Pairing effects on spinodal decomposition of asymmetric nuclear matter

International Workshop on Multi facets of Eos and Clustering - IWM-EC 2014

Dipartimento di Fisica e Astronomia and Laboratori Nazionali del Sud

Catania, 6 - 9 May 2014

Authors: Burrello S.[1], Colonna M.[1], Matera F.[2]

[1] INFN - LNS, Catania

[2] INFN - Dipartimento di Fisica e Astronomia - Firenze

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional $E(\rho, T)$
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...

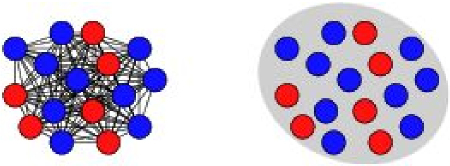
Isotope spectra

...to neutron stars

Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ, T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  → multifragmentation
- Interparticle correlations:
  pairing effects



From nuclei...

Isotope spectra

...to neutron stars

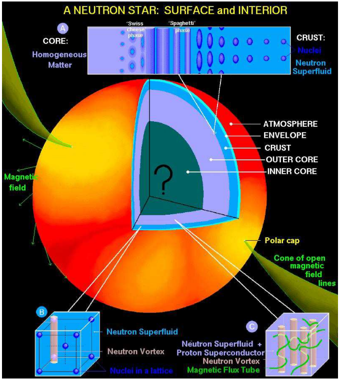
Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ, T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  → multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...

Isotope spectra



...to

neutron stars

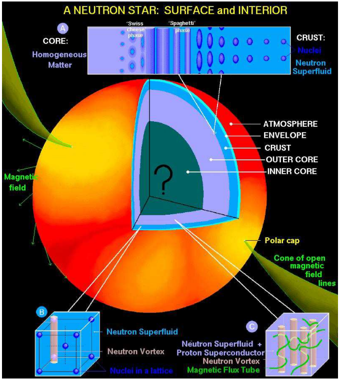
Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ, T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...

Isotope spectra



...to

neutron stars

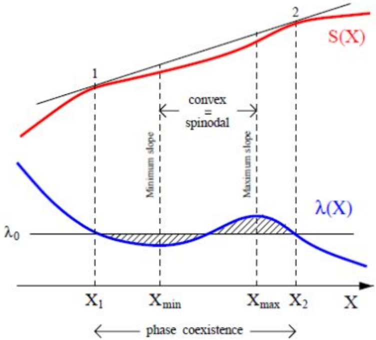
Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

From nuclei...

Isotope spectra

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ,T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  ⇒ multifragmentation
- Interparticle correlations:
  pairing effects



...to

neutron stars

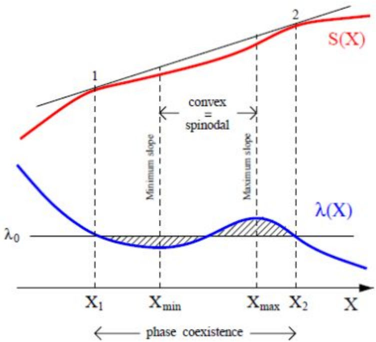
Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

From nuclei...

Isotope spectra

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ, T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects



...to

neutron stars

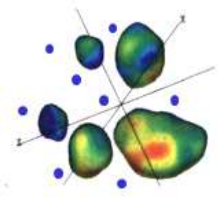
Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ,T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...

Isotope spectra



...to neutron stars

Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ,T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...

Isotope spectra

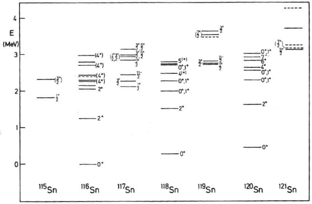
...to neutron stars

Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ,T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...



Isotope spectra

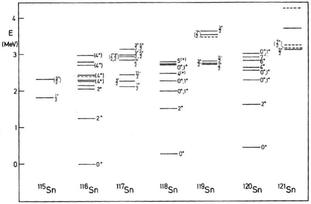
...to neutron stars

Glitch phenomena, cooling processes, ...

Introduction: interacting many-body systems

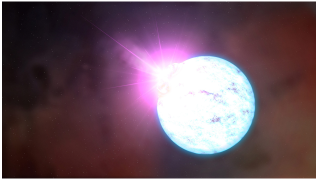
- Mean-field approximation:
  effective interactions
- Equilibrium limit: EoS
  energy functional E (ρ,T)
- Nuclear matter at low density:
  liquid-gas phase transition
- Spinodal (mechanical) instability
  $\Rightarrow$ multifragmentation
- Interparticle correlations:
  pairing effects

From nuclei...



Isotope spectra

...to neutron stars



Glitch phenomena, cooling processes, ...

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^\sigma + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft
  ⇒ nuclear structure
  ⇒ inner crust of neutron stars
  ⇒ heavy ion reactions

- Chemical potentials
  $$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$
- Curvature matrix **C**
  $$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$
- Negative eigenvalues
  ⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \quad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft
  ⇒ nuclear structure
  ⇒ inner crust of neutron stars
  ⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues
  ⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction $\Rightarrow$ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\mathsf{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues

- Symmetry term $\mathcal{C}_{\mathsf{sym}}(\rho)$: stiff - soft

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U^q_{ANM}$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft
  ⇒ nuclear structure
  ⇒ inner crust of neutron stars
  ⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues
  ⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft
  ⇒ nuclear structure
  ⇒ inner crust of neutron stars
  ⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

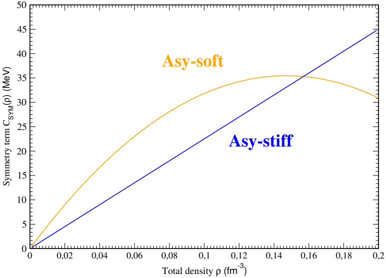
- Negative eigenvalues
  ⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft



⇒ nuclear structure
⇒ inner crust of neutron stars
⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues

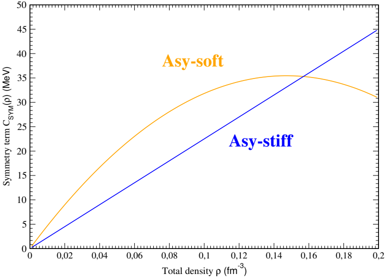
⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\mathrm{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\mathrm{sym}}(\rho)$: stiff - soft



