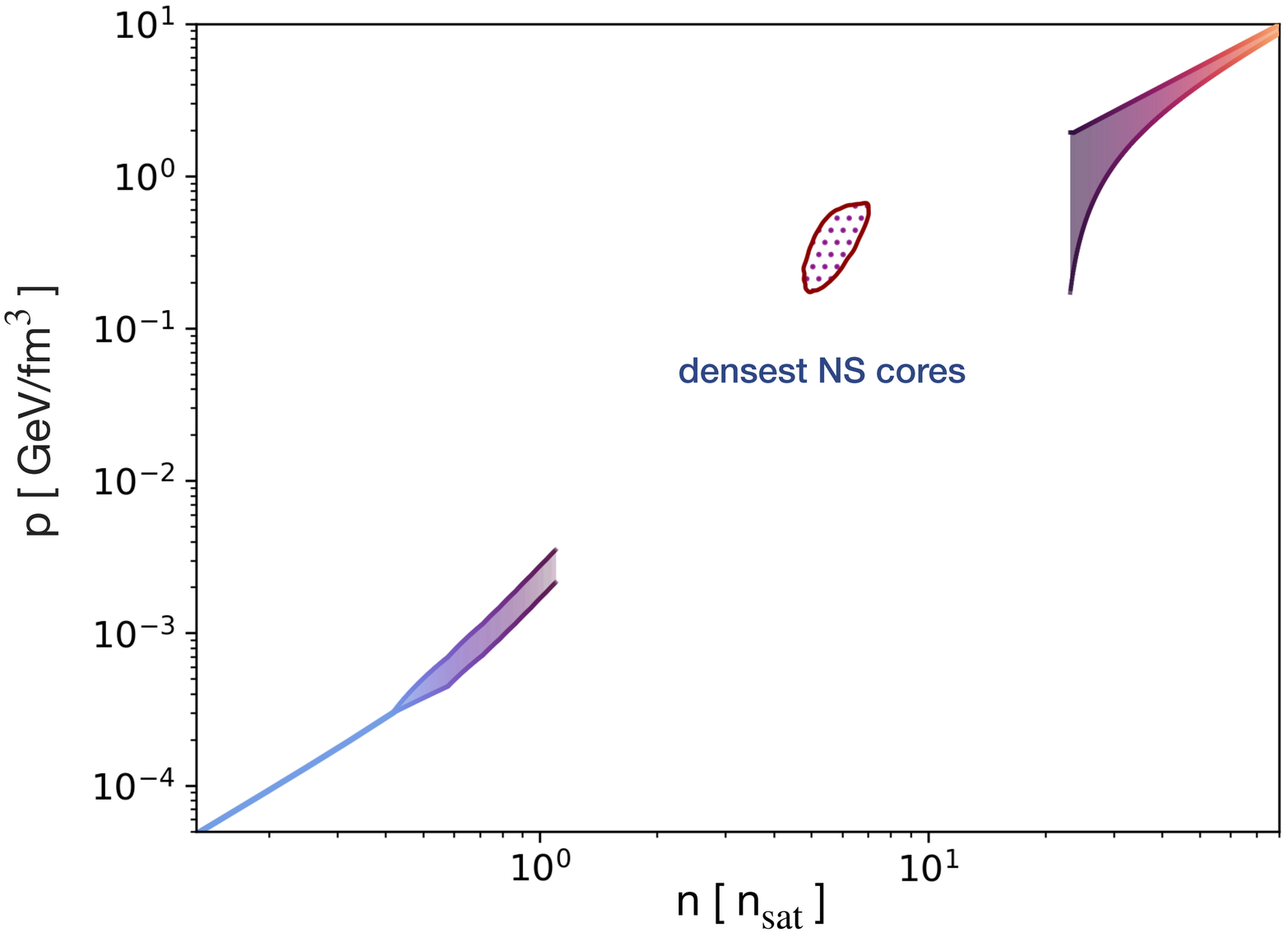

perturbative QCD (pQCD)

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polytropic interpolation
c_s^2 segments
Gaussian processes
GPB ← this talk

chiral effective field theory (cEFT)

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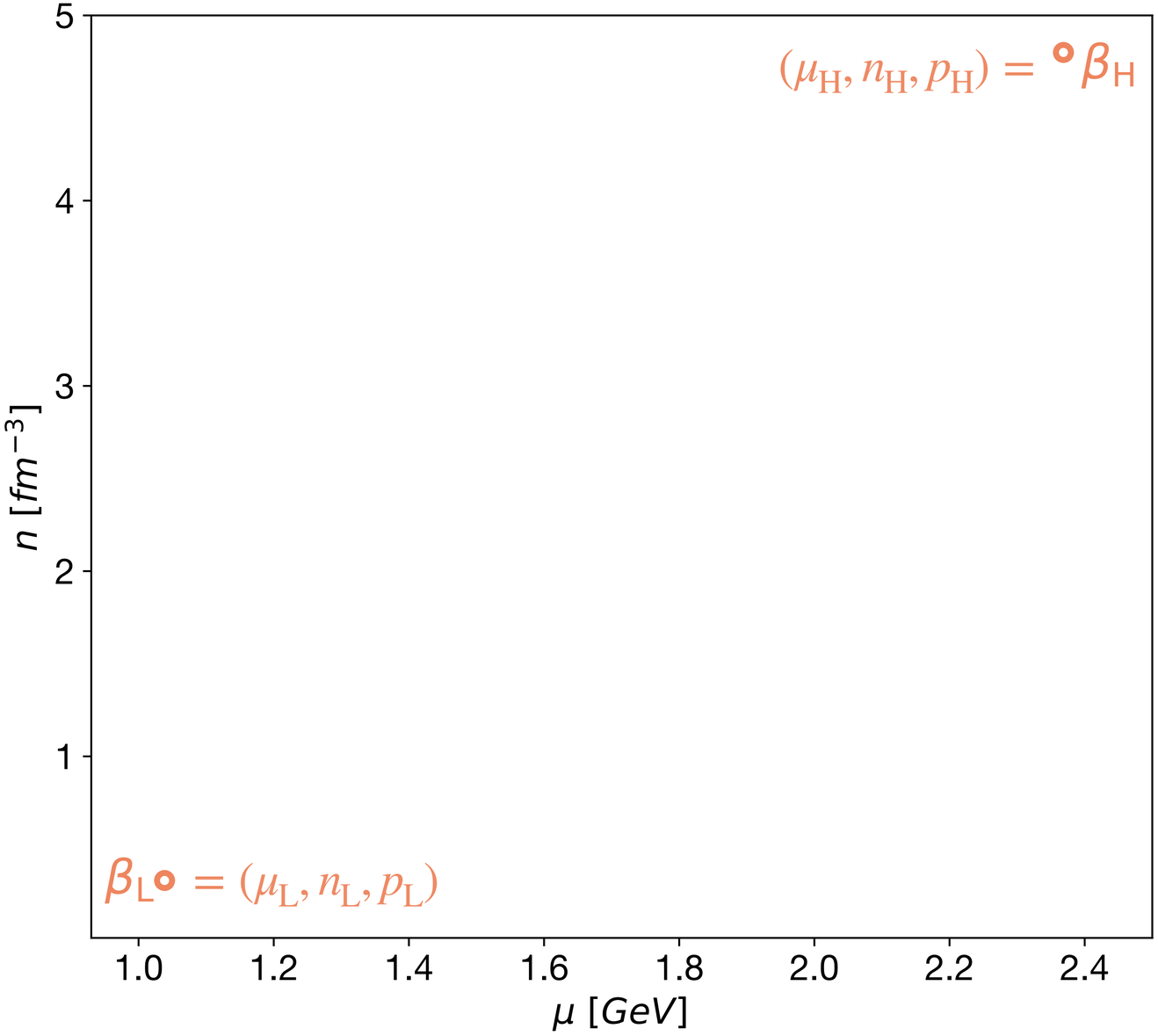
self-similar [fractal] EoS



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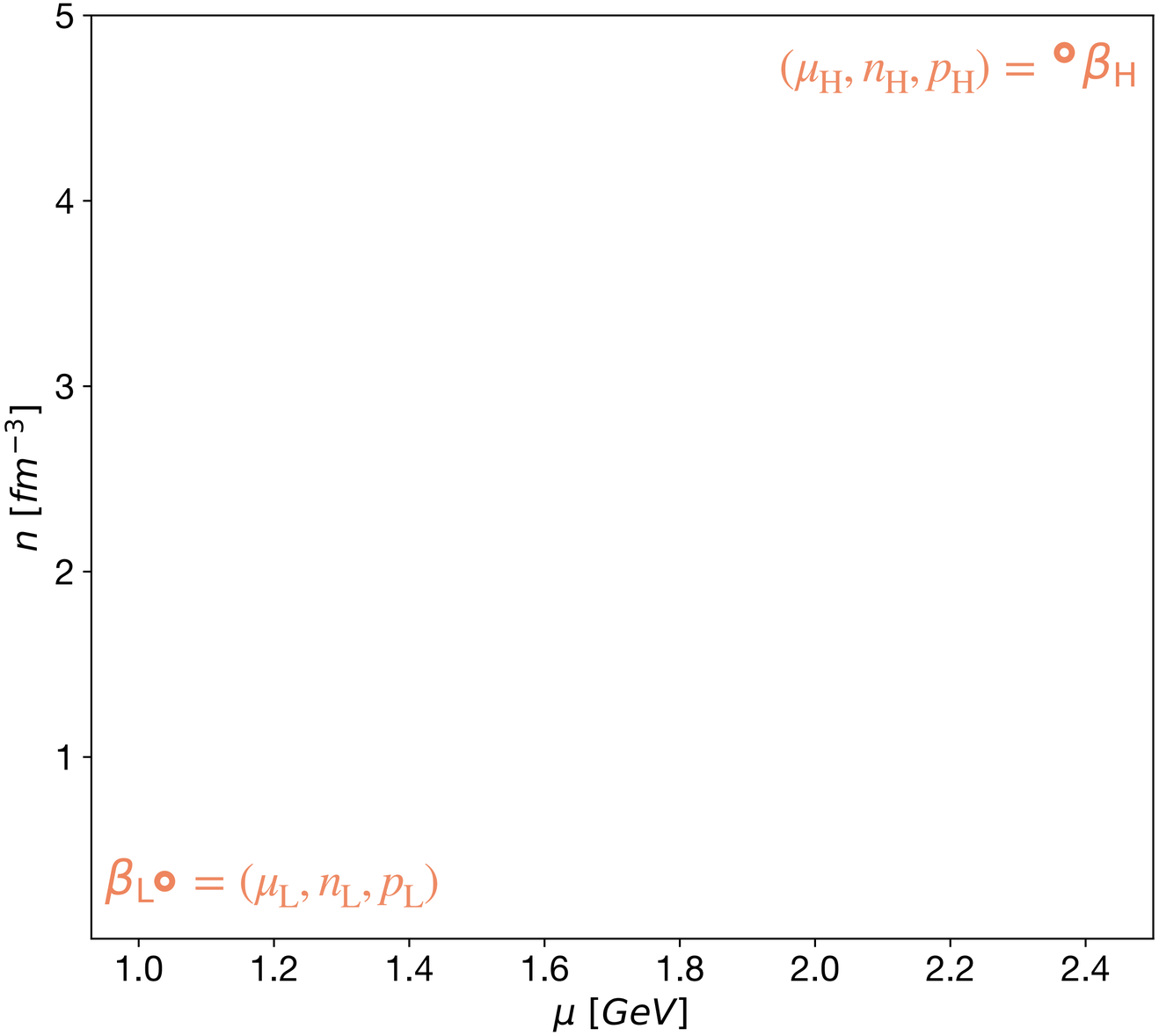
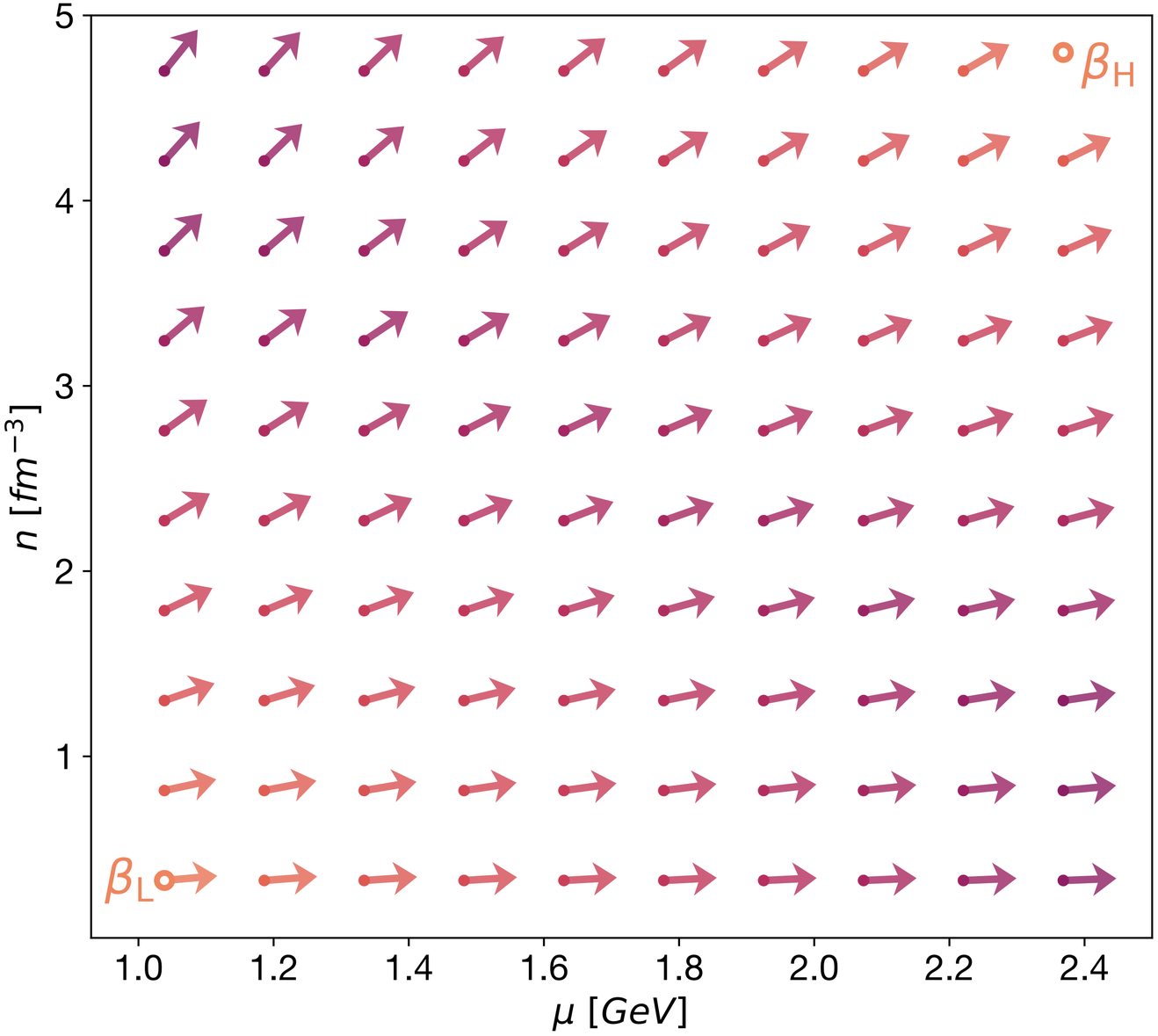


stability

$$\partial_\mu^2 \Omega(\mu) \leqslant 0 \Longrightarrow \partial_\mu n(\mu) \geqslant 0$$

