SPEED OF SOUND IN DENSE MATTER

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CONTENTS

Walecka model

$$\mu^* = \mu - g_\omega \bar{\omega}_0$$

$$m_N^* = m_N - g_\sigma \bar{\sigma}$$

$$\bar{\sigma} = -\left(\frac{g_\sigma}{m_\sigma^2}\right) \frac{\partial P_{\rm FG}}{\partial m_N^*}$$

$$\bar{\omega}_0 = \left(\frac{g_\omega}{m_\omega^2}\right) \frac{\partial P_{\rm FG}}{\partial \mu^*}$$

$$P(\mu, T) = P_{\rm FG}(\mu^*, T) - \tfrac{1}{2} m_\sigma^2 \bar{\sigma}^2 + \tfrac{1}{2} m_\omega^2 \bar{\omega}_0^2$$

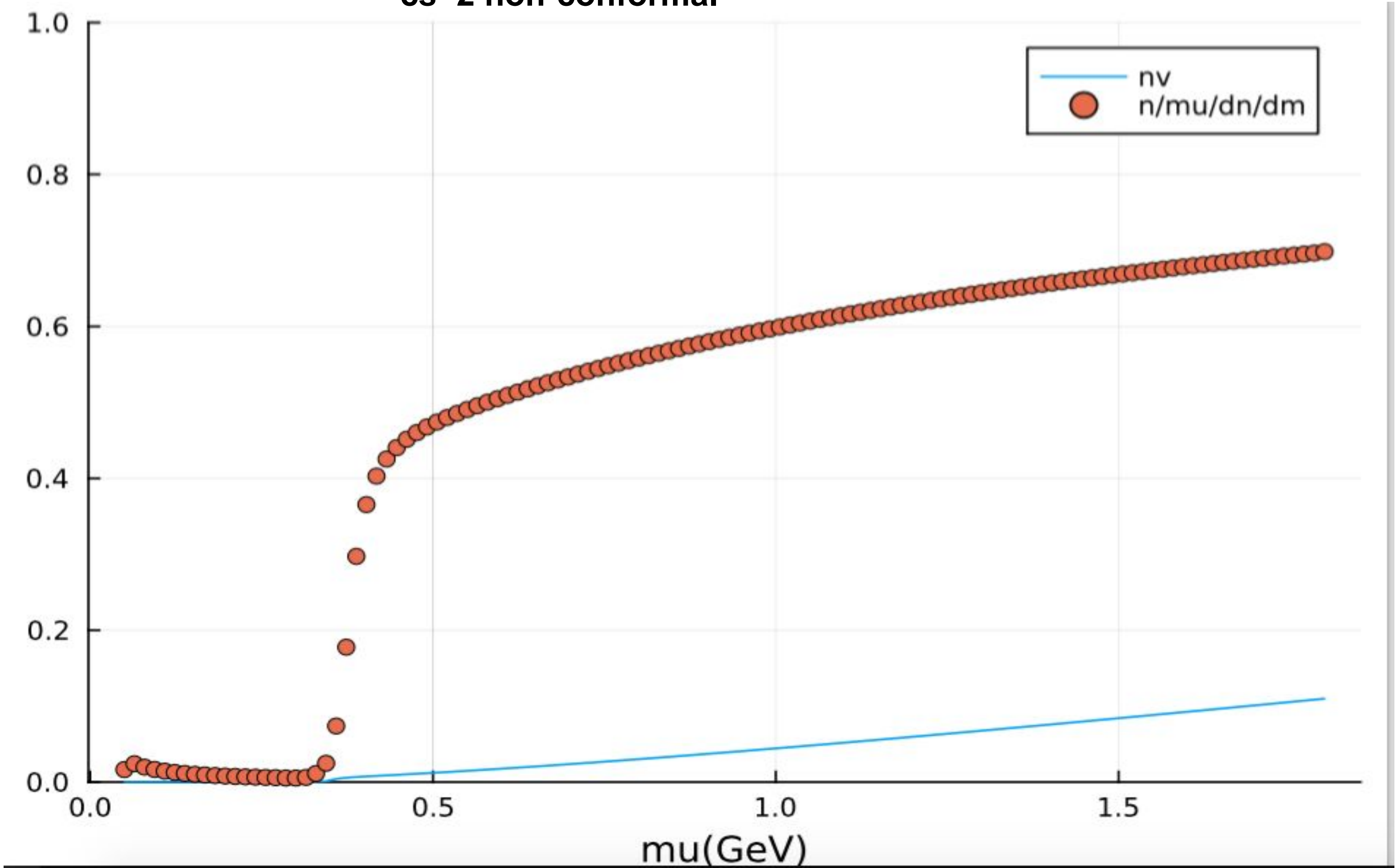
NJL (Nambu-Jona-Lasinio) model

$$m = m_0 + \sigma, \qquad \mu^* = \mu + \omega_0,$$

$$m - m_0 = 4N_f N_c G_S \int \frac{d^3p}{(2\pi)^3} \frac{m}{E_{\mathbf{p}}} \left[1 - n(\xi_{\mathbf{p}}^+) - n(\xi_{\mathbf{p}}^-)\right]$$

$$\mu - \mu^* = 4N_f N_c G_V \int \frac{d^3p}{(2\pi)^3} \left[n(\xi_{\mathbf{p}}^-) - n(\xi_{\mathbf{p}}^+)\right],$$