⇒ nuclear structure
⇒ inner crust of neutron stars

⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

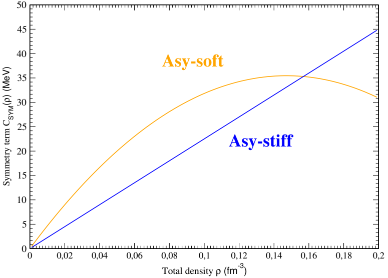
- Negative eigenvalues

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft



⇒ nuclear structure
⇒ inner crust of neutron stars

⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

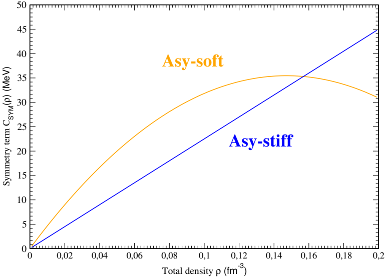
- Negative eigenvalues

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft



⇒ nuclear structure
⇒ inner crust of neutron stars

⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues

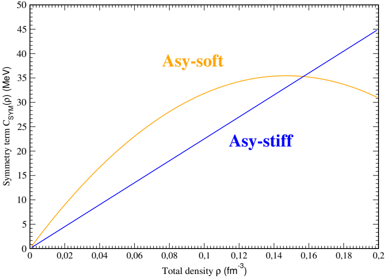
⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^\sigma + \frac{1}{2}\mathcal{C}_{\mathrm{sym}}(\rho)\mathcal{I}^2\right] \quad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\mathrm{sym}}(\rho)$: stiff - soft



⇒ nuclear structure
⇒ inner crust of neutron stars

⇒ heavy ion reactions

- Chemical potentials

$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues

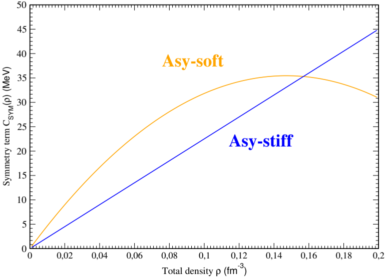
⇒ unstable oscillations (clusters)

Asymmetric nuclear matter (ANM)

- Effective interaction ⇒ simplified Skyrme-like interaction
- Energy density functional (T = 0)

$$\rho\frac{E}{A} = \frac{3}{5}\sum_{q=p,n}\rho_q\epsilon_F^q + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^{\sigma} + \frac{1}{2}\mathcal{C}_{\text{sym}}(\rho)\mathcal{I}^2\right] \qquad \mathcal{I} = \frac{\rho_n - \rho_p}{\rho}$$

- Symmetry term $\mathcal{C}_{\text{sym}}(\rho)$: stiff - soft



⇒ nuclear structure
⇒ inner crust of neutron stars
⇒ heavy ion reactions

- Chemical potentials

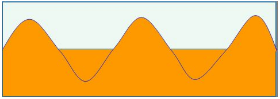
$$\mu_q = \frac{\partial(\rho E/A)}{\partial\rho_q} = \epsilon_F^q + U_{ANM}^q$$

- Curvature matrix **C**

$$\mathbf{C} = \begin{pmatrix} \partial\mu_p/\partial\rho_p & \partial\mu_p/\partial\rho_n \\ \partial\mu_n/\partial\rho_p & \partial\mu_n/\partial\rho_n \end{pmatrix} = \begin{pmatrix} a & \frac{c}{2} \\ \frac{c}{2} & b \end{pmatrix}$$

- Negative eigenvalues

⇒ unstable oscillations (clusters)



Isospin distillation mechanism

- Isoscalar-like ⇒ unstable mode
- Rotation of θ in the plane (ρ_p, ρ_n)

$$\tan\theta = \frac{\delta\rho_n}{\delta\rho_p} \quad \Leftarrow \quad \tan 2\theta = \frac{c}{a-b}$$

- Asymmetry $\delta\mathcal{I}$ of the density fluctuation

Isospin distillation mechanism

- Isoscalar-like $\Rightarrow$ unstable mode
- Rotation of θ in the plane (ρ_p, ρ_n)

$$\tan\theta = \frac{\delta\rho_n}{\delta\rho_p} \quad \Leftarrow \quad \tan 2\theta = \frac{c}{a-b}$$

- Asymmetry $\delta\mathcal{I}$ of the density fluctuation

$$\delta\mathcal{I} = \frac{\delta\rho_n - \delta\rho_p}{\delta\rho_n + \delta\rho_p} = \frac{\delta\rho_n/\delta\rho_p - 1}{\delta\rho_n/\delta\rho_p + 1}$$

Liquid phase is more symmetric than gas phase!

- Isospin distillation mechanism

$$\delta\mathcal{I} < \mathcal{I}$$

Isospin distillation mechanism

- Isoscalar-like $\Rightarrow$ unstable mode
- Rotation of θ in the plane (ρ_p, ρ_n)

$$\tan\theta = \frac{\delta\rho_n}{\delta\rho_p} \quad \Leftarrow \quad \tan 2\theta = \frac{c}{a-b}$$

- Asymmetry $\delta\mathcal{I}$ of the density fluctuation

$$\delta\mathcal{I} = \frac{\delta\rho_n - \delta\rho_p}{\delta\rho_n + \delta\rho_p} = \frac{\delta\rho_n/\delta\rho_p - 1}{\delta\rho_n/\delta\rho_p + 1}$$

Liquid phase is more symmetric than gas phase!

- Isospin distillation mechanism

$$\delta\mathcal{I} < \mathcal{I}$$

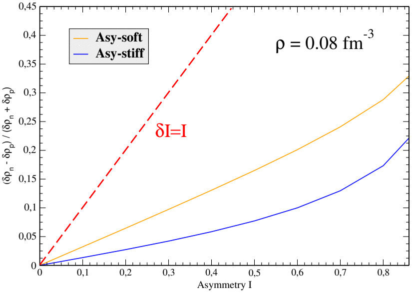
Isospin distillation mechanism

- Isoscalar-like $\Rightarrow$ unstable mode
- Rotation of θ in the plane (ρ_p, ρ_n)

$$\tan\theta = \frac{\delta\rho_n}{\delta\rho_p} \quad \Leftarrow \quad \tan 2\theta = \frac{c}{a-b}$$

- Asymmetry $\delta\mathcal{I}$ of the density fluctuation

$$\delta\mathcal{I} = \frac{\delta\rho_n - \delta\rho_p}{\delta\rho_n + \delta\rho_p} = \frac{\delta\rho_n/\delta\rho_p - 1}{\delta\rho_n/\delta\rho_p + 1}$$



- Isospin distillation mechanism

$$\delta\mathcal{I} < \mathcal{I}$$

Neutron distillation

Liquid phase is more symmetric than gas phase!