self-similar [fractal] EoS



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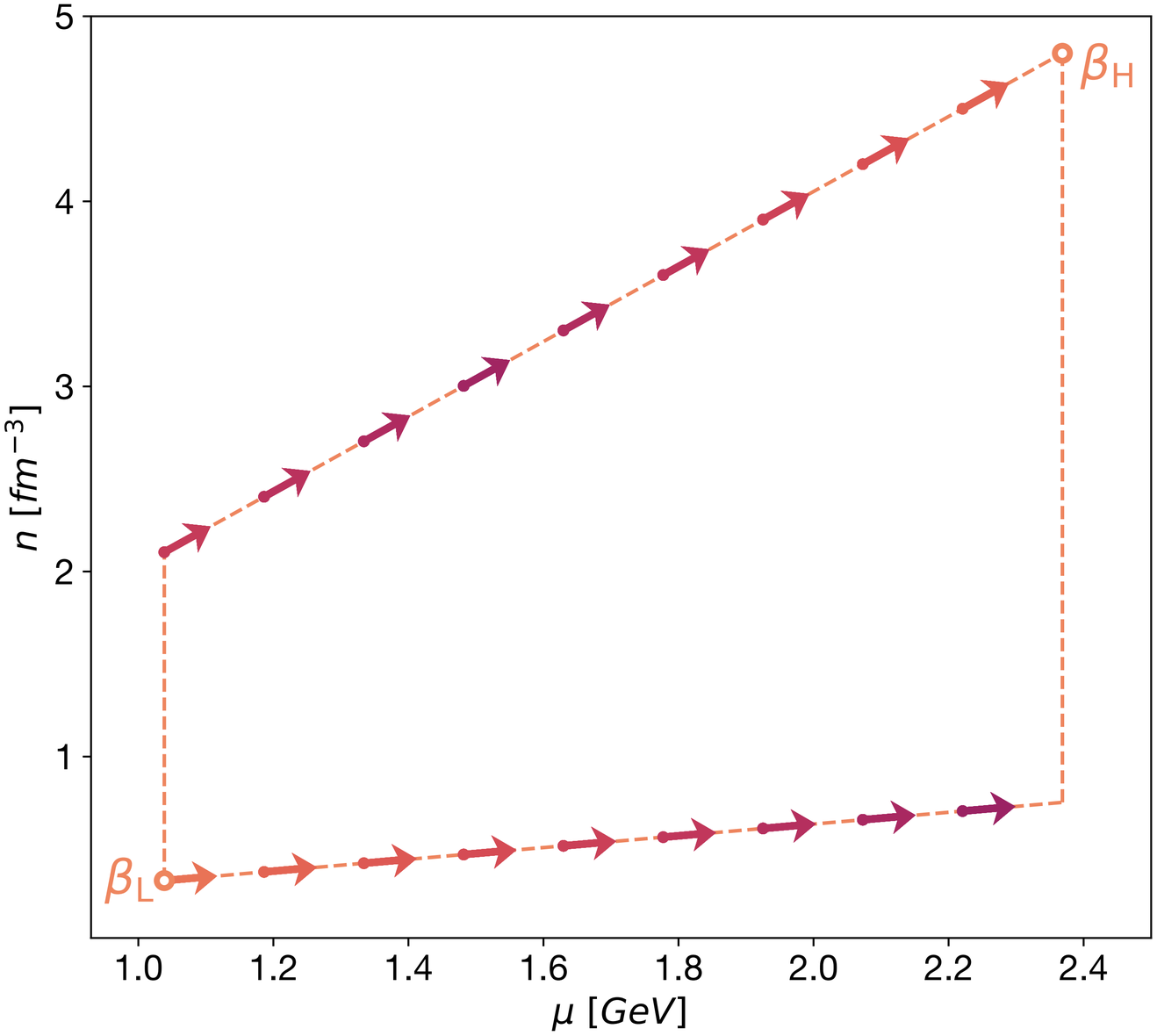
$$\partial_\mu^2 \Omega(\mu) \leqslant 0 \Longrightarrow \partial_\mu n(\mu) \geqslant 0$$

causality

$$c_s^{-2} = \frac{\mu}{n}\frac{\partial n}{\partial \mu} \geqslant 1$$

self-similar [fractal] EoS



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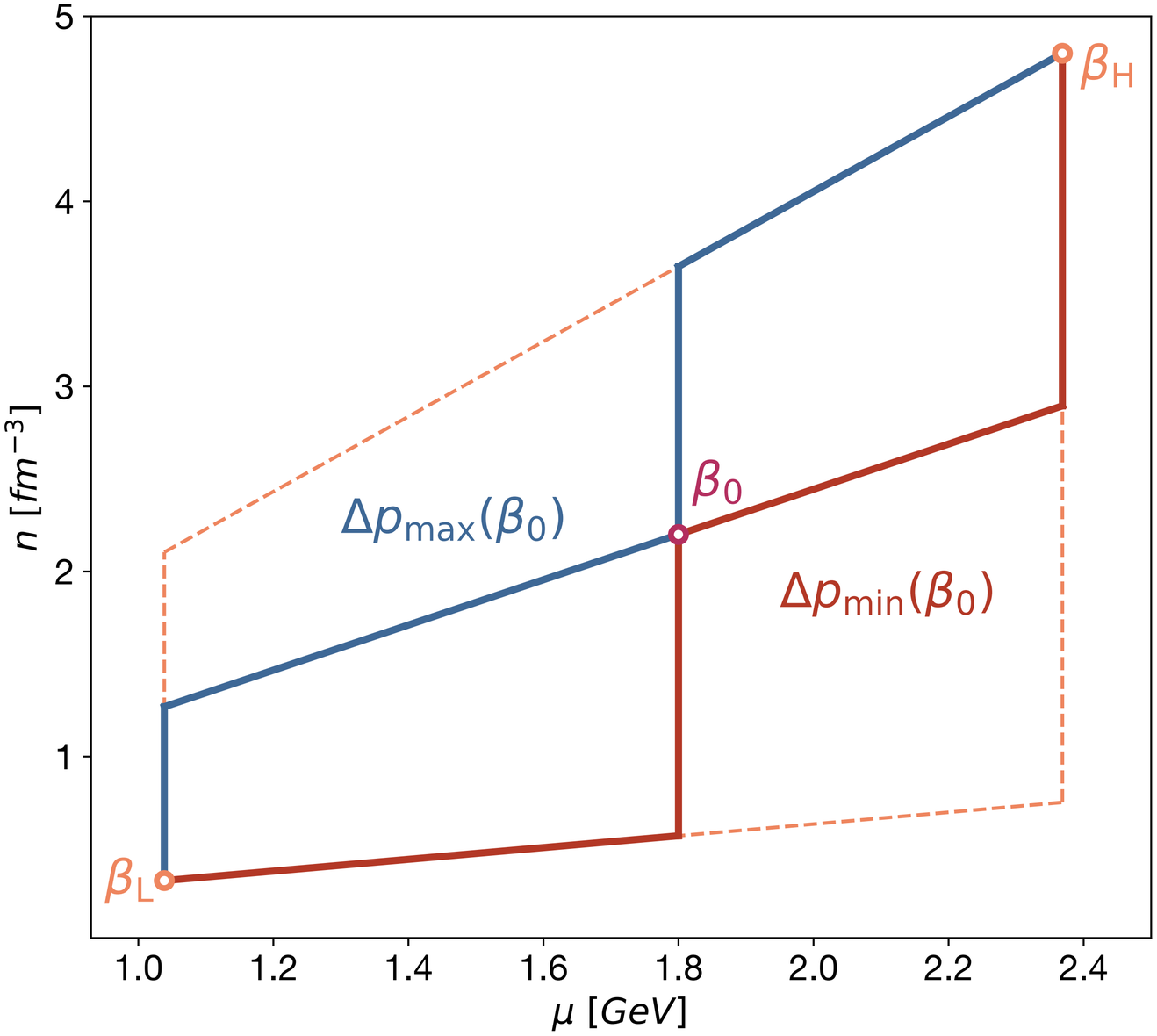

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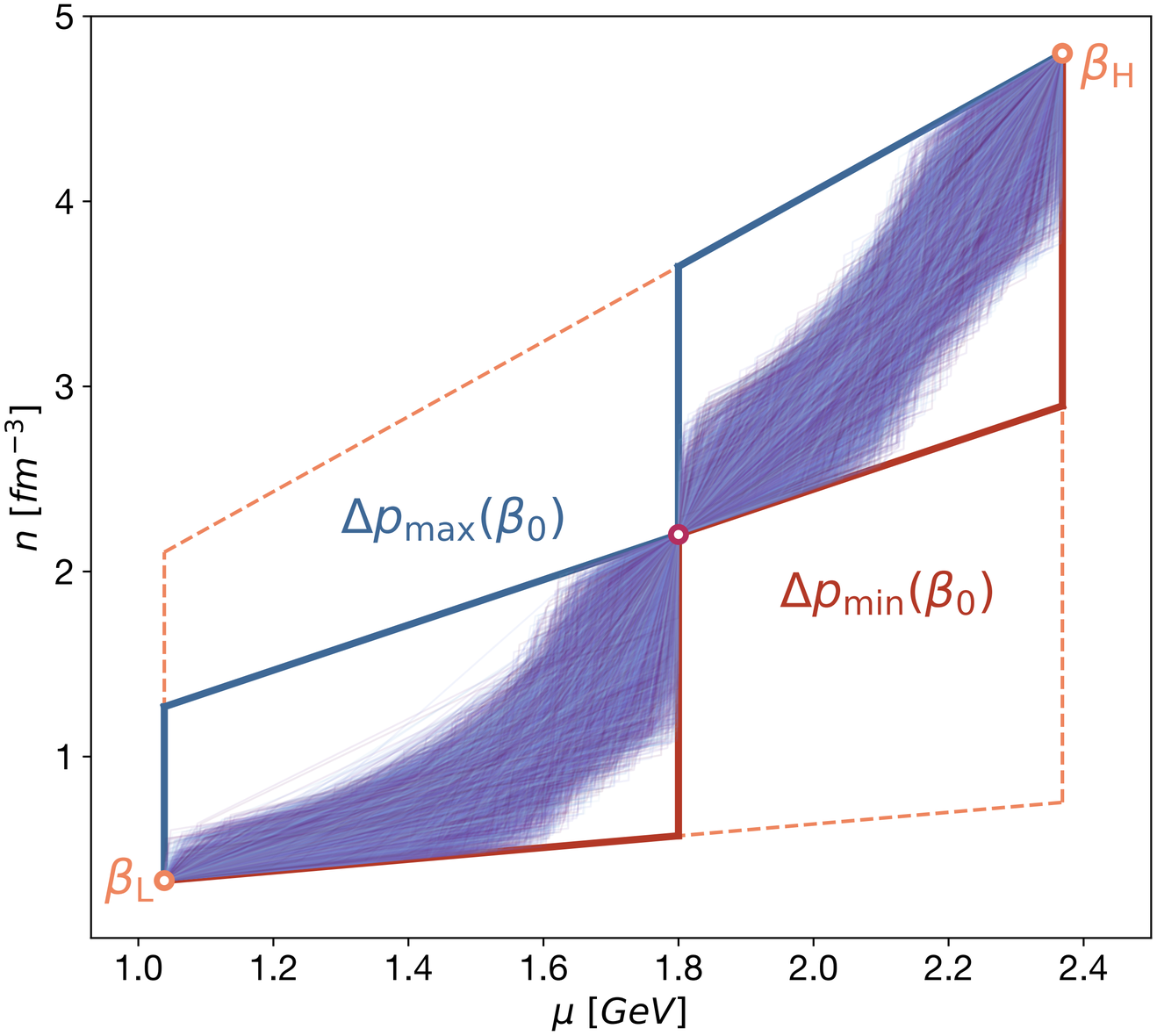
consistency

$$\int_{\mu_L}^{\mu_H} n(\mu)\, d\mu = p_L - p_H = \Delta p$$

self-similar [fractal] EoS



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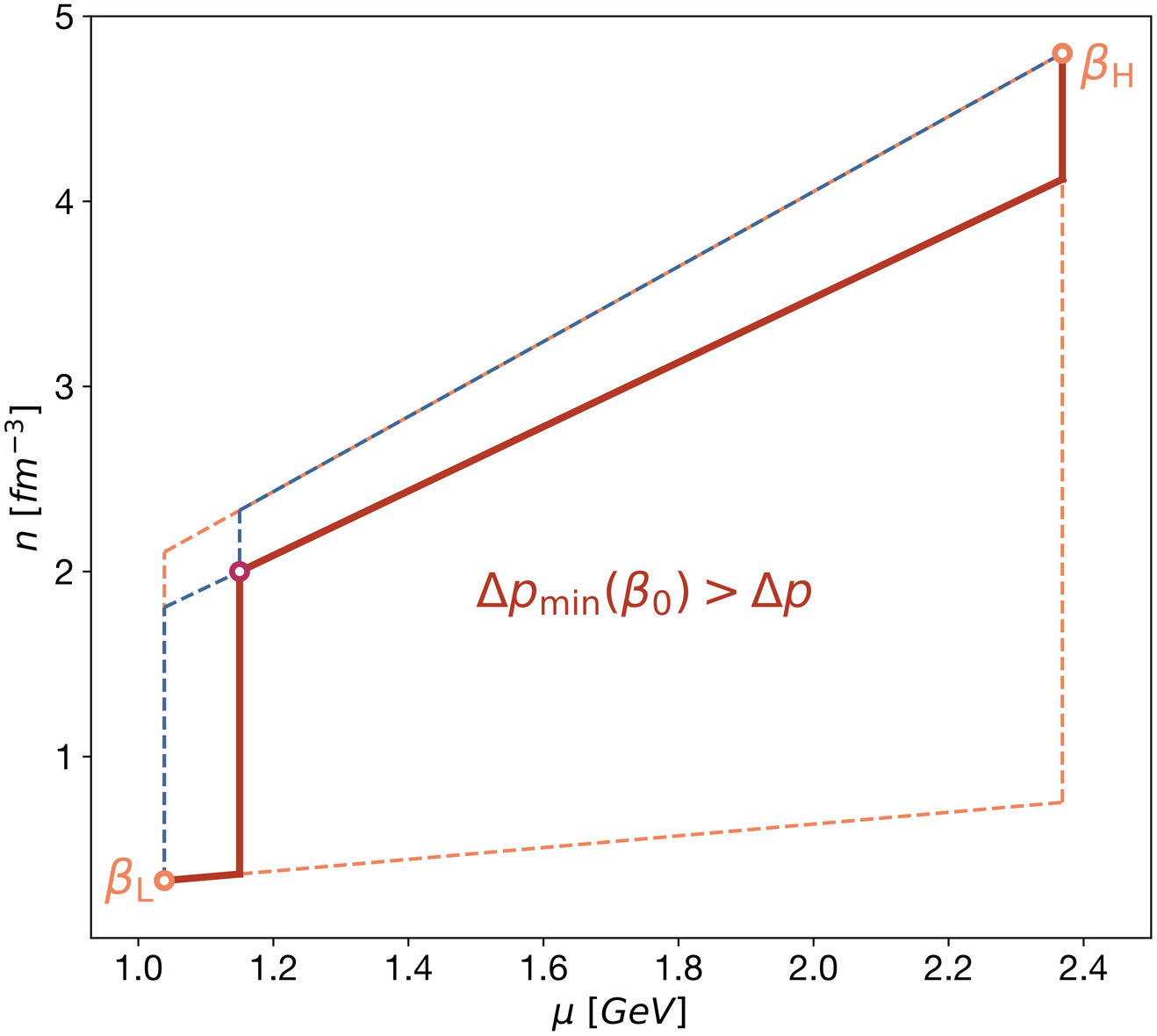

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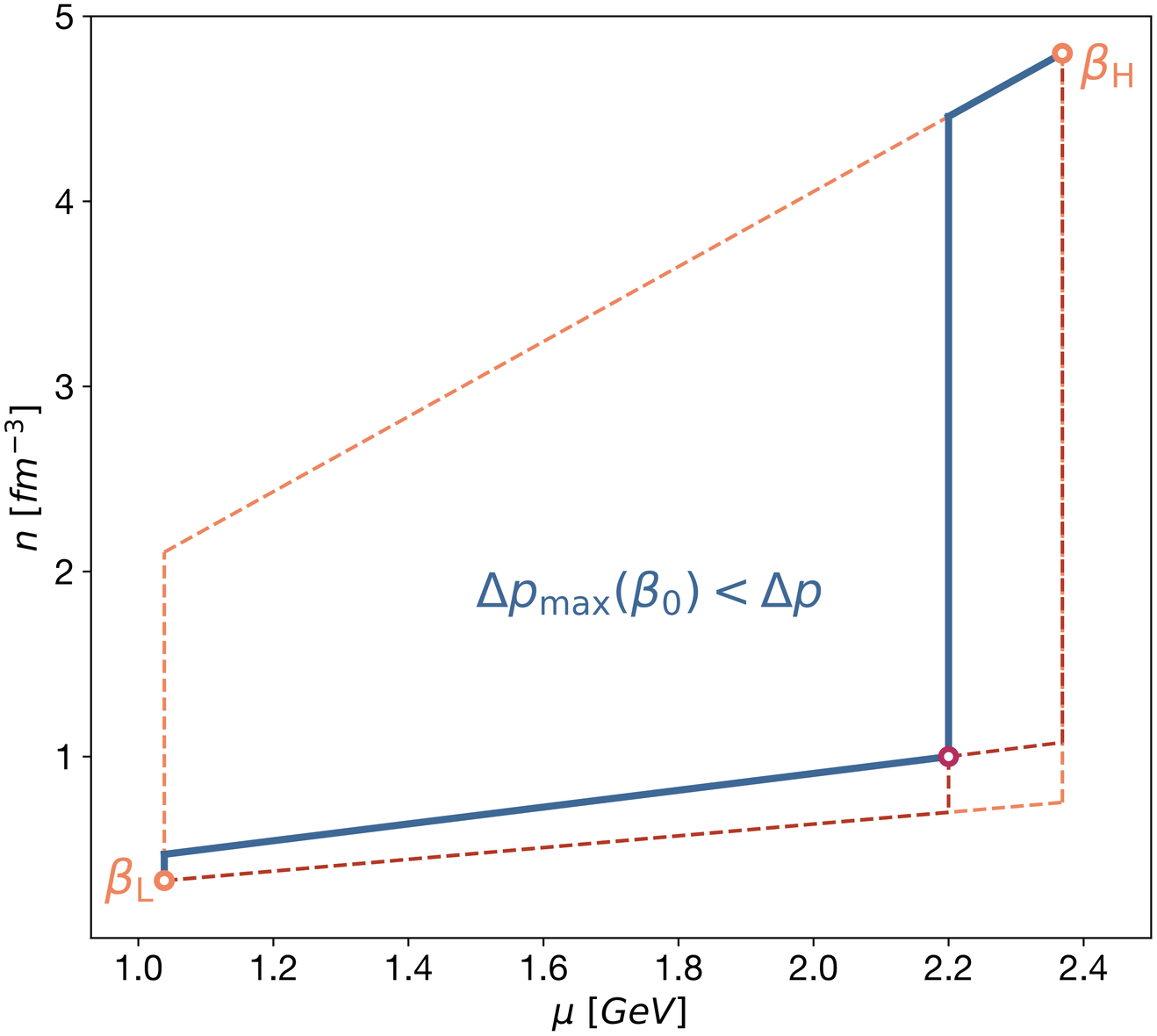

