Spinodal and dynamical instabilities

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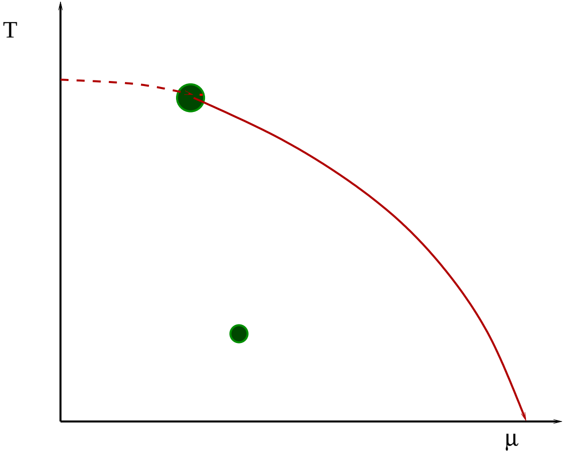
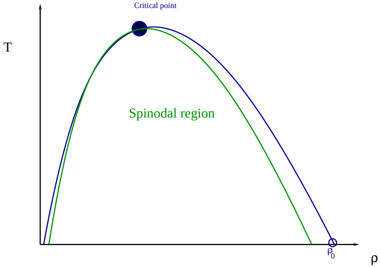
Phase diagram

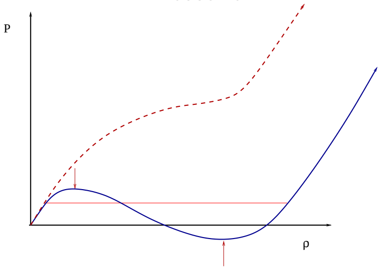


Nuclear matter liquid-gas transition

Mixed phase and spinodal region



Pressure



$$\frac{\partial P}{\partial \rho} < 0$$

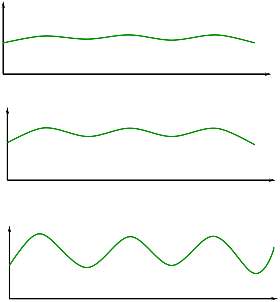
Instability in Fermi liquids

Pethick, Ravenhall
linear response $f_0 + \delta f$

$$\partial_t \delta f + \mathbf{v} \nabla \delta f - \partial_p f_0 \frac{\mathbf{p}}{m} \nabla F \times \delta f$$

instability $\Gamma_k \propto k$ for $F_0 < -1$
$\Gamma_k \simeq \frac{-2}{\pi}(1 + F_0) v_F k$

Vlasov (BUU) equation



Ayik, Chomaz, Colona, Randrup
Dynamical model for HI collisions
$f(\mathbf{x}, \mathbf{p})$

$$f_0(p) + \delta f(p, k)$$

$$\partial_t \delta f + \frac{\mathbf{p}}{m} \nabla \delta f - \nabla_p f_0 \nabla U(\rho) = 0$$

Dispersion relation

$$\omega_k = i\Gamma_k \propto k$$

– molecular dynamics

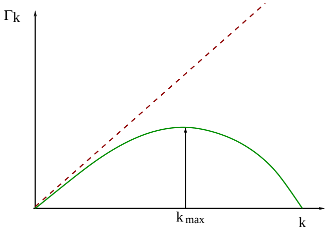
Multifragmentation

Intermediate energy HI collisions

- several intermediate mass fragments
- critical behavior
- liquid, gas regimes
- izospin effects

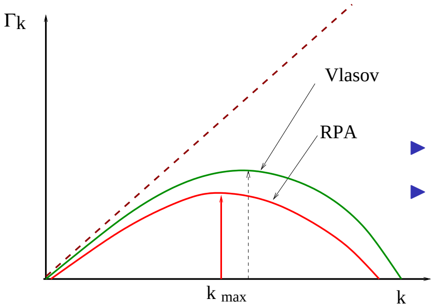
Fragment size

Finite range of interactions



- $U(\rho) \longrightarrow U(g(r - r') \times \rho(r'))$
- surface energy
- fragment size $L^3 \simeq 1/k^3_{max}$

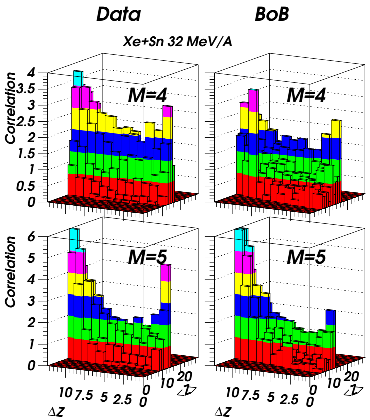
Quantum effects



- Quantum linear response
- Larger fragments

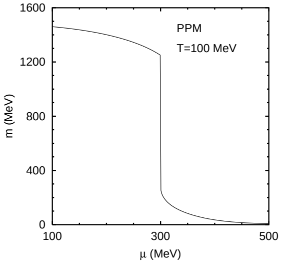
also expansion, Coulomb interaction, nonlinearities, finite system, relaxation. . .