Isospin distillation mechanism

- Isoscalar-like $\Rightarrow$ unstable mode
- Rotation of θ in the plane (ρ_p, ρ_n)

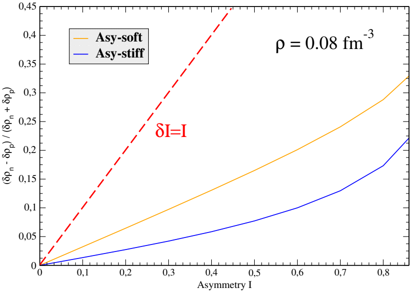
$$\tan\theta = \frac{\delta\rho_n}{\delta\rho_p} \quad \Leftarrow \quad \tan 2\theta = \frac{c}{a-b}$$

- Asymmetry $\delta\mathcal{I}$ of the density fluctuation

$$\delta\mathcal{I} = \frac{\delta\rho_n - \delta\rho_p}{\delta\rho_n + \delta\rho_p} = \frac{\delta\rho_n/\delta\rho_p - 1}{\delta\rho_n/\delta\rho_p + 1}$$

- Isospin distillation mechanism

$$\delta\mathcal{I} < \mathcal{I}$$



Neutron distillation

Liquid phase is more symmetric than gas phase!

Isospin distillation mechanism

- Isoscalar-like $\Rightarrow$ unstable mode
- Rotation of θ in the plane (ρ_p, ρ_n)

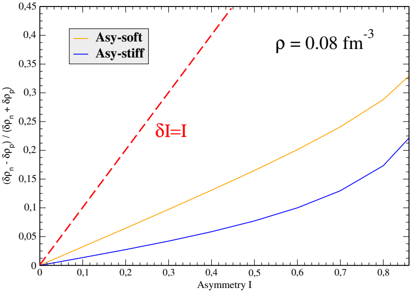
$$\tan\theta = \frac{\delta\rho_n}{\delta\rho_p} \quad \Leftarrow \quad \tan 2\theta = \frac{c}{a-b}$$

- Asymmetry $\delta\mathcal{I}$ of the density fluctuation

$$\delta\mathcal{I} = \frac{\delta\rho_n - \delta\rho_p}{\delta\rho_n + \delta\rho_p} = \frac{\delta\rho_n/\delta\rho_p - 1}{\delta\rho_n/\delta\rho_p + 1}$$

- Isospin distillation mechanism

$$\delta\mathcal{I} < \mathcal{I}$$



Neutron distillation

Liquid phase is more symmetric than gas phase!

Pairing effect on ANM instability: why and how?

- Nucleons form paired states (Cooper pairs)
  ⇒ Pairing treatment: BCS theory (analogous to electrons in metals in the superconducting phase)
- Pairing correlations active at low density ⇒ impact on spinodal instability
- ANM ⇒ only nn or pp pairing
- Pairing interaction: nucleons of the same type
  vs.
  Symmetry potential: nucleons of different type
  ⇒ Different isotopic feature of ANM
- Extension of mean-field approach: Hartree-Fock-Bogoliubov (HFB) theory
  ⇒ unified formalism for pairing and mean-field effective interaction

Pairing effect on ANM instability: why and how?

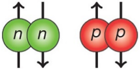
- Nucleons form paired states (Cooper pairs)
  ⇒ Pairing treatment: BCS theory (analogous to electrons in metals in the superconducting phase)
- Pairing correlations active at low density ⇒ impact on spinodal instability
- ANM ⇒ only nn or pp pairing
- Pairing interaction: nucleons of the same type
  vs.
  Symmetry potential: nucleons of different type
  ⇒ Different isotopic feature of ANM
- Extension of mean-field approach: Hartree-Fock-Bogoliubov (HFB) theory
  ⇒ unified formalism for pairing and mean-field effective interaction

Pairing effect on ANM instability: why and how?

- Nucleons form paired states (Cooper pairs)
  ⇒ Pairing treatment: BCS theory (analogous to electrons in metals in the superconducting phase)
- Pairing correlations active at low density ⇒ impact on spinodal instability
- ANM ⇒ only nn or pp pairing
- Pairing interaction: nucleons of the same type
  vs.
  Symmetry potential: nucleons of different type
  ⇒ Different isotopic feature of ANM
- Extension of mean-field approach: Hartree-Fock-Bogoliubov (HFB) theory
  ⇒ unified formalism for pairing and mean-field effective interaction

Pairing effect on ANM instability: why and how?

- Nucleons form paired states (Cooper pairs)
  ⇒ Pairing treatment: BCS theory (analogous to electrons in metals in the superconducting phase)
- Pairing correlations active at low density ⇒ impact on spinodal instability
- ANM ⇒ only nn or pp pairing



- Pairing interaction: nucleons of the same type
  vs.
  Symmetry potential: nucleons of different type
  ⇒ Different isotopic feature of ANM
- Extension of mean-field approach: Hartree-Fock-Bogoliubov (HFB) theory
  ⇒ unified formalism for pairing and mean-field effective interaction

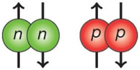
Pairing effect on ANM instability: why and how?

- Nucleons form paired states (Cooper pairs)

  ⇒ Pairing treatment: BCS theory (analogous to electrons in metals in the superconducting phase)

- Pairing correlations active at low density ⇒ impact on spinodal instability

- ANM ⇒ only nn or pp pairing



- Pairing interaction: nucleons of the same type

  vs.

  Symmetry potential: nucleons of different type

  ⇒ Different isotopic feature of ANM

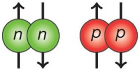
- Extension of mean-field approach: Hartree-Fock-Bogoliubov (HFB) theory

  ⇒ unified formalism for pairing and mean-field effective interaction

Pairing effect on ANM instability: why and how?

- Nucleons form paired states (Cooper pairs)

  ⇒ Pairing treatment: BCS theory (analogous to electrons in metals in the superconducting phase)
- Pairing correlations active at low density ⇒ impact on spinodal instability



- ANM ⇒ only nn or pp pairing
- Pairing interaction: nucleons of the same type

  vs.

  Symmetry potential: nucleons of different type

  ⇒ Different isotopic feature of ANM
- Extension of mean-field approach: Hartree-Fock-Bogoliubov (HFB) theory

  ⇒ unified formalism for pairing and mean-field effective interaction

BCS theory at zero temperature: gap equation

Ground state: Fermi sea

Ground state: only Cooper pairs

HF theory

$$|HF\rangle = \prod_{k<k_F} \hat{a}_k^\dagger \,|0\rangle$$

$$E_n = \sum_{k<k_F} \left(2\xi_k v_k^2|_n - \Gamma_k v_k^2|_n\right)$$

$\Longrightarrow$

BCS theory

$$|BCS\rangle = \prod_{k>0} (u_k|_s + v_k|_s \hat{a}_k^\dagger \hat{a}_{\bar{k}}^\dagger)\,|0\rangle$$

$$E_s = \sum_{k>0} \left(2\xi_k v_k^2|_s - \Gamma_k v_k^2|_s - \Delta_k v_k u_k|_s\right)$$

v_k^2 — Occupation number

$\xi_k = \epsilon_k - \mu_k^* \quad \mu_k^* = \mu - \Gamma_k$ — Effective chemical potential