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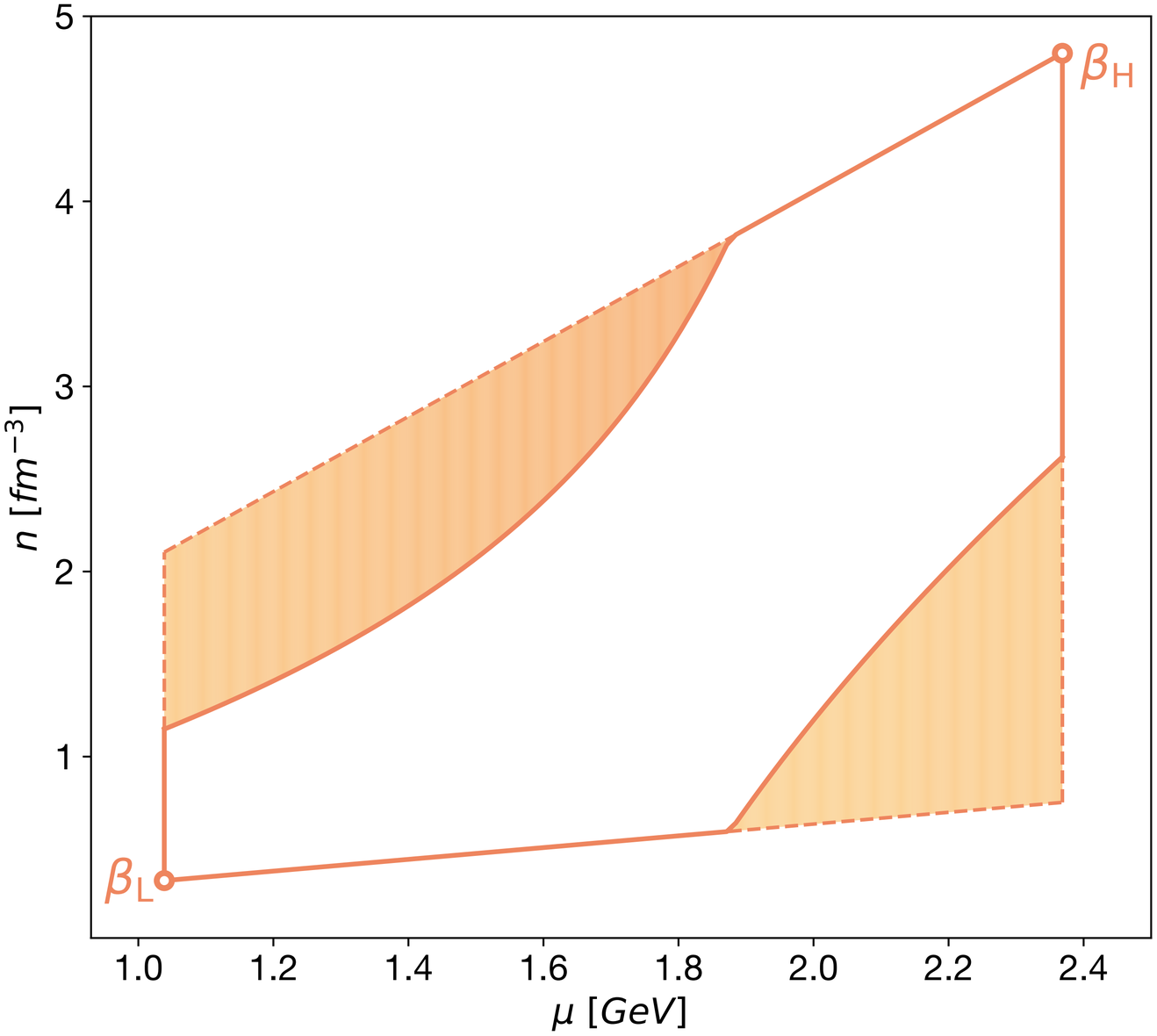

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O.K., A. Kurkela. PRL 128 (2022) 20, 202701

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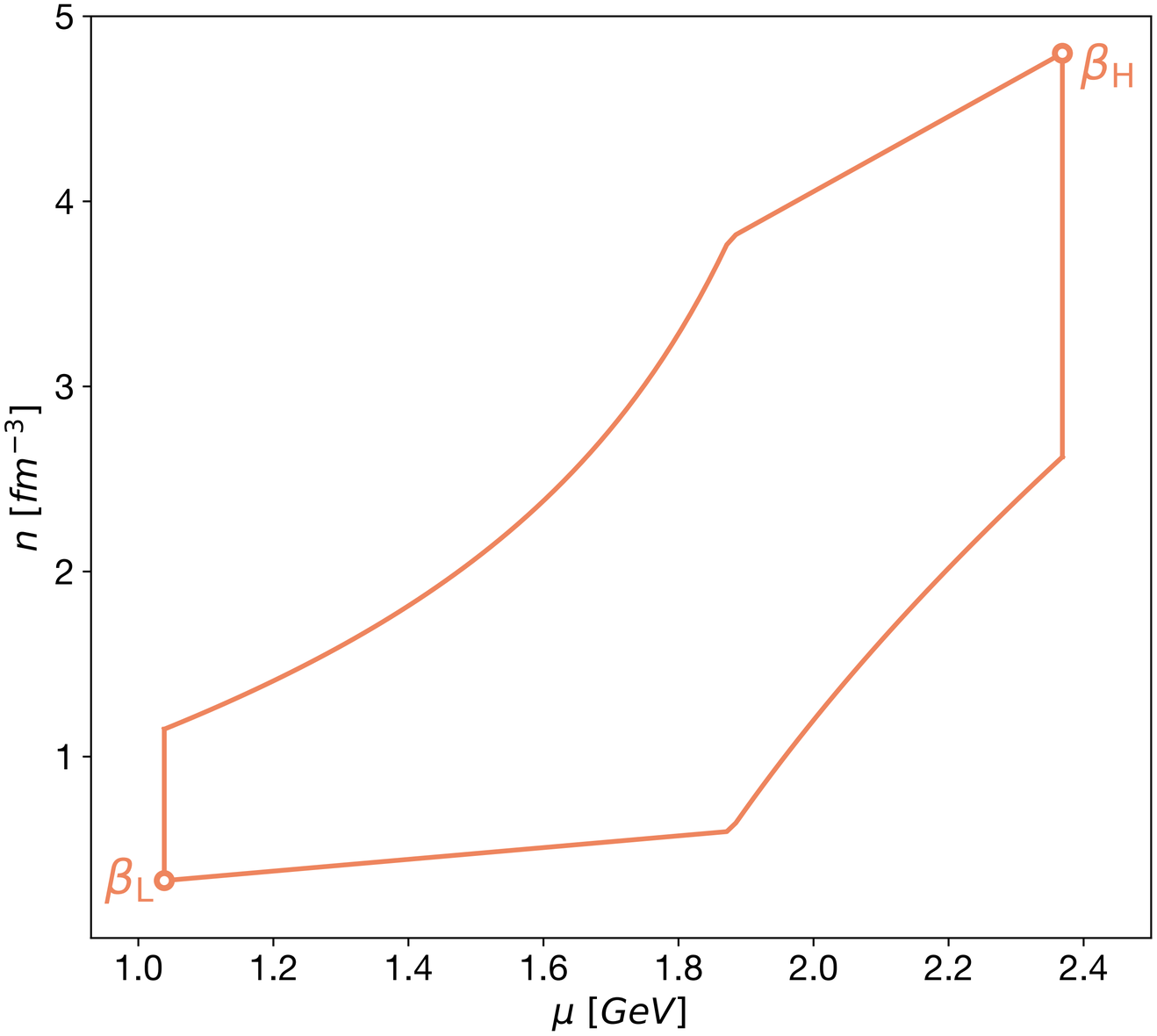
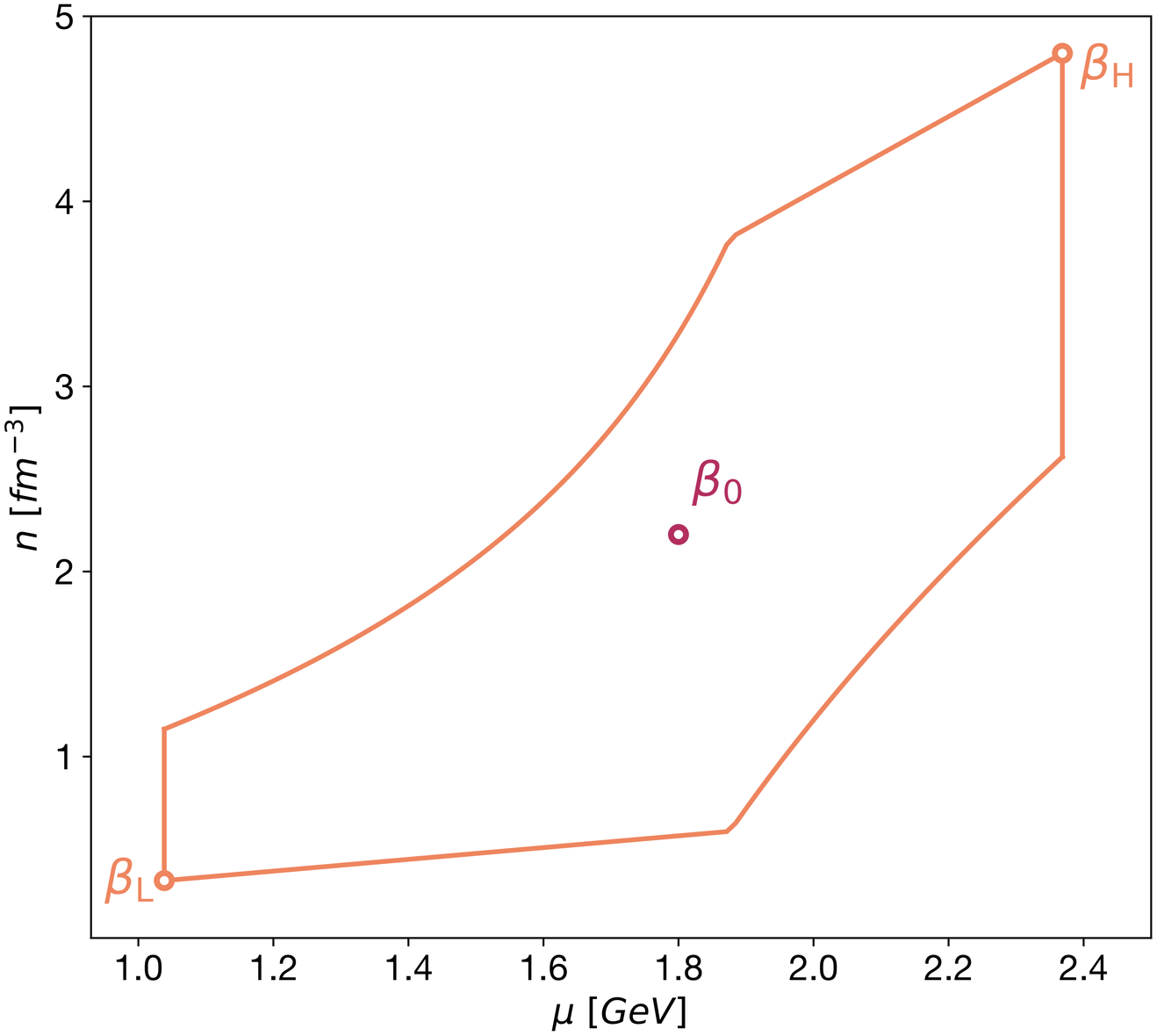
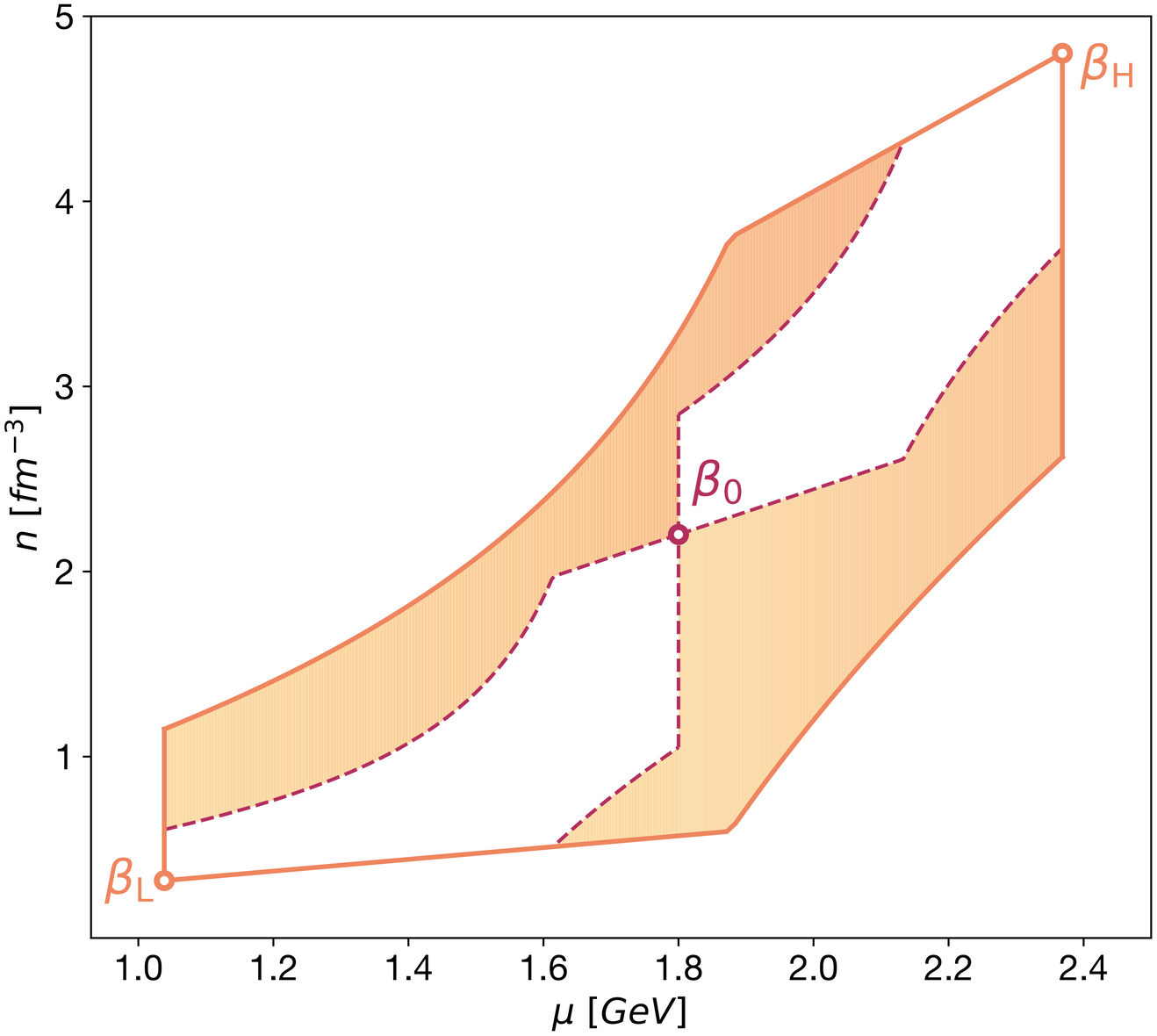