LOCAL NJL
cs^2 non-conformal



DYNAMICAL EFFECT - GLUON - EXCHANGE → MOMENTUM-DEPENDENT POTENTIAL

$$V(p) = e^{-p^2/\Lambda^2}$$

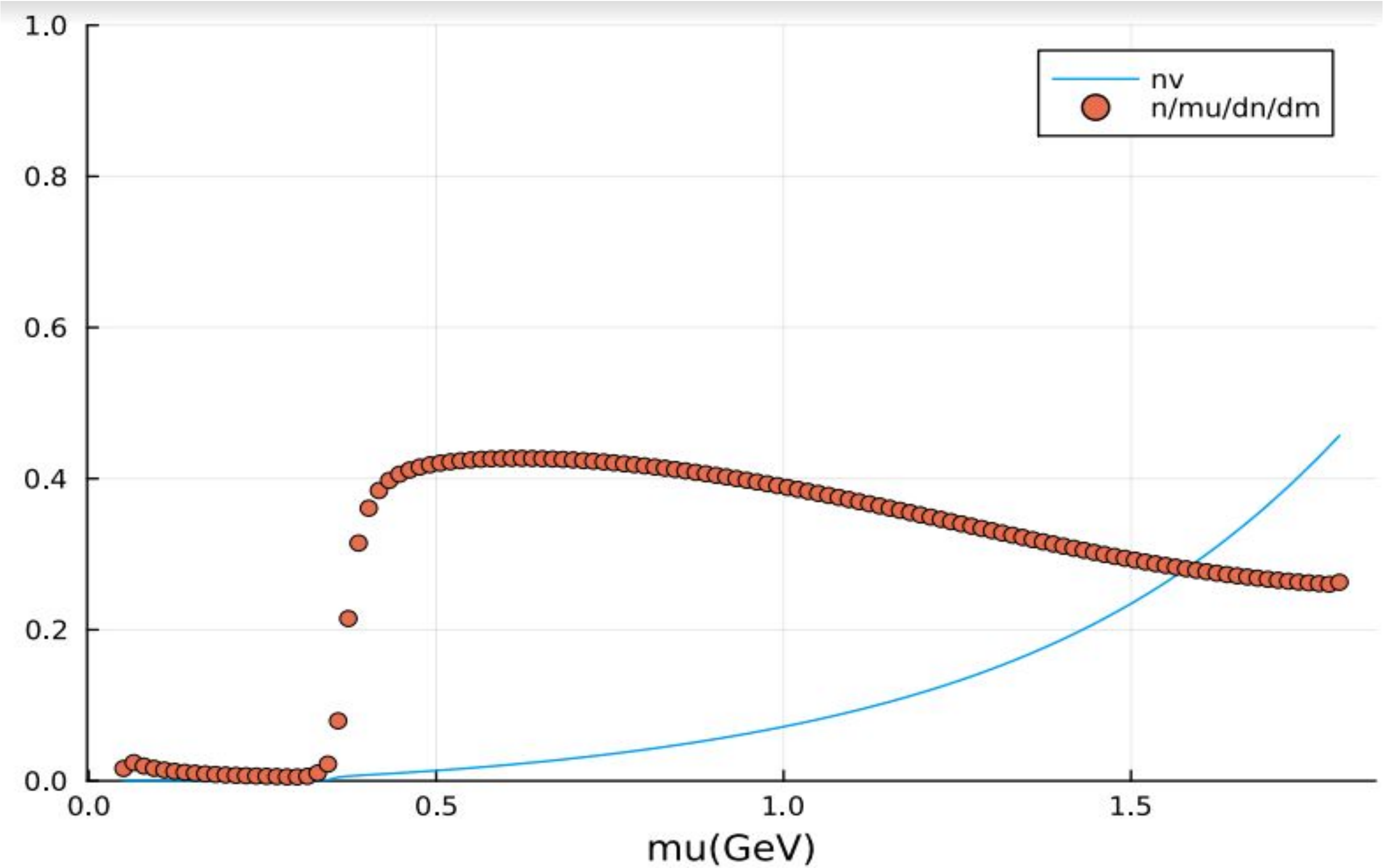
- **Quasi-particle property modified**
- **Chemical potential is dressed differently → dispersion relation**
- **Natural medium-dependence**

$$\mu^* = \mu - \int d^3p\, V(p)(n - \bar{n})$$
$$M = m + \int d^3p\, V(p)(1 - n - \bar{n})$$

Major difference from standard NJL → Momentum integrals modified

Medium-dependent parts get the dynamical factor

DYNAMICAL CHIRAL QUARK MODEL
cs^2 —> conformal!



Coulomb-gauge dynamical chiral quark model

$$
\begin{aligned}
A(\vec{p}) &= 1 + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\rm ring}(\vec{p}-\vec{q})\frac{A_q}{E_q}\frac{\vec{p}\cdot\vec{q}}{p^2}\Theta(q) \\
B(\vec{p}) &= m + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\rm ring}(\vec{p}-\vec{q})\frac{B_q}{E_q}\Theta(q) \\
\tilde{\mu}(\vec{p}) &= \mu + \frac{C_F}{2}\int \frac{d^3q}{(2\pi)^3} V_{\rm ring}(\vec{p}-\vec{q})[n(q)-\bar{n}(q)] \\
E_p^2 &= A_p^2 p^2 + B_p^2.
\end{aligned}
\qquad (13)
$$

P.M. Lo, E. S. Swanson,

Phys.Rev.D81:034030,2010

CONCLUSION

- NJL fails to reach conformal limit
- Speed of sound highly sensitive to dynamical effect
- Momentum-dependence modifies quasiparticle dispersion relation generating natural medium-dependence, satisfies conformal limit
- A dense matter theoretical model must ensure the relevant dressing of the chemical potential for correct behaviour of speed of sound

OUTLOOK

- Investigate the Coulomb-guage model with full p-dependence
- Include diquarks and it’s impact on EoS
- Investigate different implementations of gluon-exchange in potential
- Investigate non-EoS observables, eg. viscosity, transport coefficients, etc.

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