Spinodal multifragmentation



INDRA results vs theory

Parton models



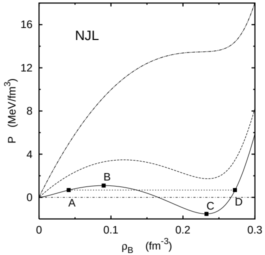
NJL model

$$\bar{\Psi}(i\partial - m)\Psi + \frac{G}{2}((\bar{\Psi}\Psi)^2 + (\bar{\Psi}i\gamma_5\tau_a\Psi)^2$$

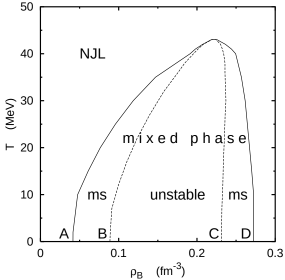
gap equation

NJL EOS

Pressure

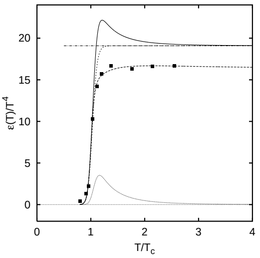


Phase diagram



Phenomenological parton model

Fit to lattice data



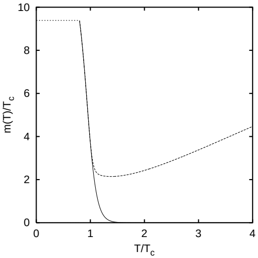
Mass=f(scalar density)
(Gorenstein Yang)

$$\frac{dV(m)}{dm} = -\sum \int dp \frac{m}{E} f(p)$$

$$P = \sum \int dp \frac{p^2}{3E} f(p) - V(m)$$

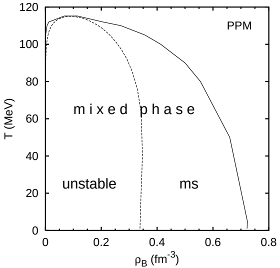
Phenomenological parton model

Rapid change of the mass

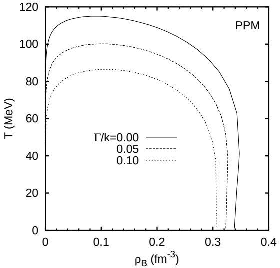


Phase diagram

two solution of the gap equation
spinodal instability

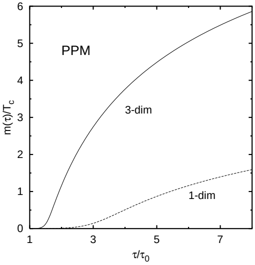


unstable region



Expansion

$$\partial_t f + \frac{\mathbf{p}}{E}\nabla f - \frac{m}{E}\nabla m \nabla_p f = 0$$



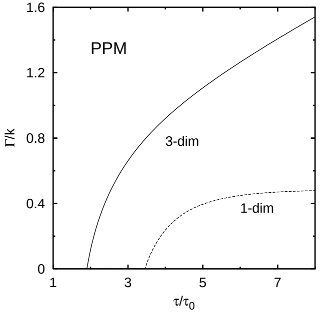
$$f(p,x,t) = f_0\left(\frac{\tau}{\tau_0}\sqrt{(p^\mu_\mu)^2 - p_\perp^2 - m(\tau)^2}, p_\perp)\right)$$

Dynamical instability

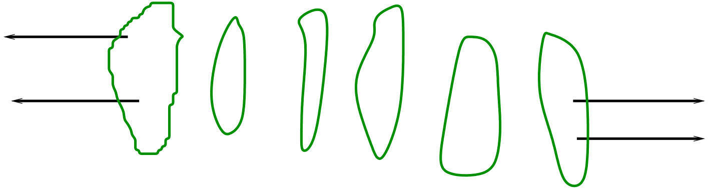
linear response

$$f = f_0 + \delta f$$

$$\Gamma_k \propto k$$



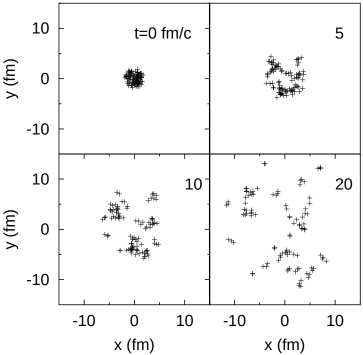
Fragmentation in rapidity



$$\Gamma = 0.5 fm/c \quad \text{for} \quad k = 1.0 fm/c$$

no filamentation

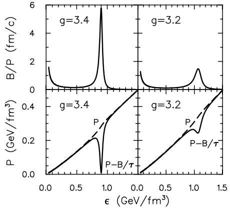
numerical illustration



Bulk viscosity instabilities, shock waves

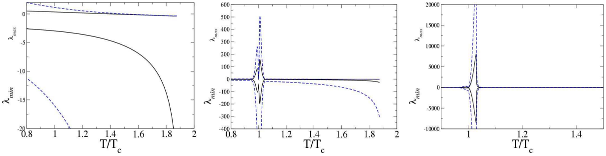
Bulk viscosity around T_c

Paech, Pratt



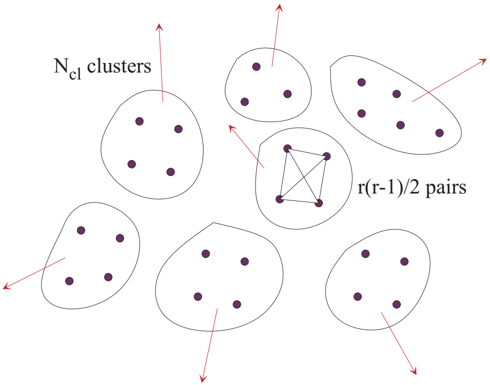
Instabilities in hydro. expansion

Mishustin, Torrieri



$p_\perp$ fluctuations

Scaling of $p_\perp$ fluctuations
Clusters!



Instabilities and fragmentation

- Confirmed in nuclear liquid-gas transition
- QGP-hadron regime?
- Experimental indication?
- Is there anything besides hadronization?

Confinement !!