β_L, β_H are not special

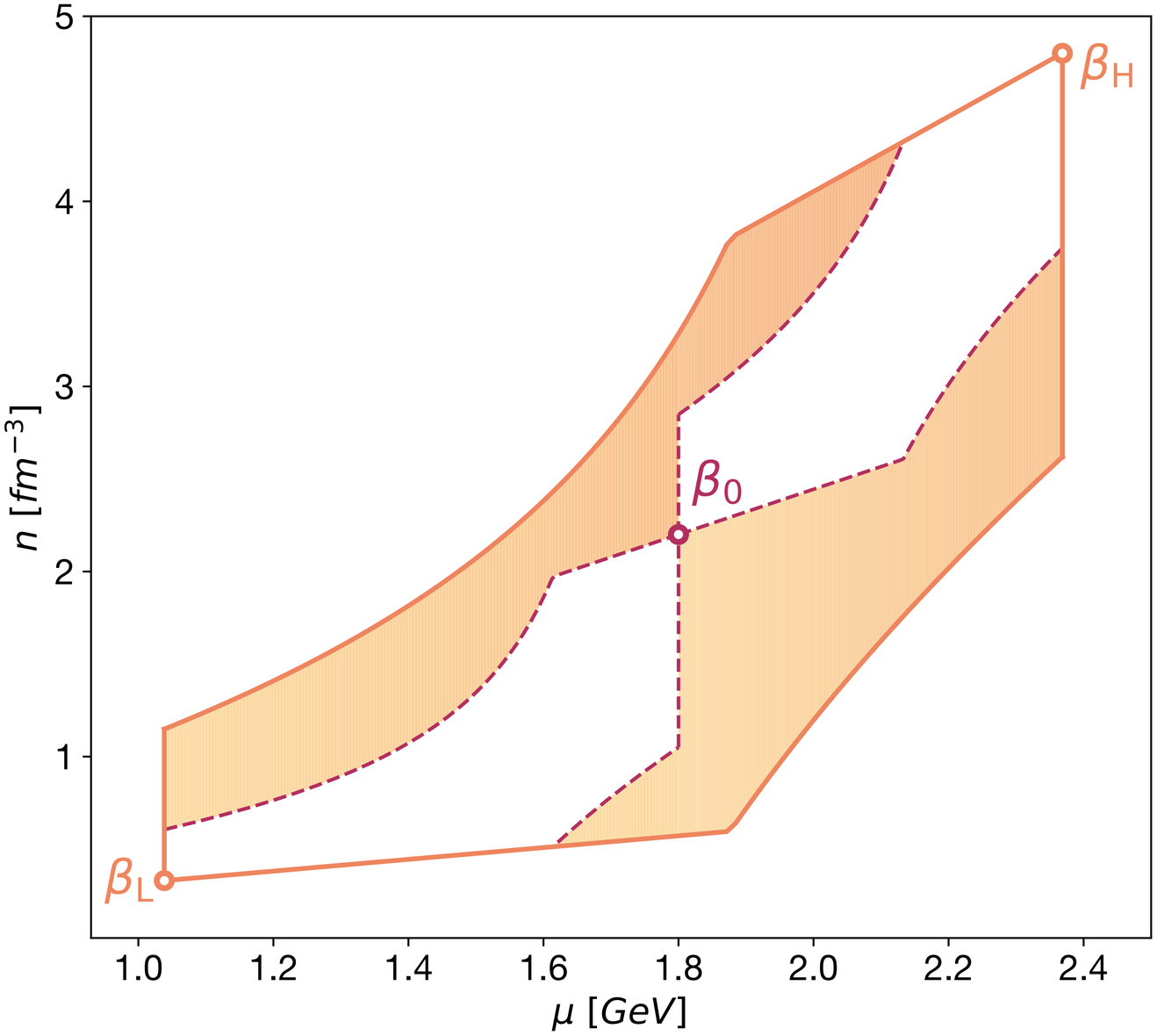
self-similar [fractal] EoS



self-similar [fractal] EoS

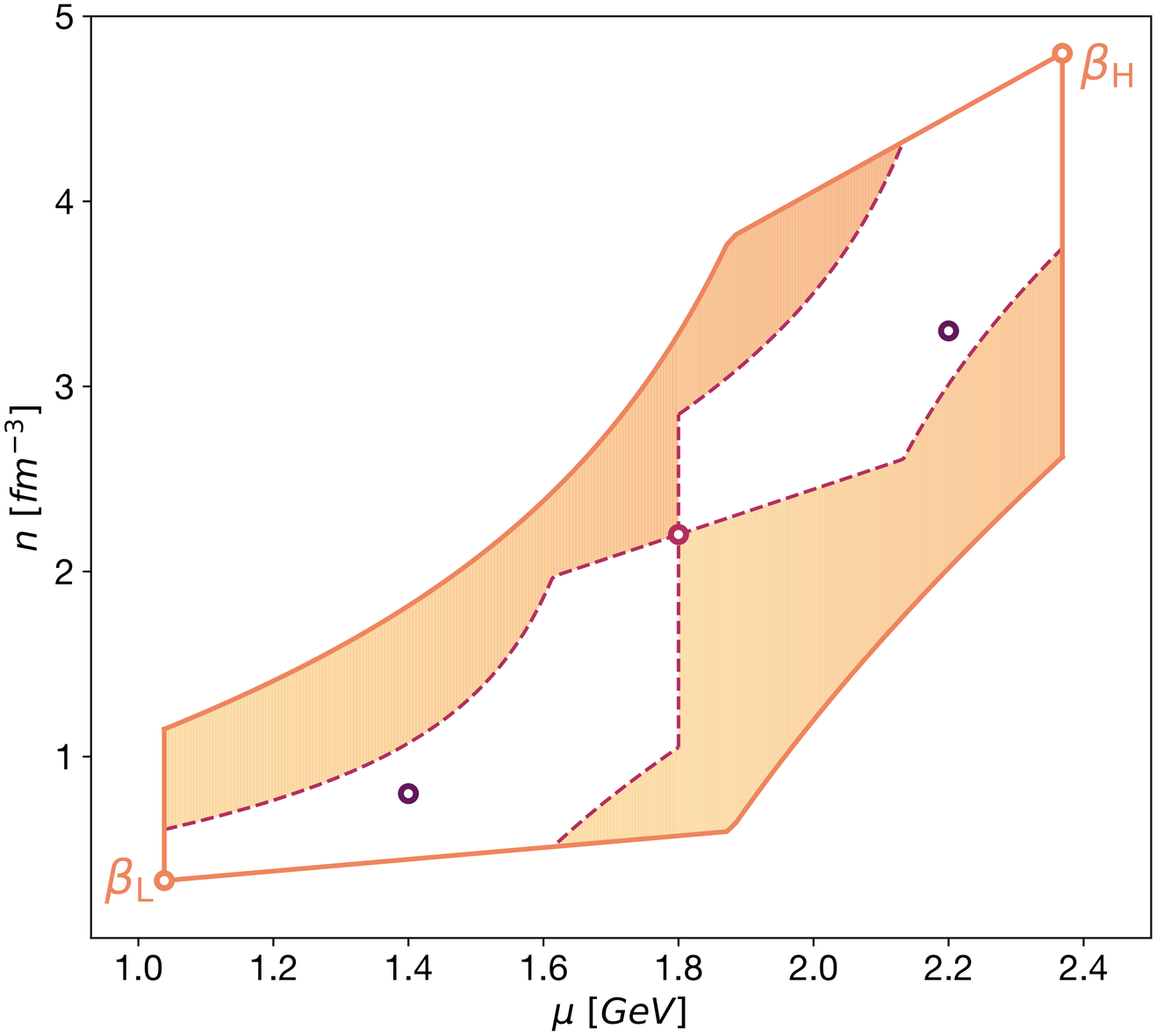


self-similar [fractal] EoS



$\beta_L, \beta_0, \beta_H$ are not special

self-similar [fractal] EoS



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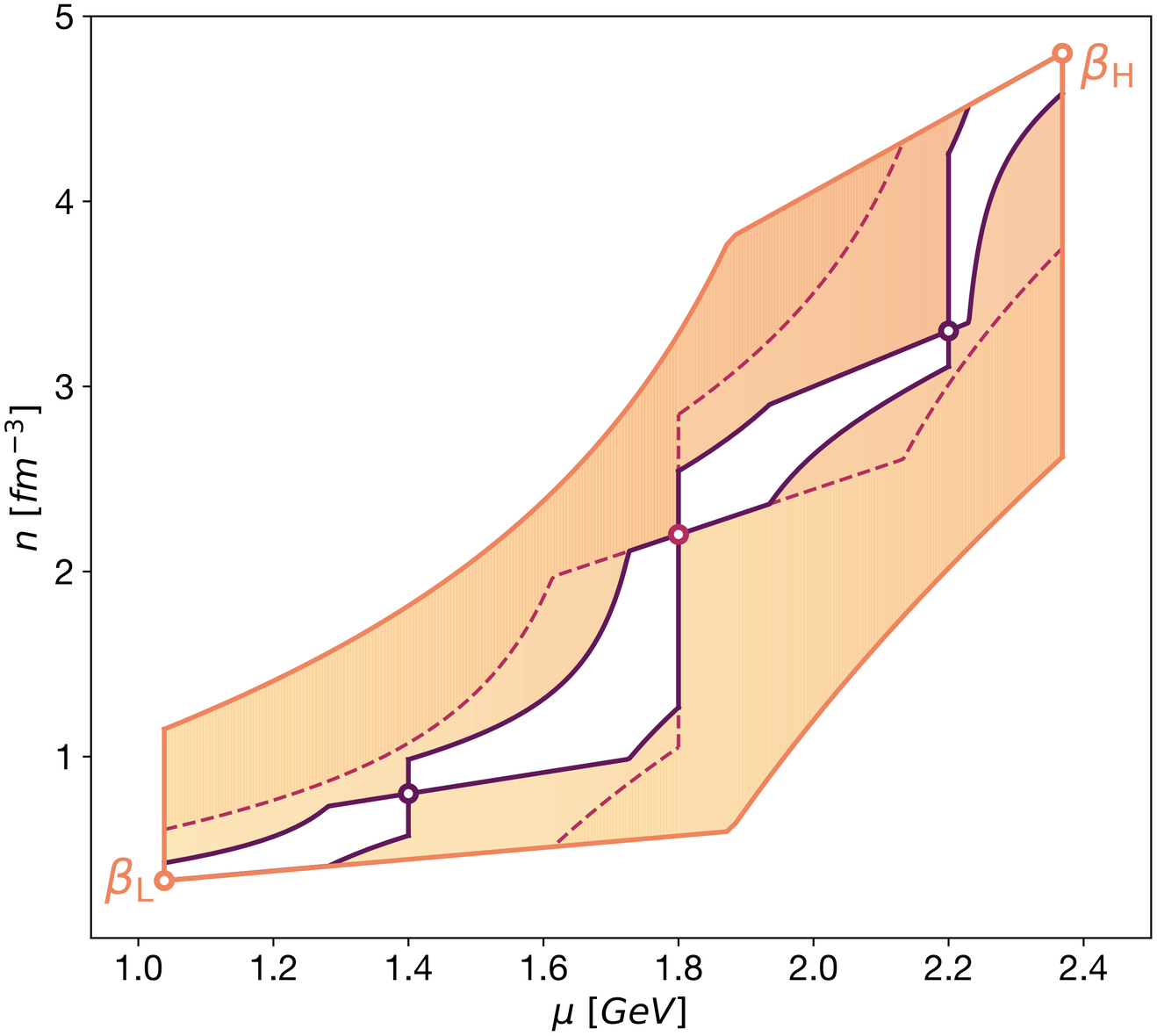
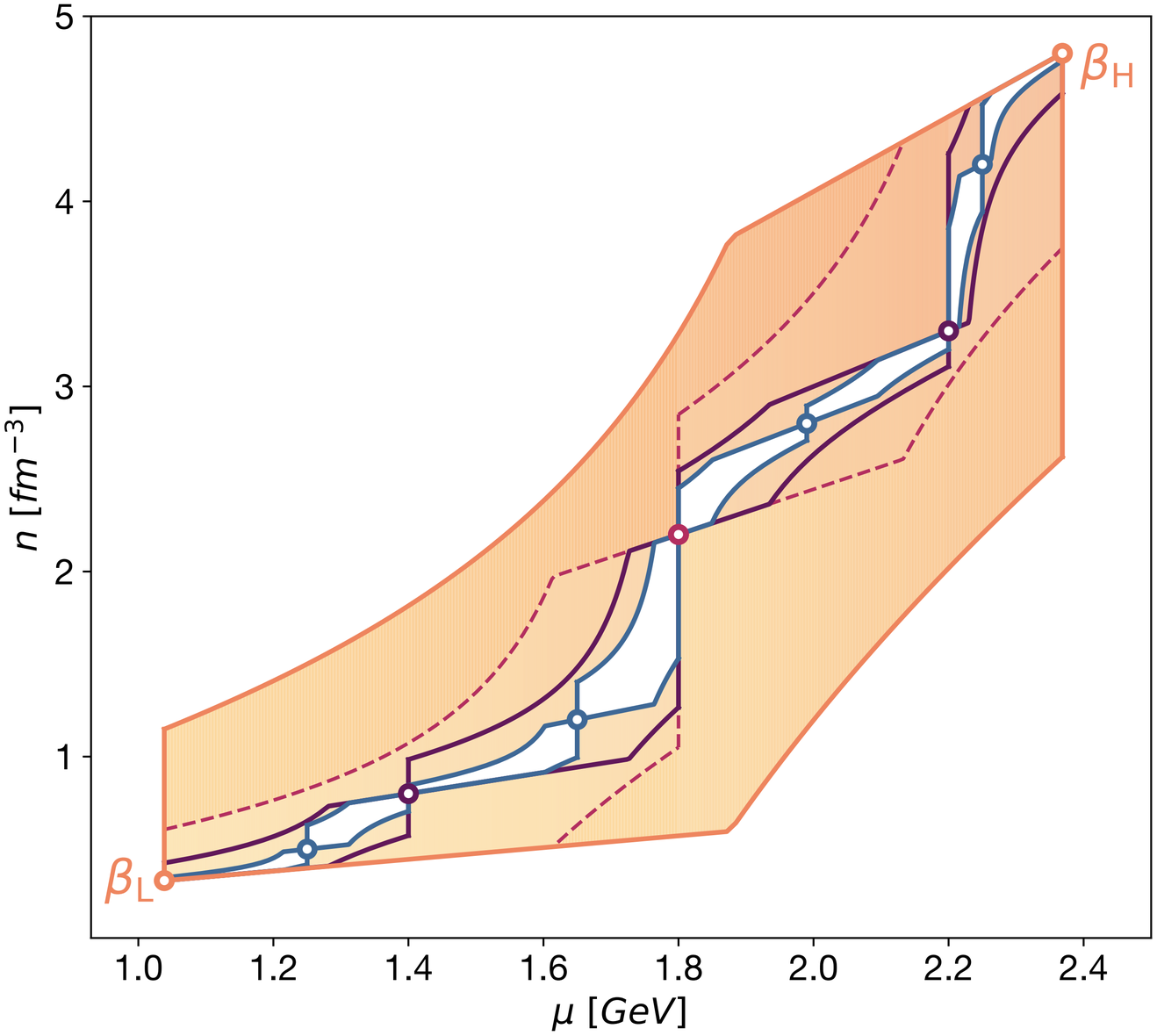