$\Gamma_k = \sum_{k'} \bar{V}_{kk'kk'} v_{k'}^2|_{n,s}$ — Mean-field potential

$\Delta_k = -\sum_{k'>0} \bar{V}_{k\bar{k}k'\bar{k}'} v_{k'} u_{k'}|_s$ — Energy gap $\Rightarrow$ Gap equation

$N = 2\sum_{k>0} v_k^2|_s$ — Particle number conservation $\Rightarrow$ Density equation

BCS theory at zero temperature: gap equation

Ground state: Fermi sea

HF theory

$$|HF\rangle = \prod_{k<k_F} \hat{a}_k^\dagger |0\rangle$$

$$E_n = \sum_{k<k_F} \left(2\xi_k v_k^2|_n - \Gamma_k v_k^2|_n\right)$$

$\Longrightarrow$

Ground state: only Cooper pairs

BCS theory

$$|BCS\rangle = \prod_{k>0} (u_k|_s + v_k|_s \hat{a}_k^\dagger \hat{a}_{\bar{k}}^\dagger) |0\rangle$$

$$E_s = \sum_{k>0} \left(2\xi_k v_k^2|_s - \Gamma_k v_k^2|_s - \Delta_k v_k u_k|_s\right)$$

v_k^2 Occupation number

$\xi_k = \epsilon_k - \mu_k^* \quad \mu_k^* = \mu - \Gamma_k$ Effective chemical potential

$\Gamma_k = \sum_{k'} \bar{V}_{kk'kk'} v_{k'}^2|_{n,s}$ Mean-field potential

$\Delta_k = -\sum_{k'>0} \bar{V}_{k\bar{k}k'\bar{k}'} v_{k'} u_{k'}|_s$ Energy gap $\Rightarrow$ Gap equation

$N = 2\sum_{k>0} v_k^2|_s$ Particle number conservation $\Rightarrow$ Density equation

BCS theory at zero temperature: gap equation

Ground state: Fermi sea

HF theory

$$|HF\rangle = \prod_{k<k_F} \hat{a}_k^\dagger |0\rangle$$

$$E_n = \sum_{k<k_F} \left(2\xi_k v_k^2|_n - \Gamma_k v_k^2|_n\right)$$

$\Longrightarrow$

Ground state: only Cooper pairs

BCS theory

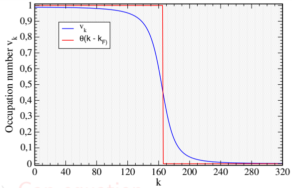
$$|BCS\rangle = \prod_{k>0} (u_k|_s + v_k|_s \hat{a}_k^\dagger \hat{a}_{\bar{k}}^\dagger)|0\rangle$$

$$E_s = \sum_{k>0} \left(2\xi_k v_k^2|_s - \Gamma_k v_k^2|_s - \Delta_k v_k u_k|_s\right)$$

v_k^2 Occupation number

$\xi_k = \epsilon_k - \mu_k^* \quad \mu_k^* = \mu - \Gamma_k$ Effective chemical potential

$\Gamma_k = \sum_{k'} \bar{V}_{kk'kk'} v_{k'}^2|_{n,s}$ Mean-field potential



$\Delta_k = -\sum_{k'>0} \bar{V}_{k\bar{k}k'\bar{k}'} v_{k'} u_{k'}|_s$ Energy gap $\Rightarrow$ Gap equation

$N = 2\sum_{k>0} v_k^2|_s$ Particle number conservation $\Rightarrow$ Density equation

BCS theory at zero temperature: gap equation

Ground state: Fermi sea

Ground state: only Cooper pairs

HF theory

$$|HF\rangle = \prod_{k<k_F} \hat{a}_k^\dagger |0\rangle$$

$$E_n = \sum_{k<k_F} \left(2\xi_k v_k^2|_n - \Gamma_k v_k^2|_n\right)$$

$\Longrightarrow$

BCS theory

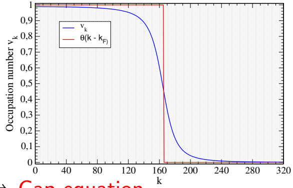
$$|BCS\rangle = \prod_{k>0} (u_k|_s + v_k|_s \hat{a}_k^\dagger \hat{a}_{\bar{k}}^\dagger) |0\rangle$$

$$E_s = \sum_{k>0} \left(2\xi_k v_k^2|_s - \Gamma_k v_k^2|_s - \Delta_k v_k u_k|_s\right)$$

v_k^2 Occupation number

$\xi_k = \epsilon_k - \mu_k^* \quad \mu_k^* = \mu - \Gamma_k$ Effective chemical potential

$\Gamma_k = \sum_{k'} \bar{V}_{kk'kk'} v_{k'}^2|_{n,s}$ Mean-field potential



$$\Delta_k = -\sum_{k'>0} \bar{V}_{k\bar{k}k'\bar{k}'} v_{k'} u_{k'}|_s$$ Energy gap $\Rightarrow$ Gap equation

$$N = 2\sum_{k>0} v_k^2|_s$$ Particle number conservation $\Rightarrow$ Density equation

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i, \mathbf{r}_j) = \frac{1}{2}(1 - P_\sigma) v_\pi^q(\rho_q)\delta(\mathbf{r}_{ij}) \qquad q = p, n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q = \frac{(2m)^{3/2}}{4\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \sqrt{\epsilon} \left[1 - \frac{\xi}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

$$1 = -v_\pi(\rho_q) \frac{(2m)^{3/2}}{8\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \frac{\sqrt{\epsilon}}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)$$

$$\beta = \frac{1}{T},\ E_\Delta = \sqrt{\xi^2 + \Delta^2},\ \xi = \epsilon - \mu_q^*,\ \mu_q^* = \mu_q - U_q$$

- T = 0 $\Rightarrow$ strength $v_\pi^q(\rho_q) \equiv v_\pi(\rho_q)$

$$v_\pi(\rho_q) = V_\pi^\Lambda \left[1 - \eta \left(\frac{\rho_q}{\rho_0}\right)^\alpha\right] \text{ also for pp}$$

- $T \neq 0 \Rightarrow \Delta(T)$

- $T = T_C$ superfluid $\leftrightarrow$ normal phase

$^1S_0$ pairing gap of neutron matter
(Brueckner calculations with Argonne v_{14} potential)

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i, \mathbf{r}_j) = \frac{1}{2}(1 - P_\sigma) v_\pi^q(\rho_q)\delta(\mathbf{r}_{ij}) \qquad q = p, n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q = \frac{(2m)^{3/2}}{4\pi^2\hbar^3}\int_0^{\mu_q^*+\epsilon_\Lambda} d\epsilon\sqrt{\epsilon}\left[1 - \frac{\xi}{E_\Delta}\tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

$$1 = -v_\pi(\rho_q)\frac{(2m)^{3/2}}{8\pi^2\hbar^3}\int_0^{\mu_q^*+\epsilon_\Lambda} d\epsilon \frac{\sqrt{\epsilon}}{E_\Delta}\tanh\left(\frac{\beta E_\Delta}{2}\right)$$