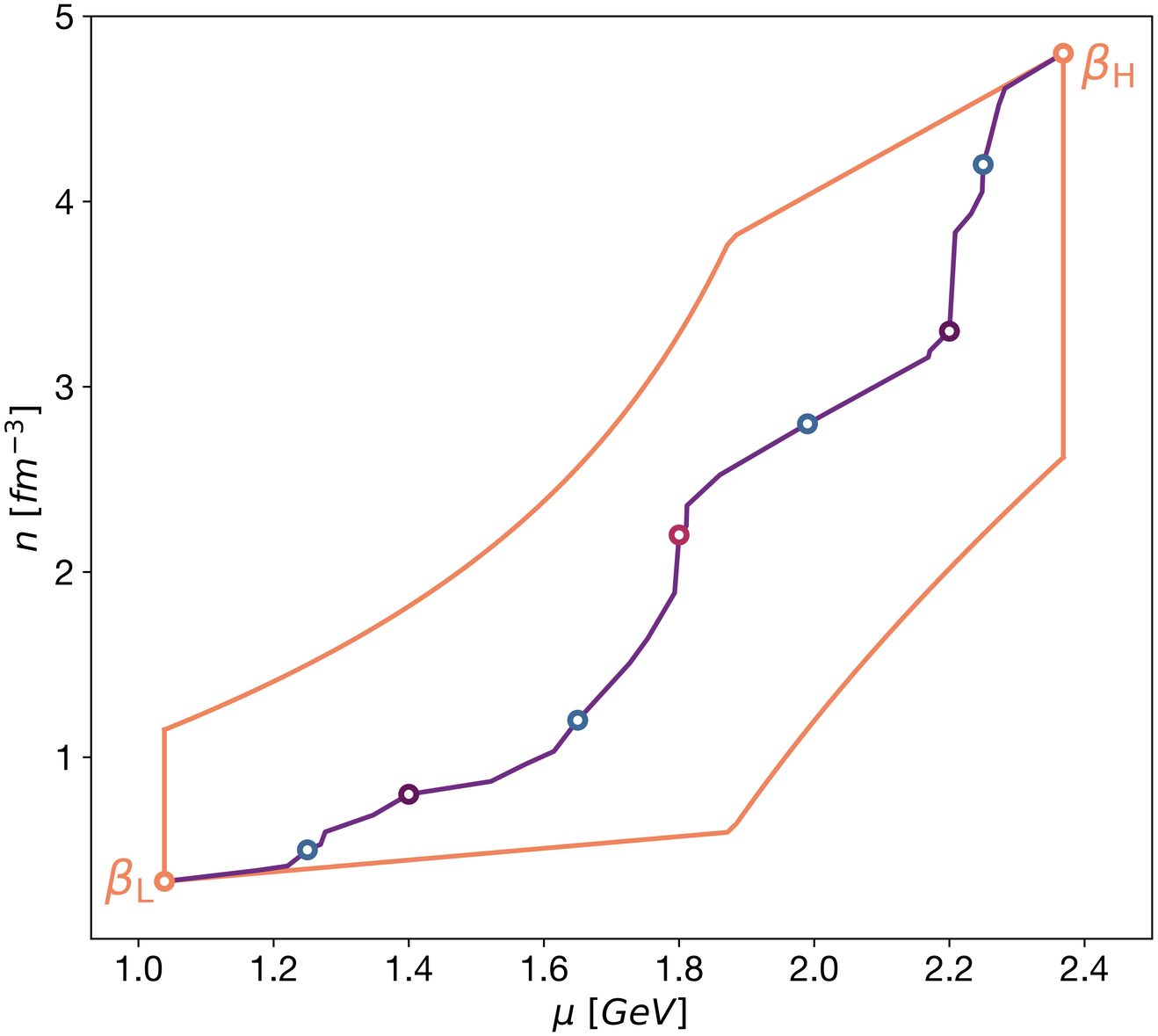
more

self-similar [fractal] EoS

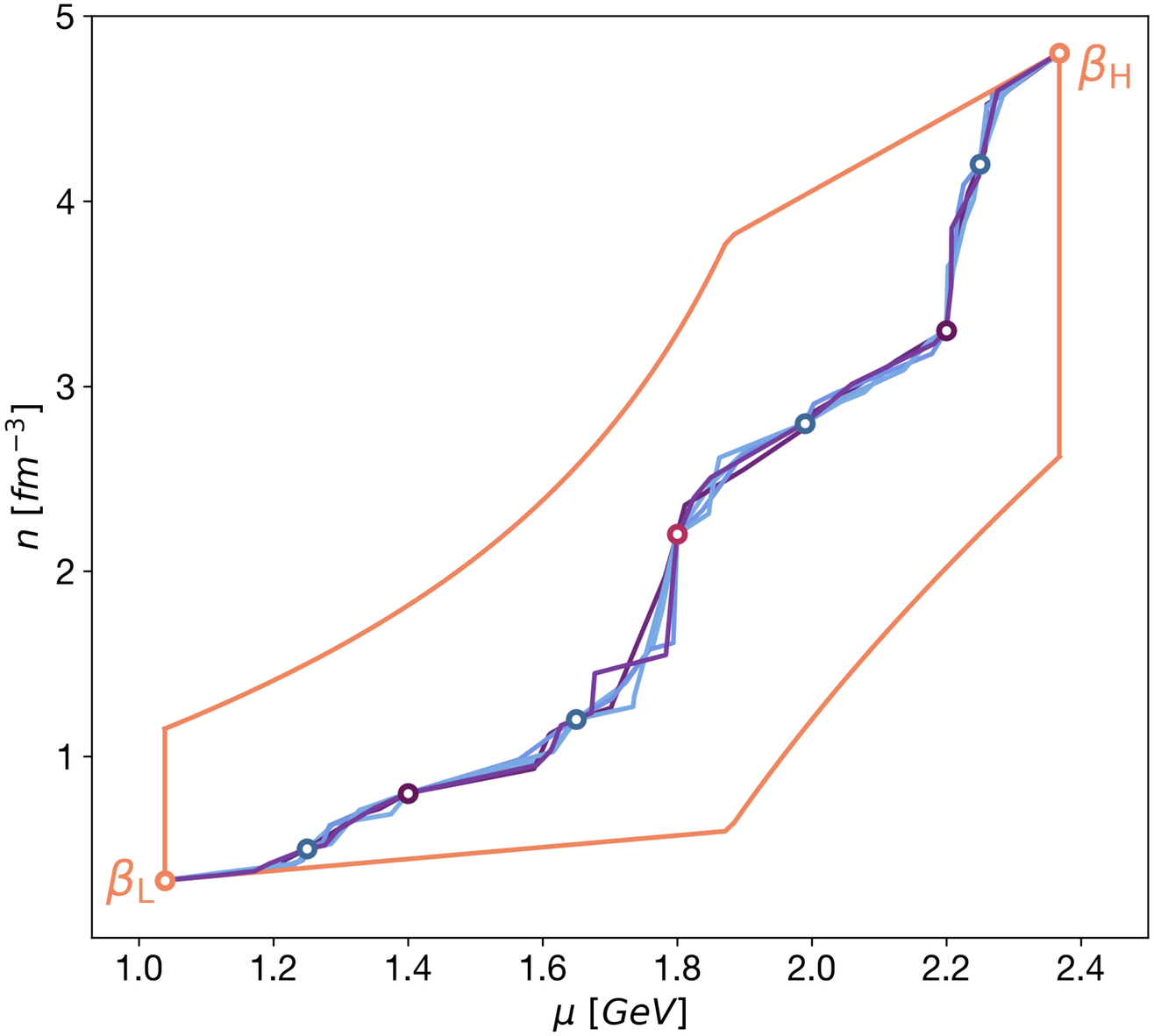


MORE

self-similar [fractal] EoS

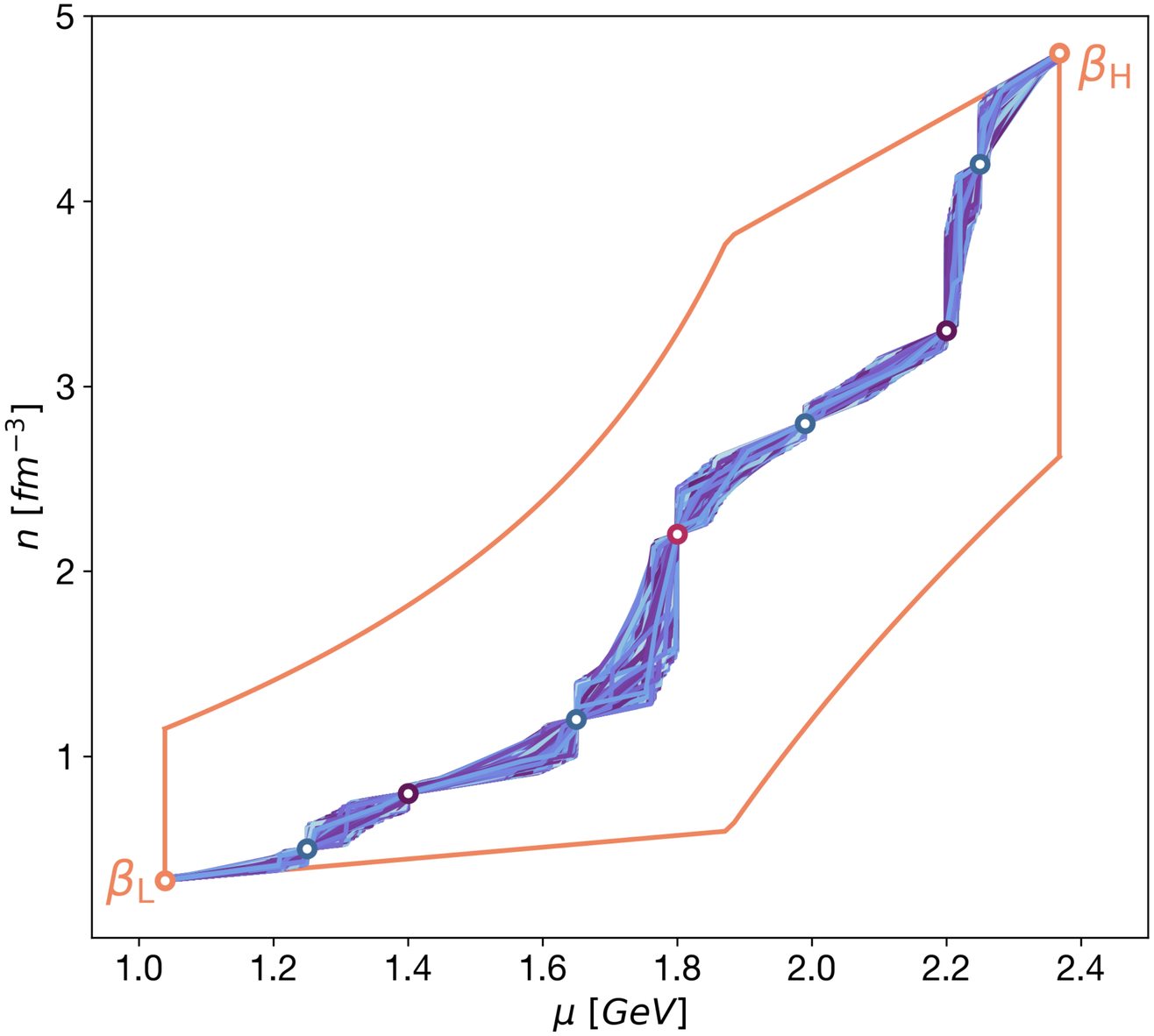


self-similar [fractal] EoS



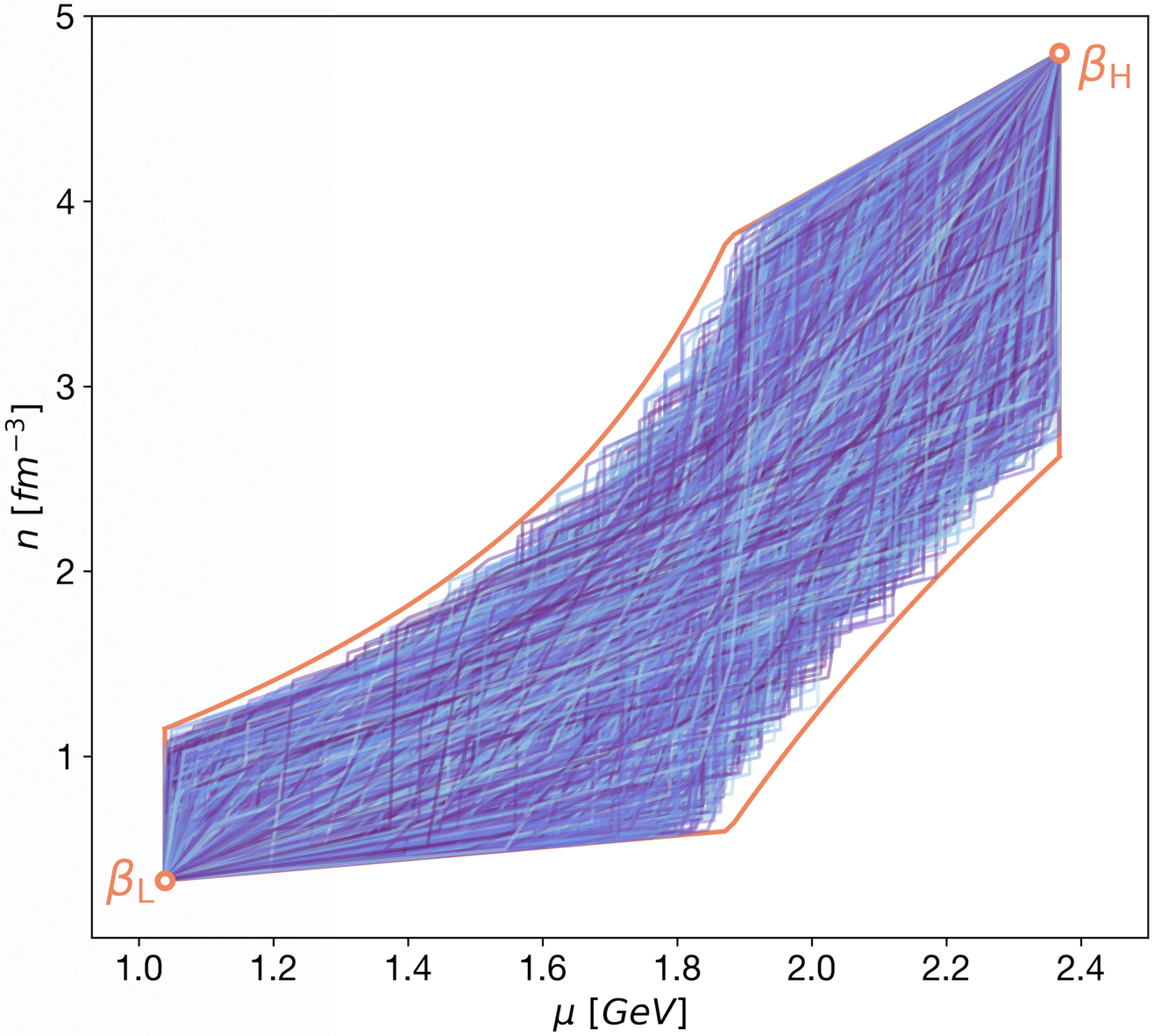
more

self-similar [fractal] EoS

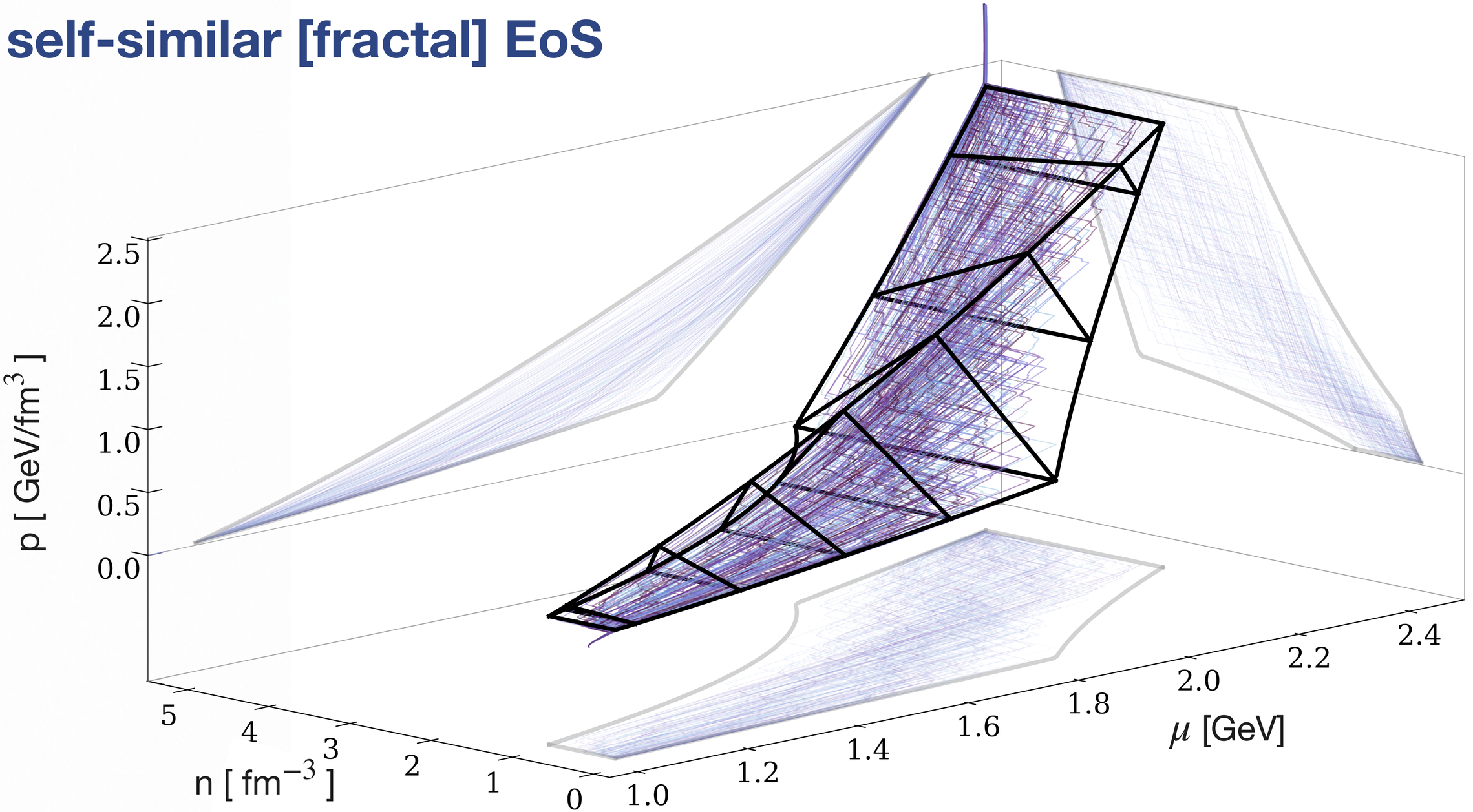


MORE

self-similar [fractal] EoS



self-similar [fractal] EoS



volume is uniformly sampled

introducing local Gaussian correlation

the diffusion equation

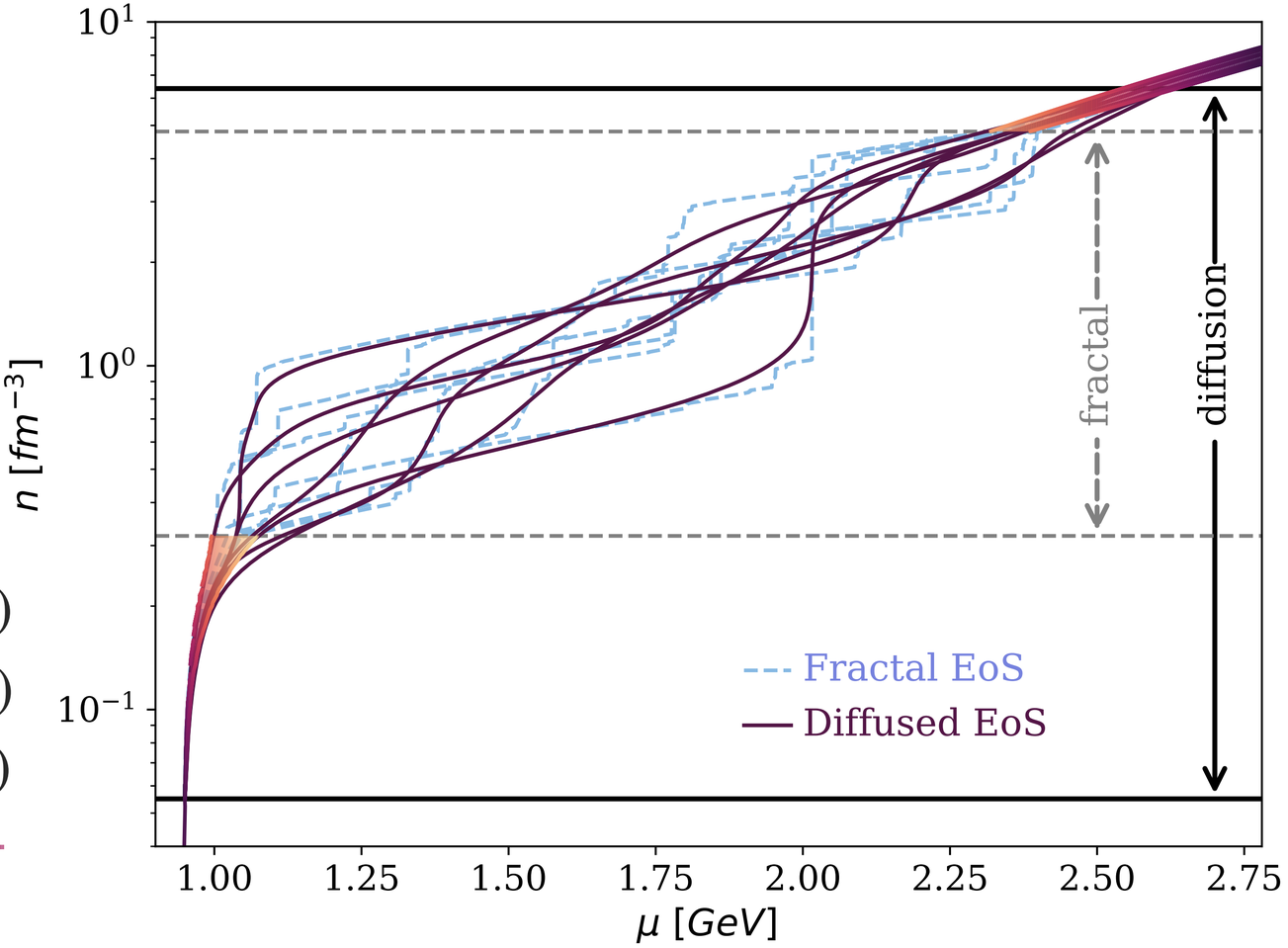
$$\partial_\tau \mu(n,\tau) = \partial_n [D(n) \partial_n \mu(n,\tau)]$$

unphysical time flow ..... $\mu(n) \rightarrow \mu(n,\tau)$

density-dependent coefficient ..... $D(n)$

initial condition ..... $\mu(n,0) = \mu(n)$

Dirichlet boundary conditions .....



introducing local Gaussian correlation

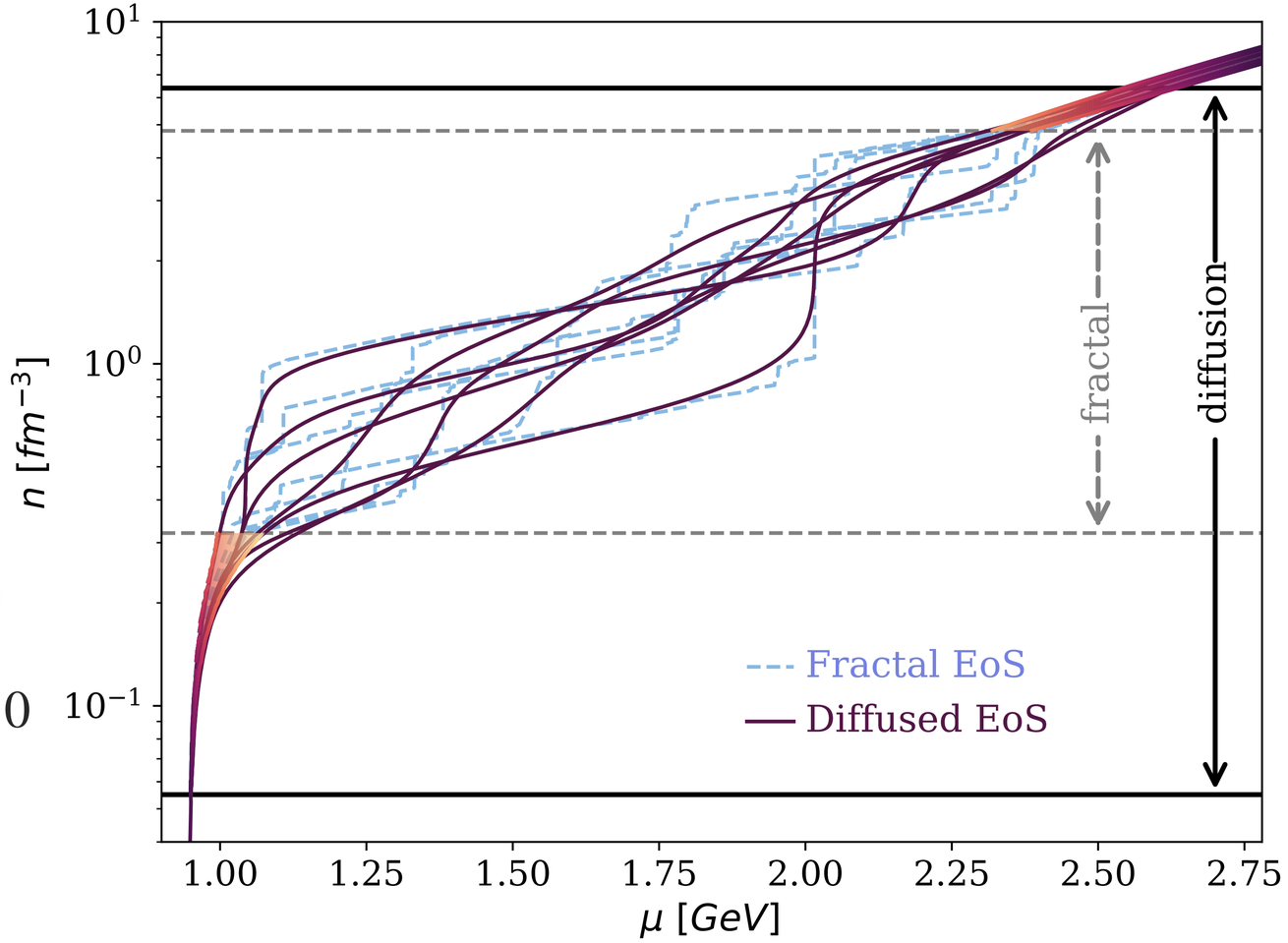
the diffusion equation

$$\partial_\tau \mu(n,\tau) = \partial_n [D(n) \partial_n \mu(n,\tau)]$$

stability ..... $\partial_n \mu(n,0) > 0 \quad \& \quad D(n) > 0$

causality ..... $c_s^2(n,0) \leqslant 1 \quad \& \quad D'' - \dfrac{D'}{n} \leqslant 0$

consistency ..... $\varepsilon' - \varepsilon = \int_n^{n'} \mu(n)\, dn$

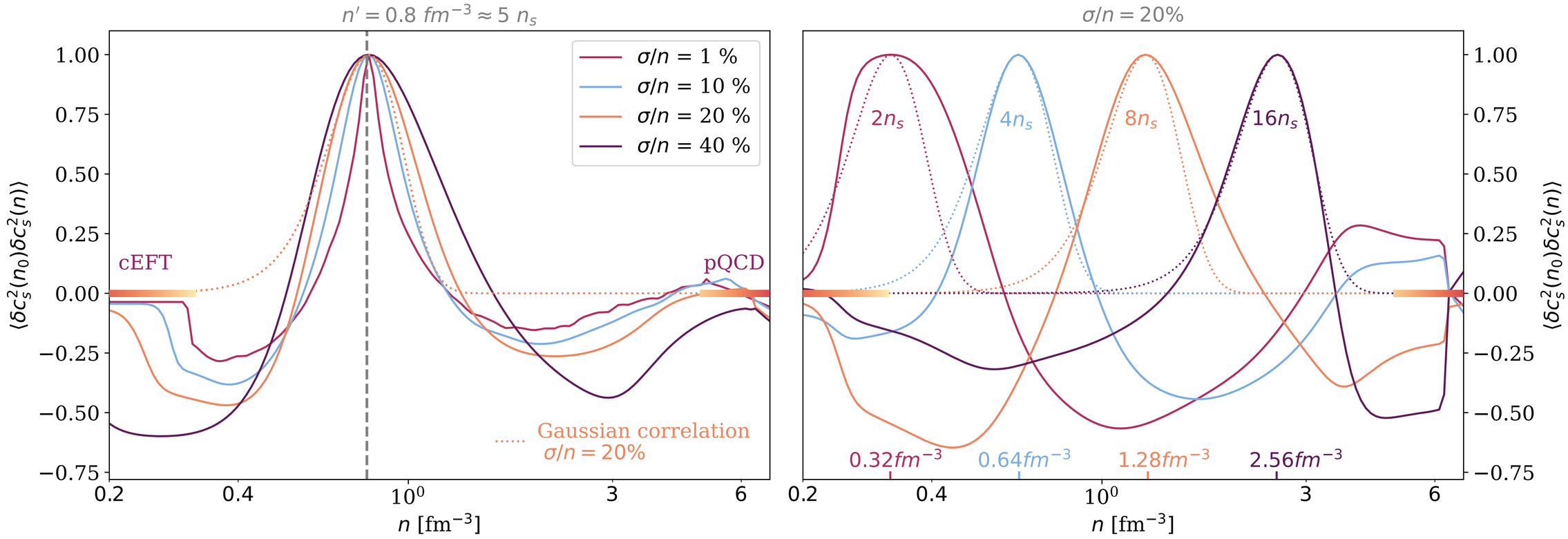


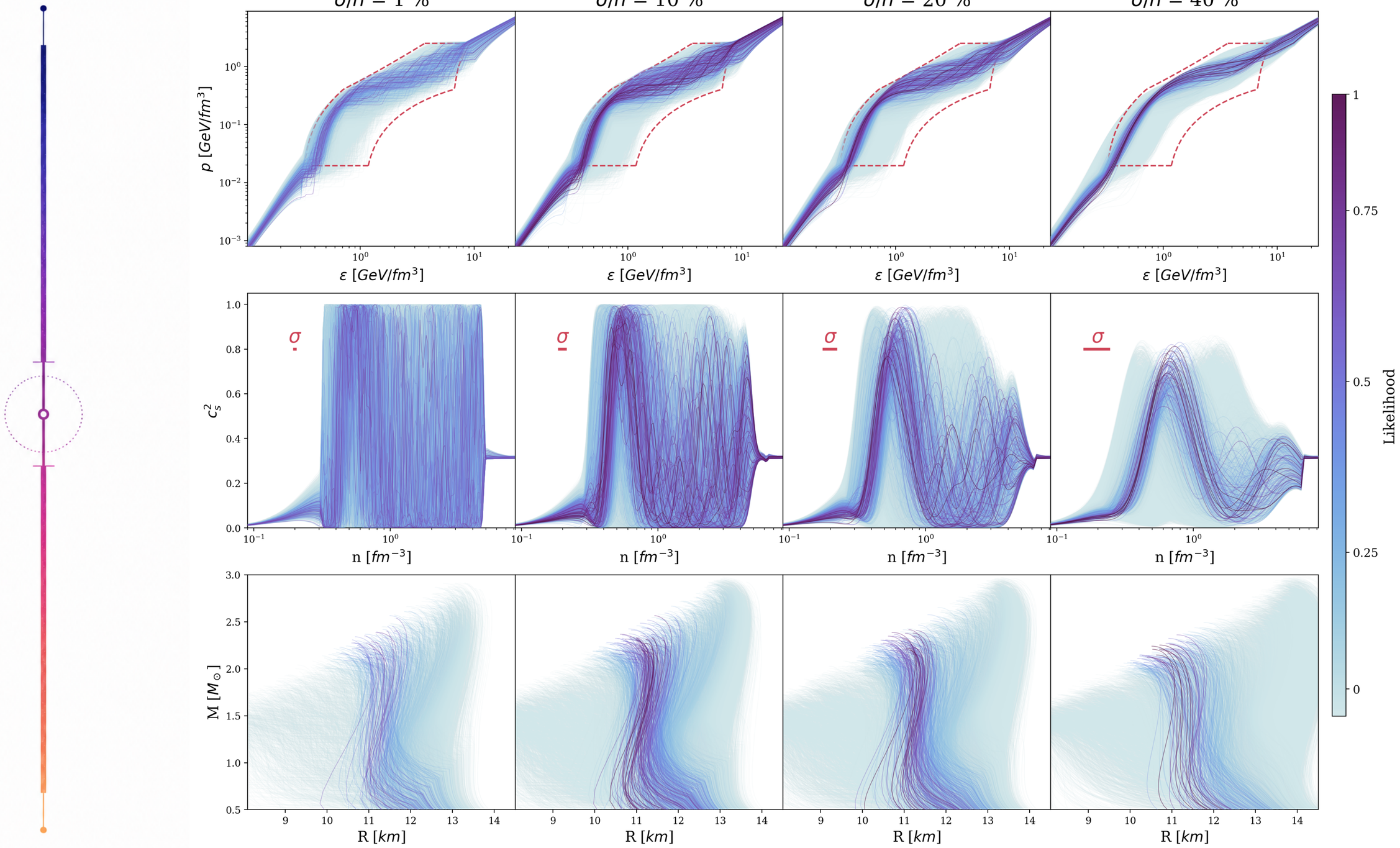
introducing local Gaussian correlation

correlation length ..... $\sigma = \sqrt{4D(n)\,\tau}$

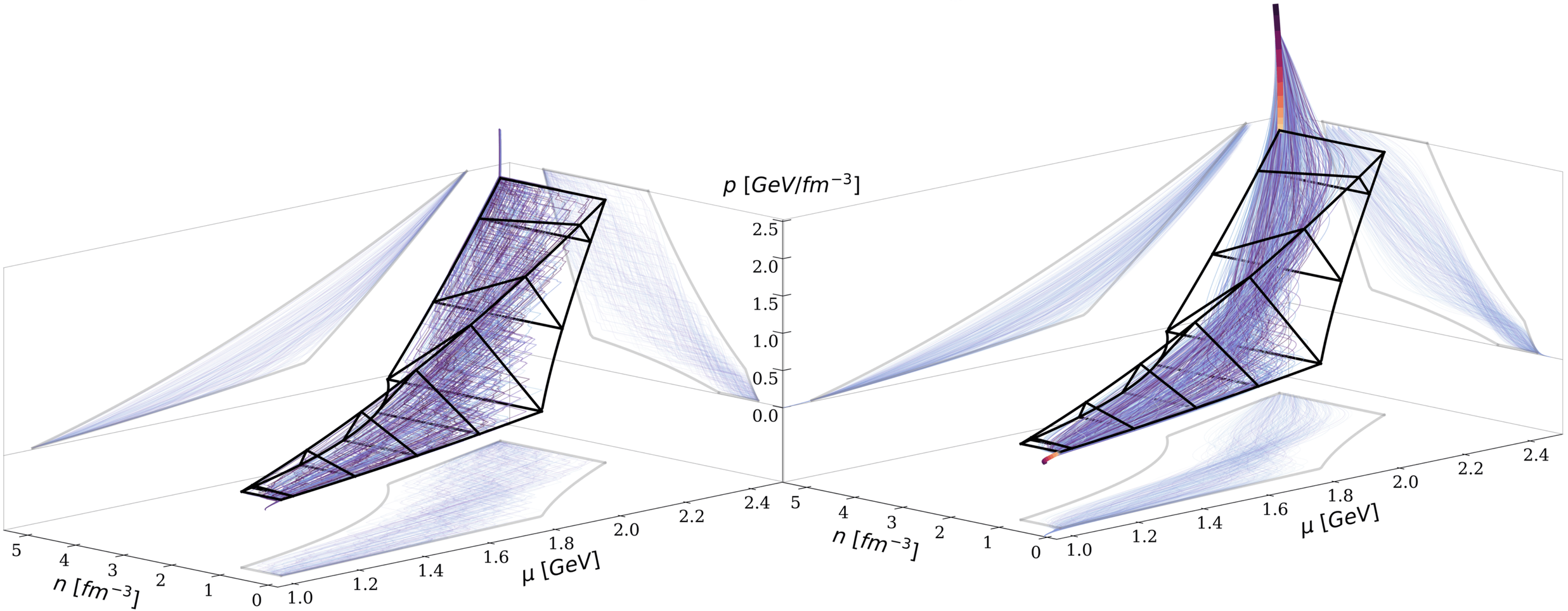
logarithmically constant ..... $\sigma/n = c$