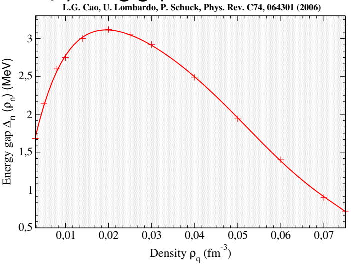
$$\beta = \frac{1}{T},\; E_\Delta = \sqrt{\xi^2 + \Delta^2},\; \xi = \epsilon - \mu_q^*,\; \mu_q^* = \mu_q - U_q$$

- $T = 0 \Rightarrow$ strength $v_\pi^q(\rho_q) \equiv v_\pi(\rho_q)$

$$v_\pi(\rho_q) = V_\pi^\Lambda\left[1 - \eta\left(\frac{\rho_q}{\rho_0}\right)^\alpha\right] \quad \text{also for pp}$$

- $T \neq 0 \Rightarrow \Delta(T)$
- $T = T_C$ superfluid $\leftrightarrow$ normal phase

$^1S_0$ pairing gap of neutron matter



(Brueckner calculations with Argonne v_{14} potential)

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i,\mathbf{r}_j)=\frac{1}{2}(1-P_\sigma)v_\pi^q(\rho_q)\delta(\mathbf{r}_{ij})\qquad q=p,n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q=\frac{(2m)^{3/2}}{4\pi^2\hbar^3}\int_0^{\mu_q^*+\epsilon_\Lambda}d\epsilon\sqrt{\epsilon}\left[1-\frac{\xi}{E_\Delta}\tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

$$1=-v_\pi(\rho_q)\frac{(2m)^{3/2}}{8\pi^2\hbar^3}\int_0^{\mu_q^*+\epsilon_\Lambda}d\epsilon\frac{\sqrt{\epsilon}}{E_\Delta}\tanh\left(\frac{\beta E_\Delta}{2}\right)$$

$$\beta=\frac{1}{T},\ E_\Delta=\sqrt{\xi^2+\Delta^2},\ \xi=\epsilon-\mu_q^*,\ \mu_q^*=\mu_q-U_q$$

- $T=0 \Rightarrow$ strength $v_\pi^q(\rho_q)\equiv v_\pi(\rho_q)$

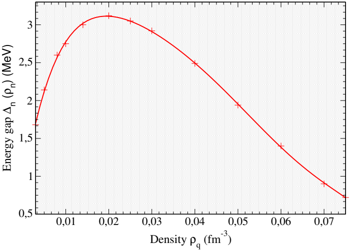
$$v_\pi(\rho_q)=V_\pi^\Lambda\left[1-\eta\left(\frac{\rho_q}{\rho_0}\right)^\alpha\right]\quad \text{also for pp}$$

- $T\neq 0 \Rightarrow \Delta(T)$

- $T=T_C$ superfluid $\leftrightarrow$ normal phase

$^1S_0$ pairing gap of neutron matter

L.G. Cao, U. Lombardo, P. Schuck, Phys. Rev. C74, 064301 (2006)



(Brueckner calculations with Argonne v_{14} potential)

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i, \mathbf{r}_j) = \frac{1}{2}(1 - P_\sigma) v_\pi^q(\rho_q) \delta(\mathbf{r}_{ij}) \qquad q = p, n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q = \frac{(2m)^{3/2}}{4\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \sqrt{\epsilon} \left[1 - \frac{\xi}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

$$1 = -v_\pi(\rho_q) \frac{(2m)^{3/2}}{8\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \frac{\sqrt{\epsilon}}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)$$

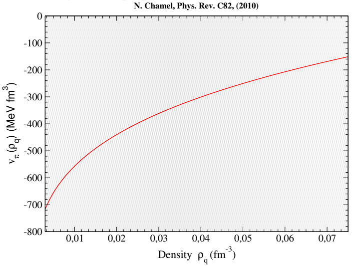
$$\beta = \frac{1}{T}, \; E_\Delta = \sqrt{\xi^2 + \Delta^2}, \; \xi = \epsilon - \mu_q^*, \; \mu_q^* = \mu_q - U_q$$

- T $= 0 \Rightarrow$ strength $v_\pi^q(\rho_q) \equiv v_\pi(\rho_q)$

$$v_\pi(\rho_q) = V_\pi^\Lambda \left[1 - \eta \left(\frac{\rho_q}{\rho_0}\right)^\alpha\right] \quad \text{also for pp}$$

- $T \neq 0 \Rightarrow \Delta(T)$
- $T = T_C$ superfluid $\leftrightarrow$ normal phase

$^1S_0$ pairing gap of neutron matter



(Brueckner calculations with Argonne v_{14} potential)

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i, \mathbf{r}_j) = \frac{1}{2}(1 - P_\sigma) v_\pi^q(\rho_q)\delta(\mathbf{r}_{ij}) \qquad q = p, n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q = \frac{(2m)^{3/2}}{4\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \sqrt{\epsilon} \left[1 - \frac{\xi}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

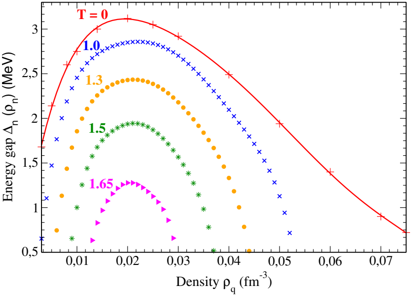
$$1 = -v_\pi(\rho_q) \frac{(2m)^{3/2}}{8\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \frac{\sqrt{\epsilon}}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)$$

$$\beta = \frac{1}{T}, \; E_\Delta = \sqrt{\xi^2 + \Delta^2}, \; \xi = \epsilon - \mu_q^*, \; \mu_q^* = \mu_q - U_q$$

- $T = 0 \Rightarrow$ strength $v_\pi^q(\rho_q) \equiv v_\pi(\rho_q)$

$$v_\pi(\rho_q) = V_\pi^\Lambda \left[1 - \eta \left(\frac{\rho_q}{\rho_0}\right)^\alpha\right] \quad \text{also for pp}$$

- $T \neq 0 \Rightarrow \Delta(T)$



- $T = T_C$ superfluid $\leftrightarrow$ normal phase

$^1S_0$ pairing gap of neutron matter

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i,\mathbf{r}_j) = \frac{1}{2}(1-P_\sigma)v_\pi^q(\rho_q)\delta(\mathbf{r}_{ij}) \qquad q=p,n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q = \frac{(2m)^{3/2}}{4\pi^2\hbar^3}\int_0^{\mu_q^*+\epsilon_\Lambda} d\epsilon\sqrt{\epsilon}\left[1-\frac{\xi}{E_\Delta}\tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

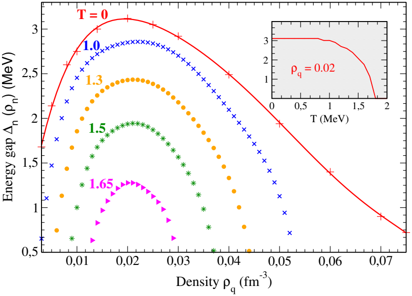
$$1 = -v_\pi(\rho_q)\frac{(2m)^{3/2}}{8\pi^2\hbar^3}\int_0^{\mu_q^*+\epsilon_\Lambda} d\epsilon\,\frac{\sqrt{\epsilon}}{E_\Delta}\tanh\left(\frac{\beta E_\Delta}{2}\right)$$

$$\beta = \frac{1}{T},\ \ E_\Delta = \sqrt{\xi^2+\Delta^2},\ \ \xi = \epsilon-\mu_q^*,\ \ \mu_q^* = \mu_q - U_q$$

- $T=0 \Rightarrow$ strength $v_\pi^q(\rho_q) \equiv v_\pi(\rho_q)$

$$v_\pi(\rho_q) = V_\pi^\Lambda\left[1-\eta\left(\frac{\rho_q}{\rho_0}\right)^\alpha\right] \quad \text{also for pp}$$

- $T \neq 0 \Rightarrow \Delta(T)$



- $T = T_C$ superfluid $\leftrightarrow$ normal phase

$^1S_0$ pairing gap of neutron matter

Gap and density equations: effective interaction

- Effective pairing interaction

$$V_\pi(\mathbf{r}_i, \mathbf{r}_j) = \frac{1}{2}(1 - P_\sigma) v_\pi^q(\rho_q)\delta(\mathbf{r}_{ij}) \qquad q = p, n$$

zero range $\Rightarrow$ energy cutoff $\epsilon_\Lambda = 16$ MeV

- Density equation

$$\rho_q = \frac{(2m)^{3/2}}{4\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \sqrt{\epsilon} \left[1 - \frac{\xi}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)\right]$$

- Gap equation

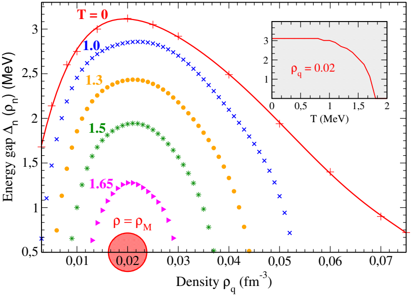
$$1 = -v_\pi(\rho_q) \frac{(2m)^{3/2}}{8\pi^2\hbar^3} \int_0^{\mu_q^* + \epsilon_\Lambda} d\epsilon \frac{\sqrt{\epsilon}}{E_\Delta} \tanh\left(\frac{\beta E_\Delta}{2}\right)$$

$$\beta = \frac{1}{T}, \; E_\Delta = \sqrt{\xi^2 + \Delta^2}, \; \xi = \epsilon - \mu_q^*, \; \mu_q^* = \mu_q - U_q$$

- $T = 0 \Rightarrow$ strength $v_\pi^q(\rho_q) \equiv v_\pi(\rho_q)$

$$v_\pi(\rho_q) = V_\pi^\Lambda \left[1 - \eta \left(\frac{\rho_q}{\rho_0}\right)^\alpha\right] \quad \text{also for pp}$$

- $T \neq 0 \Rightarrow \Delta(T)$



- $T = T_C$ superfluid $\leftrightarrow$ normal phase

${}^1S_0$ pairing gap of neutron matter

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta / v_\pi$):

$$\rho \frac{E}{A} = \sum_q \left[2 \int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p}) \frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q) \frac{|\tilde{\rho}_q|^2}{4} \right] + \rho \left[\frac{\mathcal{A}}{2} \left(\frac{\rho}{\rho_0} \right) + \frac{\mathcal{B}}{\sigma + 1} \left(\frac{\rho}{\rho_0} \right)^\sigma + \frac{\mathcal{C}_{sym}}{2} \mathcal{I}^2 \right]$$

$$\mu^q_\pi = \frac{\partial (\rho E/A)}{\partial \rho_q} \Big|_{\tilde{\rho}_q} = \mu^*_q + U^q_\pi + U^q_{ANM}$$

- Effect on the asymmetry of unstable oscillation
  $\Rightarrow$ (isospin distillation)
  - increase at most of 20% of the asymmetry $\mathcal{I}$
  - competition between pairing and $\mathcal{C}_{sym}$
  - confirmed the leading role of $\mathcal{C}_{sym}$ on distillation

$$\frac{\partial \mu^q_\pi}{\partial \rho_q} = \frac{\partial \mu^*_q}{\partial \rho_q} + \frac{\partial U^q_\pi}{\partial \rho_q}$$

$$\frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon^q_F}{\partial \rho_q}$$

$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho\frac{E}{A} = \sum_q \left[2\int\frac{d\mathbf{p}}{h^3} f^q(\mathbf{p})\frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q)\frac{|\tilde{\rho}_q|^2}{4}\right] + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^\sigma + \frac{\mathcal{C}_{sym}}{2}\mathcal{I}^2\right]$$

$$\mu^q_\pi = \frac{\partial(\rho E/A)}{\partial\rho_q}\Big|_{\tilde{\rho}_q} = \mu^*_q + U^q_\pi + U^q_{ANM}$$

- Effect on the asymmetry of unstable oscillation

$\Rightarrow$ (isospin distillation)

$$\frac{\partial\mu^q_\pi}{\partial\rho_q} = \frac{\partial\mu^*_q}{\partial\rho_q} + \frac{\partial U^q_\pi}{\partial\rho_q}$$

$$\frac{\partial\mu_q}{\partial\rho_q} = \frac{\partial\epsilon^q_F}{\partial\rho_q}$$

$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta / v_\pi$):

$$\rho \frac{E}{A} = \sum_q \left[2 \int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p}) \frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q) \frac{|\tilde{\rho}_q|^2}{4} \right] + \rho \left[\frac{\mathcal{A}}{2} \left(\frac{\rho}{\rho_0} \right) + \frac{\mathcal{B}}{\sigma + 1} \left(\frac{\rho}{\rho_0} \right)^\sigma + \frac{\mathcal{C}_{sym}}{2} \mathcal{I}^2 \right]$$

$$\mu_\pi^q = \left. \frac{\partial (\rho E / A)}{\partial \rho_q} \right|_{\tilde{\rho}_q} = \mu_q^* + U_\pi^q + U_{ANM}^q$$

- Effect on the asymmetry of unstable oscillation

  ⇒ (isospin distillation)

$$a_\pi\,, b_\pi = \frac{\partial \mu_\pi^q}{\partial \rho_q} = \frac{\partial \mu_q^*}{\partial \rho_q} + \frac{\partial U_\pi^q}{\partial \rho_q} + \frac{\partial U_{ANM}^q}{\partial \rho_q} \equiv \delta_q$$