choose ..... $D(n)\,\tau = n^2 c^2/4$

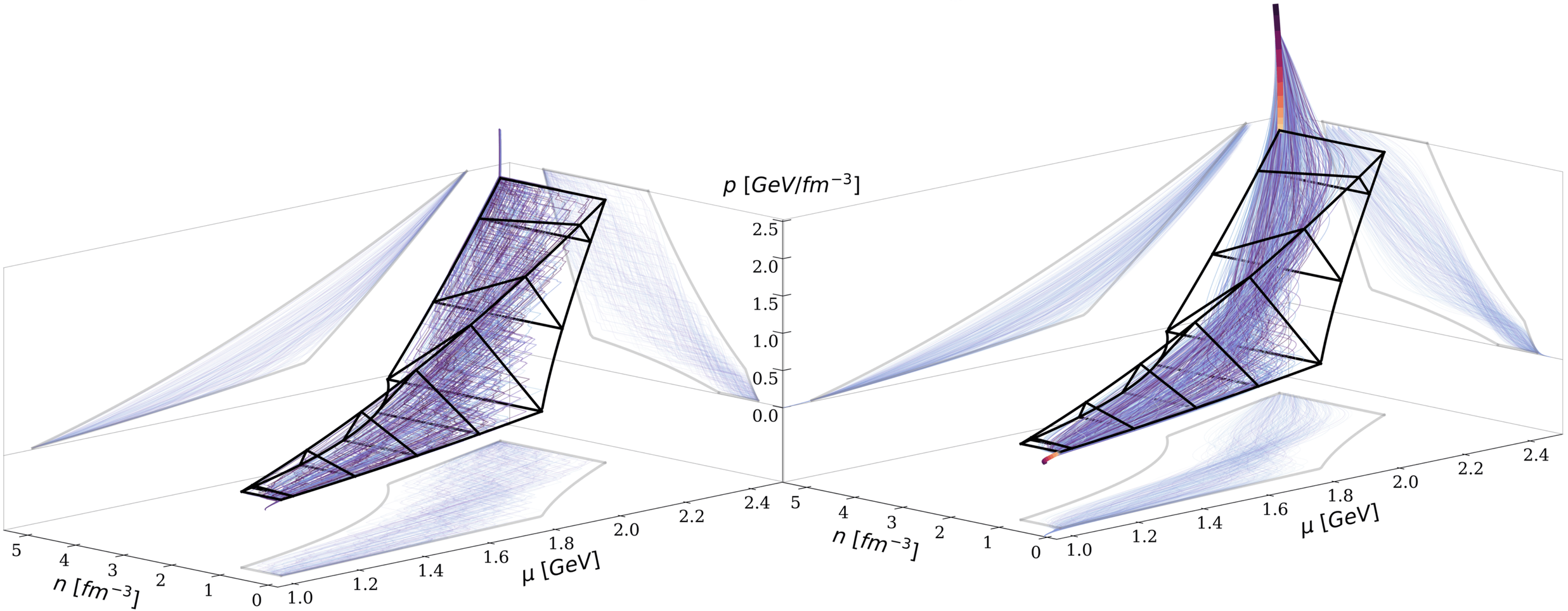



σ/n = 1 %
σ/n = 10 %
σ/n = 20 %
σ/n = 40 %
p [GeV/fm³]
ε [GeV/fm³]
c_s²
σ
n [fm⁻³]
M [M⊙]
R [km]
Likelihood
1
0.75
0.5
0.25
0

constrained Gaussian-process bridge



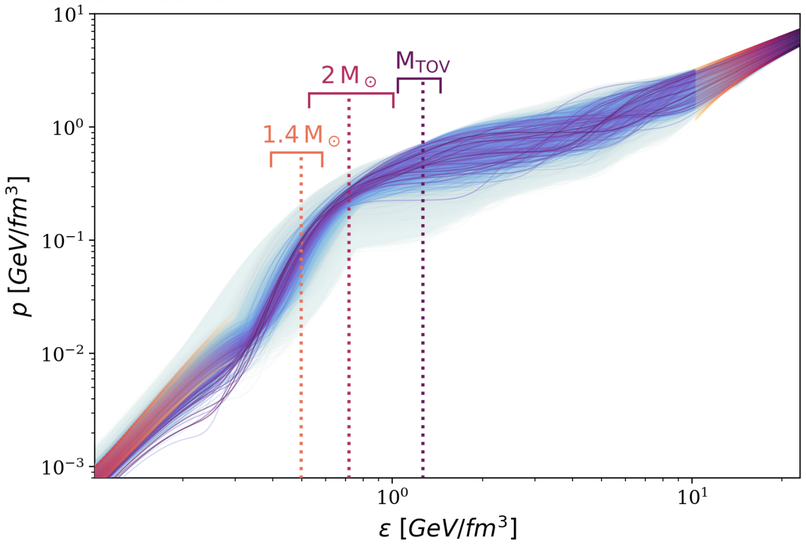
constrained Gaussian-process bridge

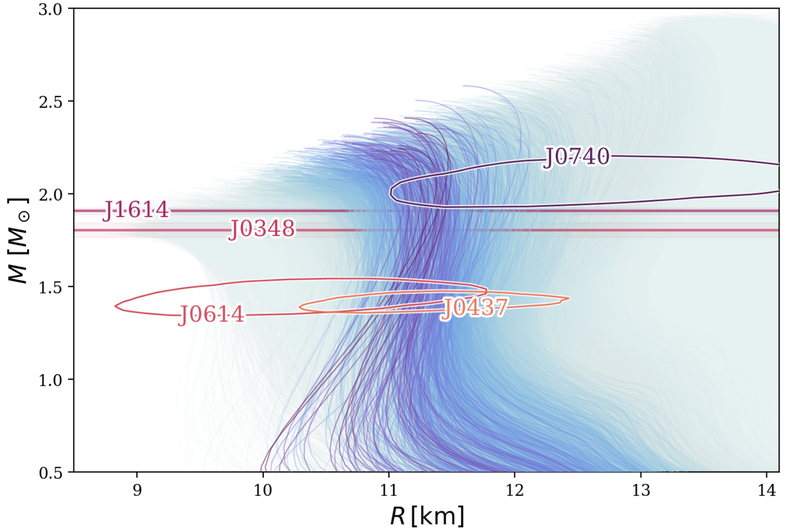


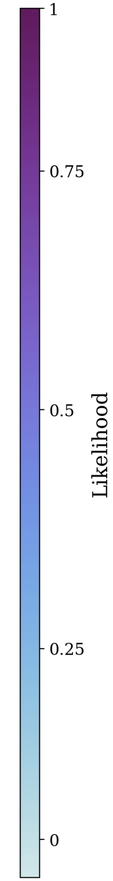
more than a mere prior

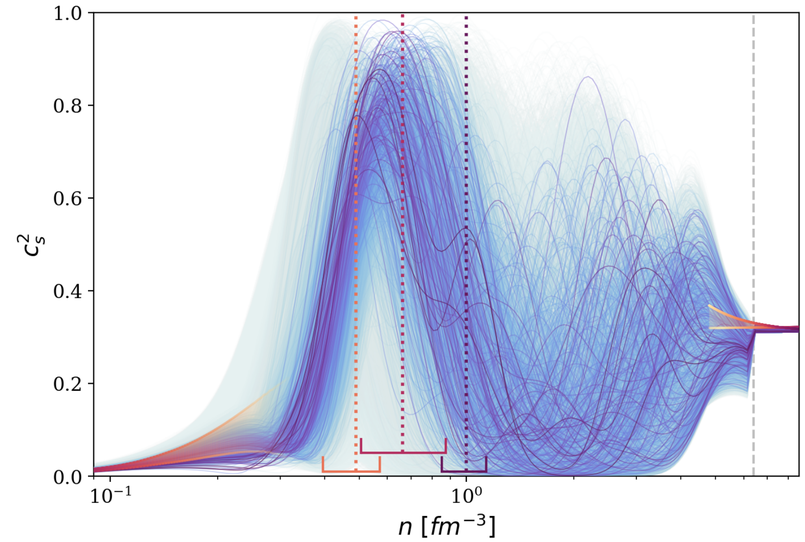
physically motivated framework

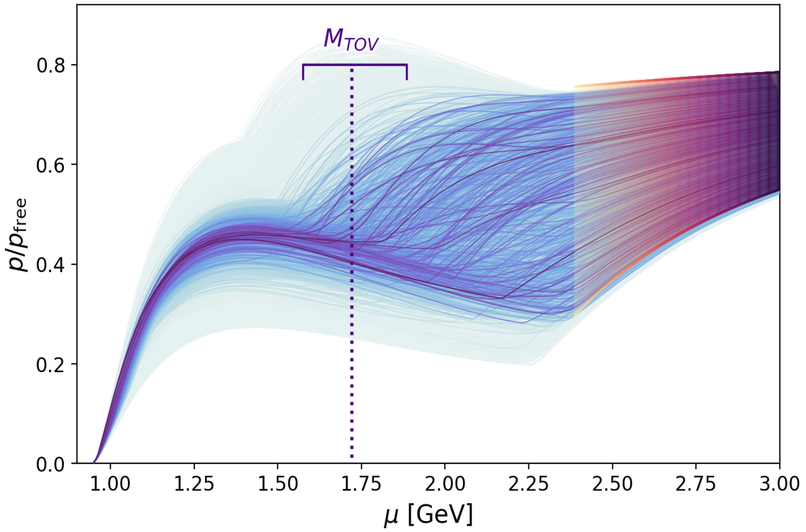
constrained Gaussian-process bridge











for the physical interpretation, see Aleksi's talk

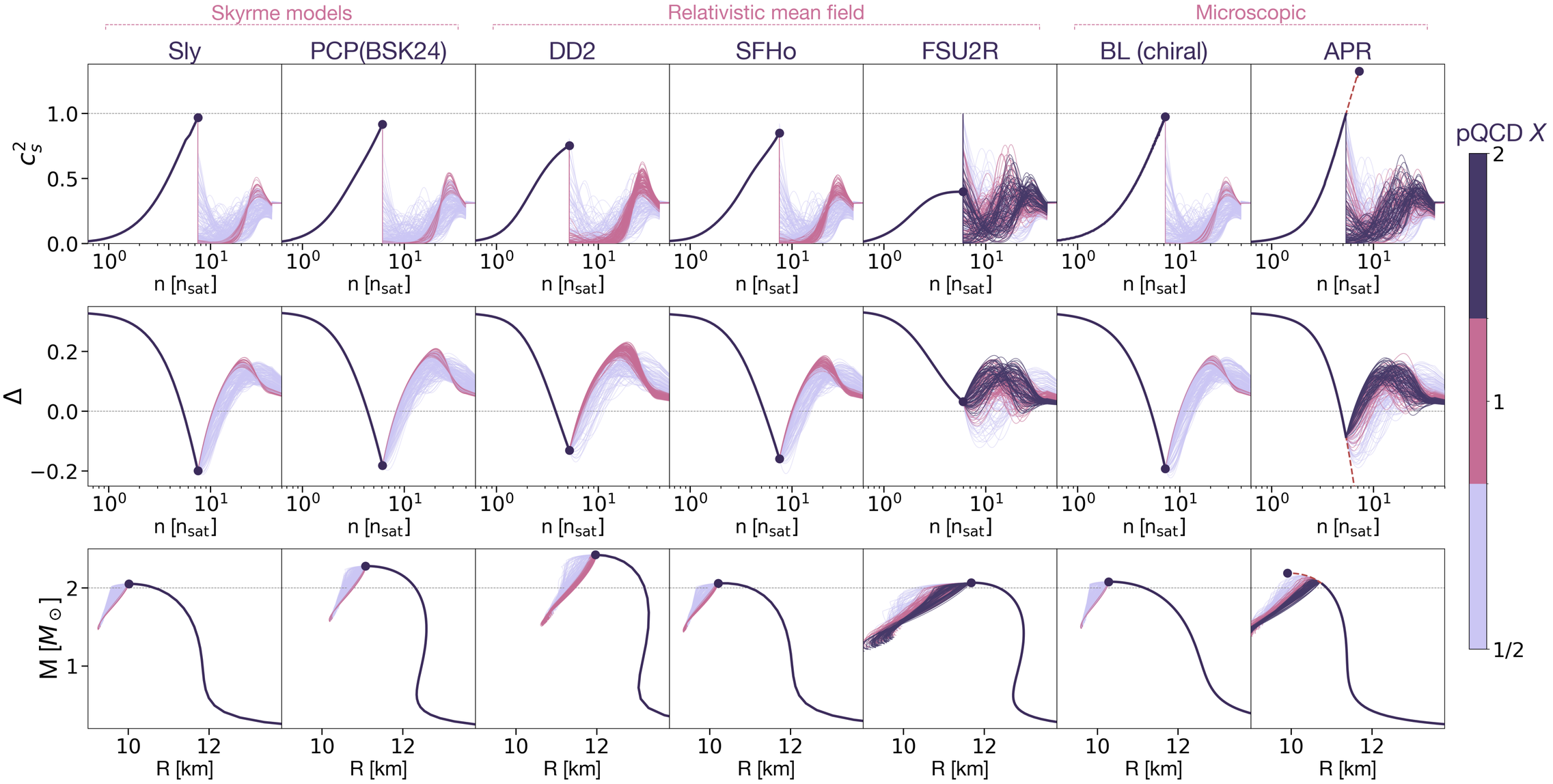
preprint

As above, so below: assessing extremeness of the neutron-star equation of state based on the unstable branch

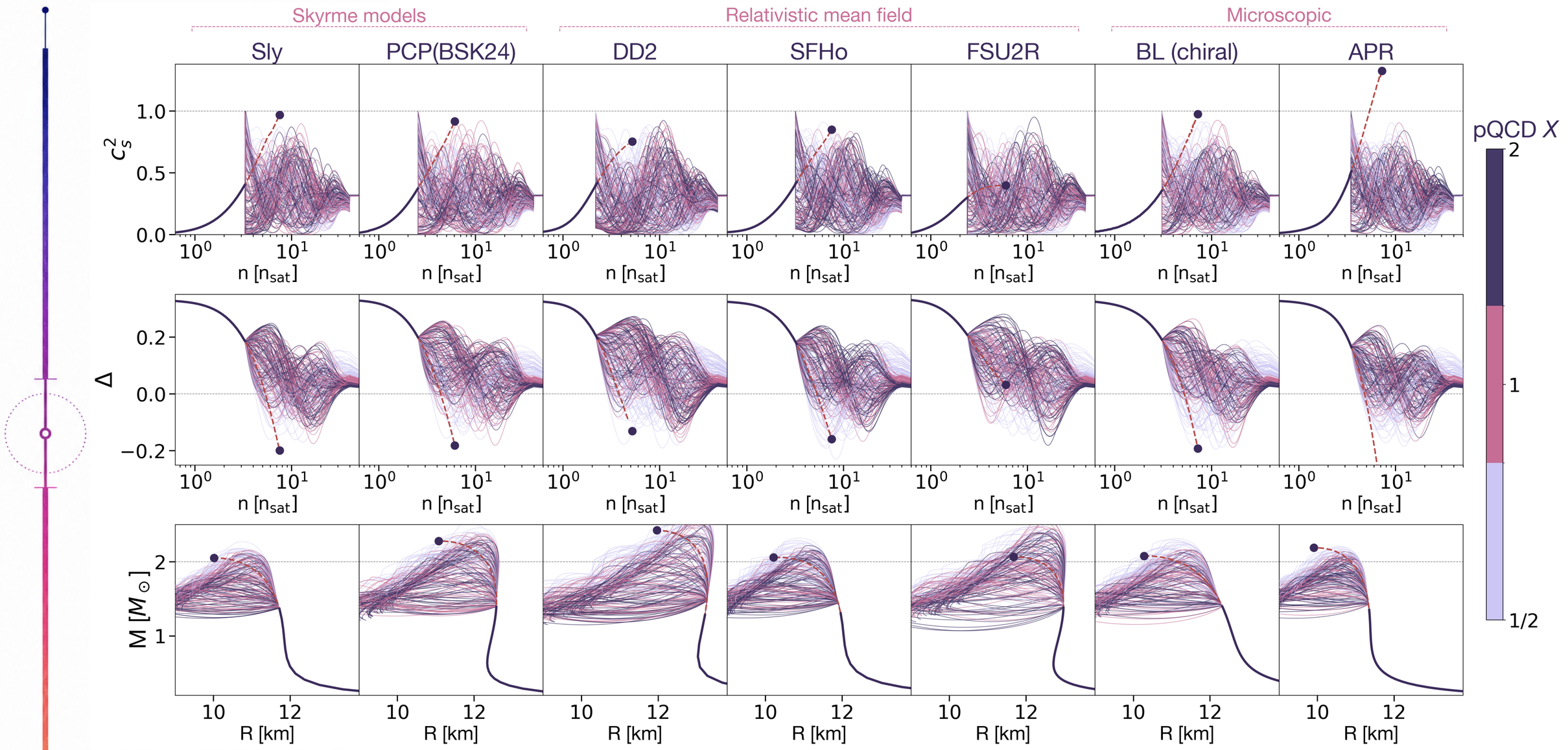
Tyler Gorda, OK, Aleksi Kurkela, Jürgen Schaffner-Bielich

arXiv:2606.23929 [nucl-th], Jun 2026





- **models terminated at the TOV density**
- **extensions colored by the pQCD renormalization scale**