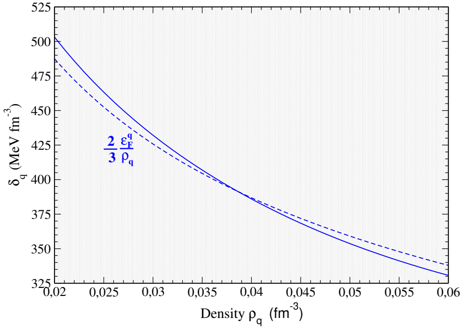
$$a, b = \frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon_F^q}{\partial \rho_q} + \frac{\partial U_{ANM}^q}{\partial \rho_q} = \frac{2}{3} \frac{\epsilon_F^q}{\rho_q}$$

$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho\frac{E}{A} = \sum_q \left[2\int\frac{d\mathbf{p}}{h^3}f^q(\mathbf{p})\frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q)\frac{|\tilde{\rho}_q|^2}{4}\right] + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^\sigma + \frac{\mathcal{C}_{sym}}{2}\mathcal{I}^2\right]$$



$$\mu_\pi^q = \frac{\partial(\rho E/A)}{\partial \rho_q}\Big|_{\tilde{\rho}_q} = \mu_q^* + U_\pi^q + U_{ANM}^q$$

$$\frac{\partial \mu_\pi^q}{\partial \rho_q} = \frac{\partial \mu_q^*}{\partial \rho_q} + \frac{\partial U_\pi^q}{\partial \rho_q} \equiv \delta_q$$

$$\frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon_F^q}{\partial \rho_q} = \frac{2}{3}\frac{\epsilon_F^q}{\rho_q}$$

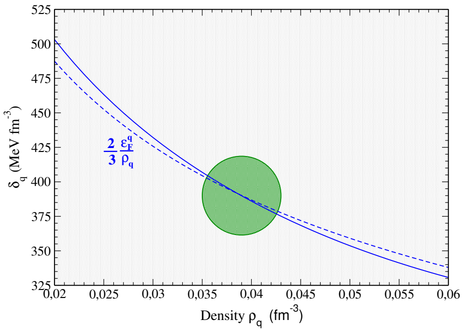
- Effect on the asymmetry of unstable oscillation
  ⇒ (isospin distillation)

$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho\frac{E}{A} = \sum_q \left[2\int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p})\frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q)\frac{|\tilde{\rho}_q|^2}{4}\right] + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^\sigma + \frac{\mathcal{C}_{sym}}{2}\mathcal{I}^2\right]$$



$$\mu_\pi^q = \frac{\partial(\rho E/A)}{\partial \rho_q}\Big|_{\tilde{\rho}_q} = \mu_q^* + U_\pi^q + U_{ANM}^q$$

$$\frac{\partial \mu_\pi^q}{\partial \rho_q} = \frac{\partial \mu_q^*}{\partial \rho_q} + \frac{\partial U_\pi^q}{\partial \rho_q} \equiv \delta_q$$

$$\frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon_F^q}{\partial \rho_q} = \frac{2}{3}\frac{\epsilon_F^q}{\rho_q}$$

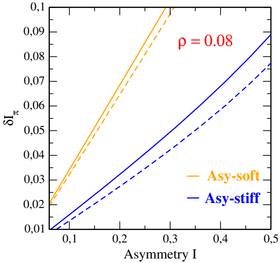
$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

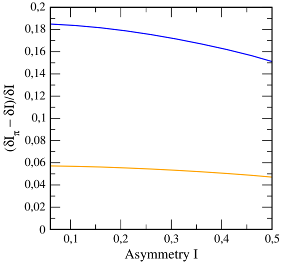
- Effect on the asymmetry of unstable oscillation
  $\Rightarrow$ (isospin distillation)
  - Increase at most of 20% of the asymmetry $\mathcal{I}$

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho \frac{E}{A} = \sum_q \left[2 \int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p}) \frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q) \frac{|\tilde{\rho}_q|^2}{4} \right] + \rho \left[\frac{\mathcal{A}}{2} \left(\frac{\rho}{\rho_0} \right) + \frac{\mathcal{B}}{\sigma+1} \left(\frac{\rho}{\rho_0} \right)^\sigma + \frac{\mathcal{C}_{sym}}{2} \mathcal{I}^2 \right]$$





$$\mu^q_\pi = \left. \frac{\partial(\rho E/A)}{\partial \rho_q} \right|_{\tilde{\rho}_q} = \mu^*_q + U^q_\pi + U^q_{ANM}$$

$$\frac{\partial \mu^q_\pi}{\partial \rho_q} = \frac{\partial \mu^*_q}{\partial \rho_q} + \frac{\partial U^q_\pi}{\partial \rho_q} \equiv \delta_q$$

$$\frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon^q_F}{\partial \rho_q} = \frac{2}{3} \frac{\epsilon^q_F}{\rho_q}$$

$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

- Effect on the asymmetry of unstable oscillation

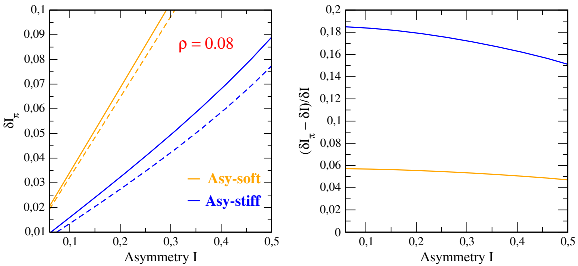
  ⇒ (isospin distillation)

  - increase at most of 20% of the asymmetry $\mathcal{I}$
  - competition between pairing and $\mathcal{C}_{sym}$
  - confirmed the leading role of $\mathcal{C}_{sym}$ on distillation

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho\frac{E}{A} = \sum_q \left[2\int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p})\frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q)\frac{|\tilde{\rho}_q|^2}{4}\right] + \rho\left[\frac{\mathcal{A}}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\mathcal{B}}{\sigma+1}\left(\frac{\rho}{\rho_0}\right)^\sigma + \frac{\mathcal{C}_{sym}}{2}\mathcal{I}^2\right]$$



$$\mu^q_\pi = \frac{\partial(\rho E/A)}{\partial\rho_q}\Big|_{\tilde{\rho}_q} = \mu^*_q + U^q_\pi + U^q_{ANM}$$

$$\frac{\partial\mu^q_\pi}{\partial\rho_q} = \frac{\partial\mu^*_q}{\partial\rho_q} + \frac{\partial U^q_\pi}{\partial\rho_q} \equiv \delta_q$$

$$\frac{\partial\mu_q}{\partial\rho_q} = \frac{\partial\epsilon^q_F}{\partial\rho_q} = \frac{2}{3}\frac{\epsilon^q_F}{\rho_q}$$