- **models terminated at the 1.4 $M_\odot$**
  - **extensions colored by the pQCD renormalization scale**

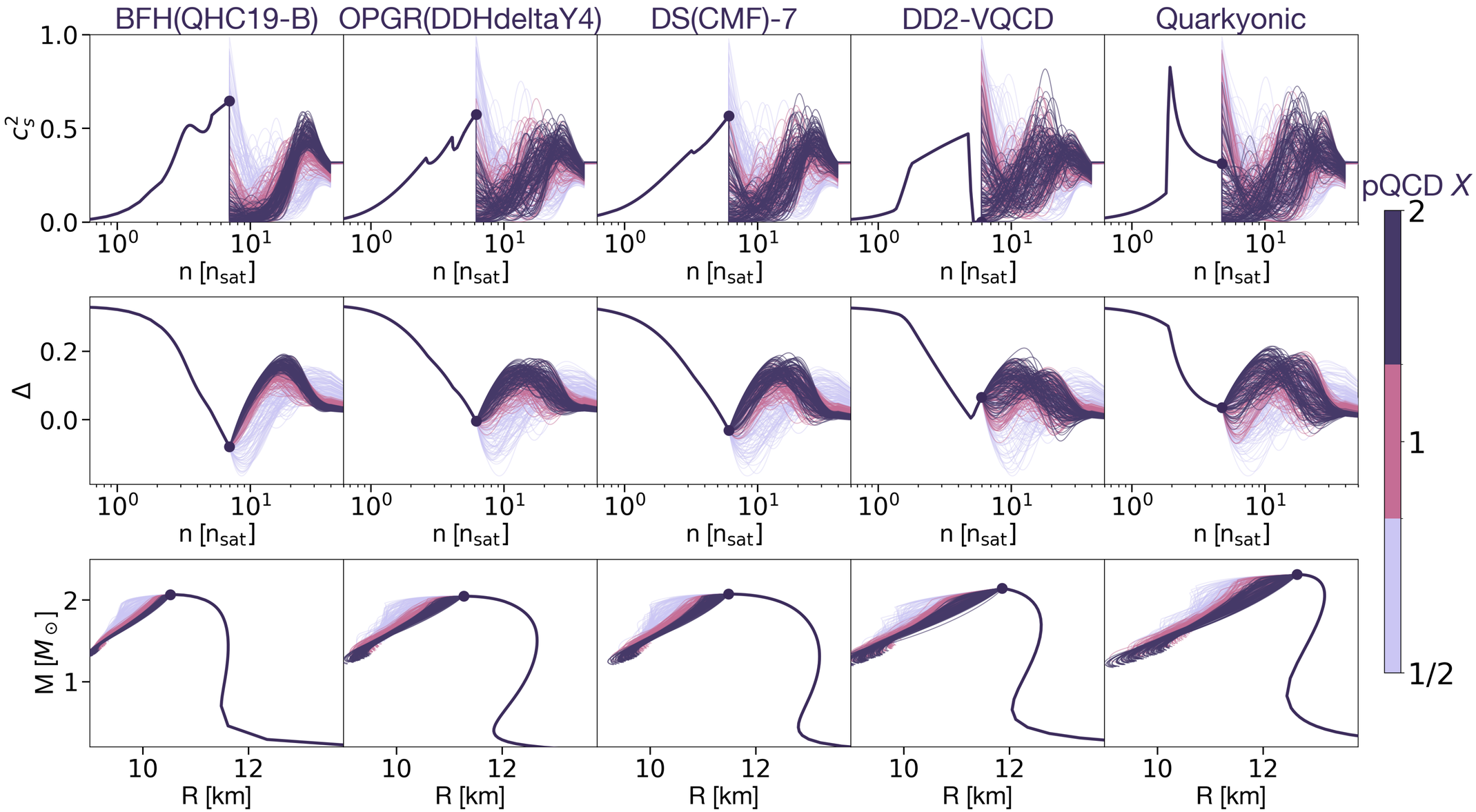
conclusions

new framework for neutron-star EoS inference

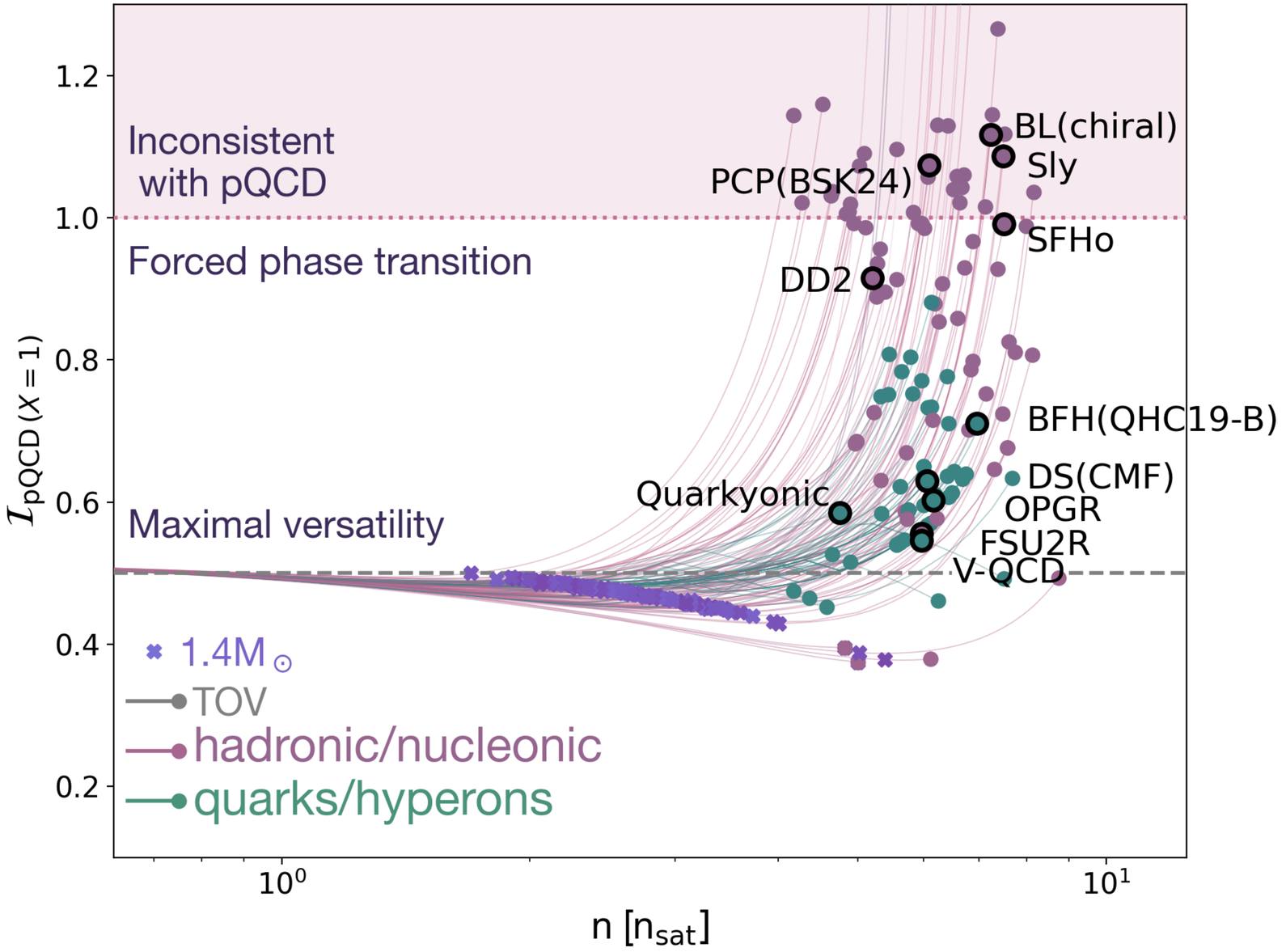
nonparametric prior
physically motivated
maximally general
no intermediate likelihoods
no shooting procedure
most efficient
transparent tuning of correlation length

global anticorrelation in sounds speed

hadronic models require radical softening at the maximal NS density



T. Gorda, O.K., A. Kurkela, J. Schaffner-Bielich: 2606.23929



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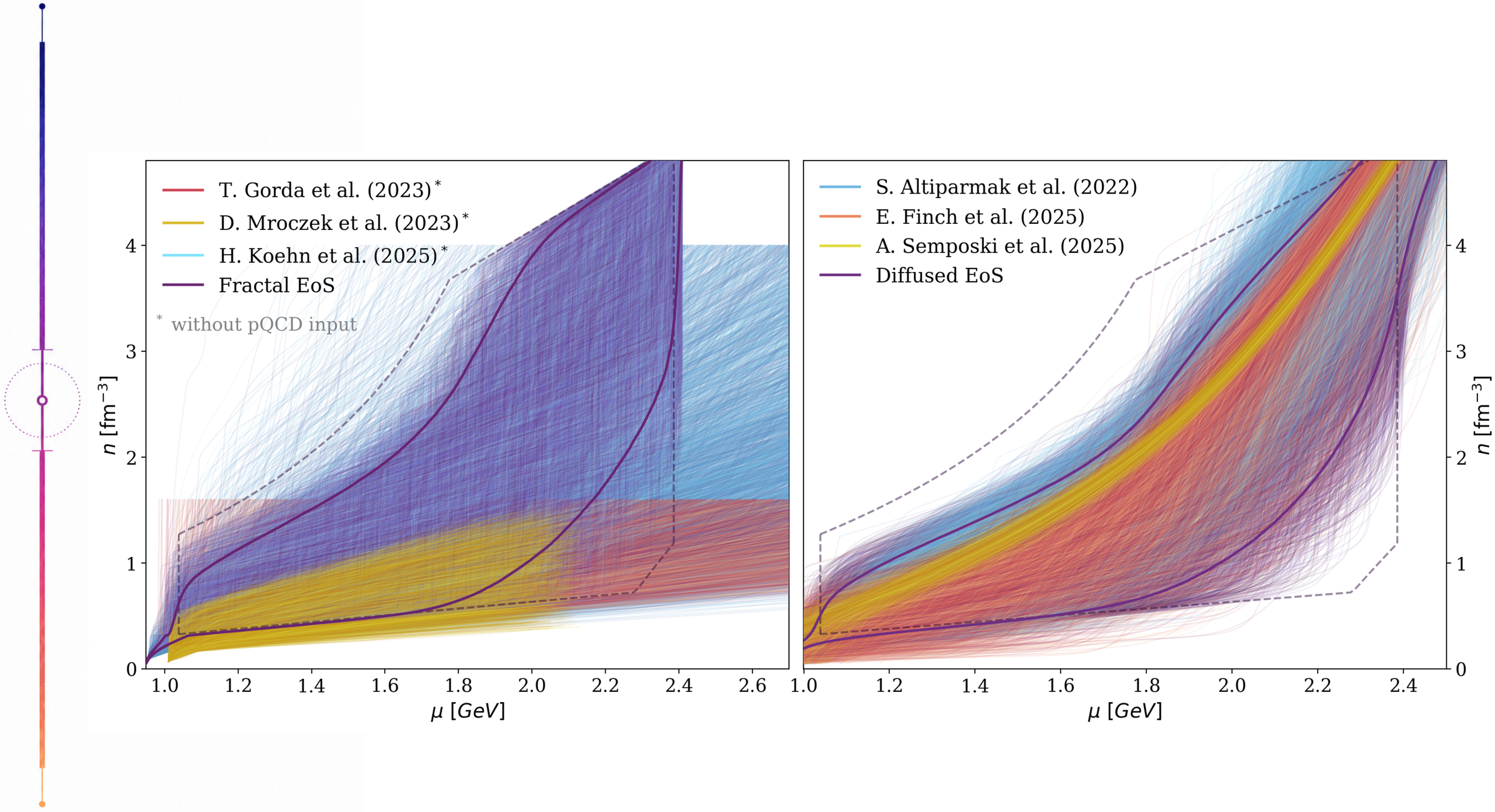
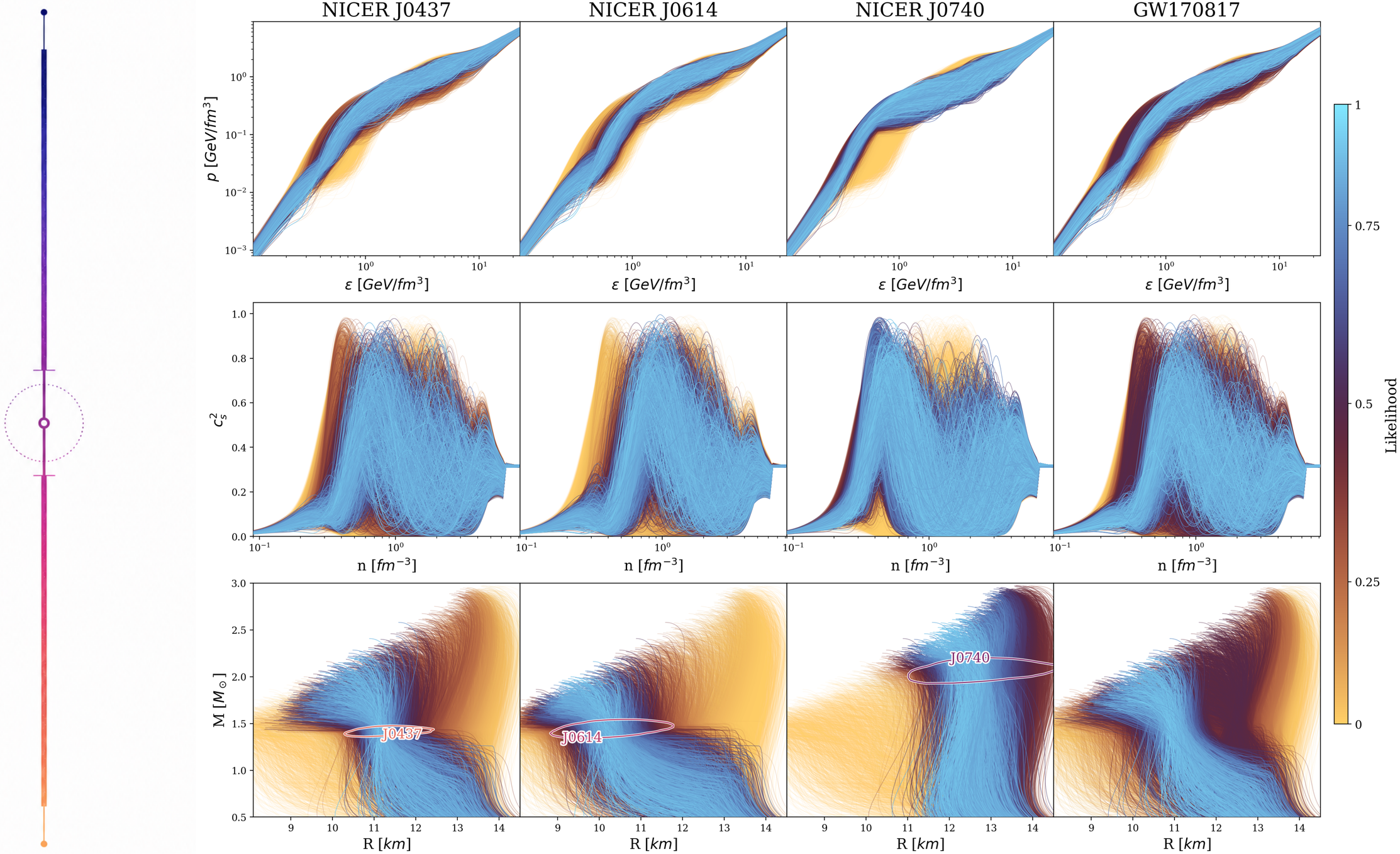

T. Gorda et al. (2023)*
D. Mroczek et al. (2023)*
H. Koehn et al. (2025)*
Fractal EoS
* without pQCD input
S. Altiparmak et al. (2022)
E. Finch et al. (2025)
A. Semposki et al. (2025)
Diffused EoS
n [fm⁻³]
μ [GeV]
0
1
2
3
4
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6


NICER J0437
NICER J0614
NICER J0740
GW170817
p [GeV/fm^3]
ε [GeV/fm^3]
c_s^2
n [fm^{-3}]
M [$M_\odot$]
R [km]
J0437
J0614
J0740
Likelihood
0
0.25
0.5
0.75
1