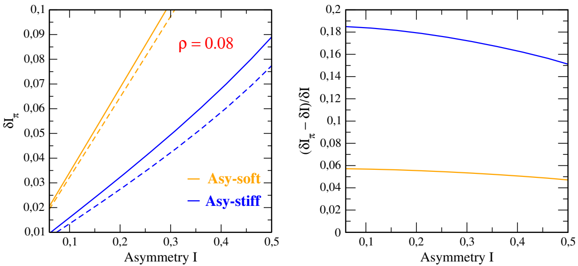
$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

- Effect on the asymmetry of unstable oscillation
  $\Rightarrow$ (isospin distillation)
  - increase at most of 20% of the asymmetry $\mathcal{I}$
  - competition between pairing and $\mathcal{C}_{sym}$
  - confirmed the leading role of $\mathcal{C}_{sym}$ on distillation

Effect on chemical potential derivatives ($T = 0$)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho \frac{E}{A} = \sum_q \left[2 \int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p}) \frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q) \frac{|\tilde{\rho}_q|^2}{4} \right] + \rho \left[\frac{\mathcal{A}}{2} \left(\frac{\rho}{\rho_0} \right) + \frac{\mathcal{B}}{\sigma+1} \left(\frac{\rho}{\rho_0} \right)^\sigma + \frac{\mathcal{C}_{sym}}{2} \mathcal{I}^2 \right]$$



$$\mu_\pi^q = \frac{\partial(\rho E/A)}{\partial \rho_q}\bigg|_{\tilde{\rho}_q} = \mu_q^* + U_\pi^q + U_{ANM}^q$$

$$\frac{\partial \mu_\pi^q}{\partial \rho_q} = \frac{\partial \mu_q^*}{\partial \rho_q} + \frac{\partial U_\pi^q}{\partial \rho_q} \equiv \delta_q$$

$$\frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon_F^q}{\partial \rho_q} = \frac{2}{3} \frac{\epsilon_F^q}{\rho_q}$$

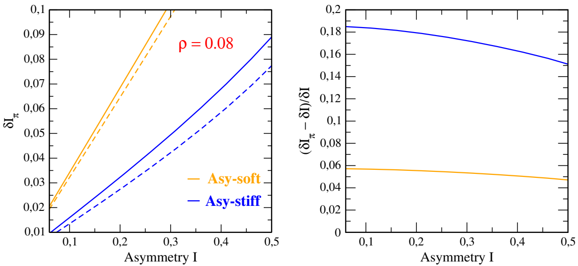
$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

- Effect on the asymmetry of unstable oscillation
  $\Rightarrow$ (isospin distillation)
  - increase at most of 20% of the asymmetry $\mathcal{I}$
  - competition between pairing and $\mathcal{C}_{sym}$
  - confirmed the leading role of $\mathcal{C}_{sym}$ on distillation

Effect on chemical potential derivatives (T = 0)

- Energy density functional in paired ANM ($\tilde{\rho} \equiv 2\Delta/v_\pi$):

$$\rho \frac{E}{A} = \sum_q \left[2 \int \frac{d\mathbf{p}}{h^3} f^q(\mathbf{p}) \frac{\mathbf{p}^2}{2m} + v_\pi(\rho_q) \frac{|\tilde{\rho}_q|^2}{4} \right] + \rho \left[\frac{\mathcal{A}}{2} \left(\frac{\rho}{\rho_0} \right) + \frac{\mathcal{B}}{\sigma+1} \left(\frac{\rho}{\rho_0} \right)^\sigma + \frac{\mathcal{C}_{sym}}{2} \mathcal{I}^2 \right]$$



$$\mu_\pi^q = \frac{\partial(\rho E/A)}{\partial \rho_q}\bigg|_{\tilde{\rho}_q} = \mu_q^* + U_\pi^q + U_{ANM}^q$$

$$\frac{\partial \mu_\pi^q}{\partial \rho_q} = \frac{\partial \mu_q^*}{\partial \rho_q} + \frac{\partial U_\pi^q}{\partial \rho_q} \equiv \delta_q$$

$$\frac{\partial \mu_q}{\partial \rho_q} = \frac{\partial \epsilon_F^q}{\partial \rho_q} = \frac{2}{3} \frac{\epsilon_F^q}{\rho_q}$$

$$\tan 2\theta_\pi = \frac{c}{a_\pi - b_\pi}$$

- Effect on the asymmetry of unstable oscillation
  $\Rightarrow$ (isospin distillation)
  - increase at most of 20% of the asymmetry $\mathcal{I}$
  - competition between pairing and $\mathcal{C}_{sym}$
  - confirmed the leading role of $\mathcal{C}_{sym}$ on distillation

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3}\frac{\epsilon_q^F}{\rho_q}\left[1 + \frac{\pi^2}{12}\left(\frac{T}{\epsilon_q^F}\right)^2\right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy
  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

- Larger effect than T = 0
- Double discontinuity
  $\Rightarrow$ n and p critical T
- Jump $\sim \left\langle \frac{\delta I}{I} \right\rangle$
  $\Rightarrow$ sizable effects on the
  isotopic properties of clusters

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy
  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

- Larger effect than T = 0
- Double discontinuity
  $\Rightarrow$ n and p critical T
- Jump $\sim \left\langle \frac{\delta I}{I} \right\rangle$
  $\Rightarrow$ sizable effects on the
  isotopic properties of clusters

Effect on chemical potential derivatives ($T \neq 0$)

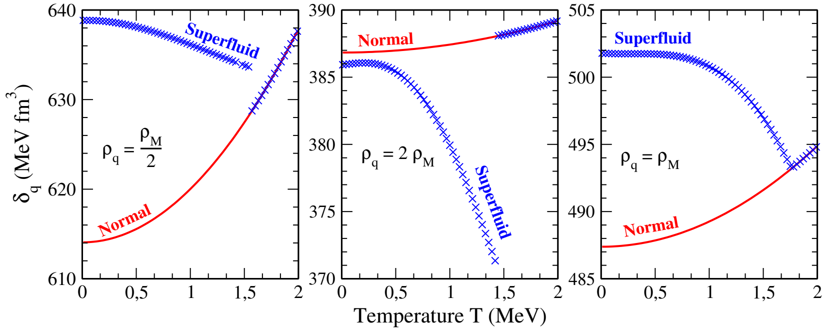
- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[phase]{superfluid}$ δ_q decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy
  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

- Larger effect than T = 0
- Double discontinuity
  $\Rightarrow$ n and p critical T
- Jump $\sim \left\langle \frac{\delta I}{I} \right\rangle$
  $\Rightarrow$ sizable effects on the
  isotopic properties of clusters

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[\text{phase}]{\text{superfluid}}$ δ_q decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy

  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

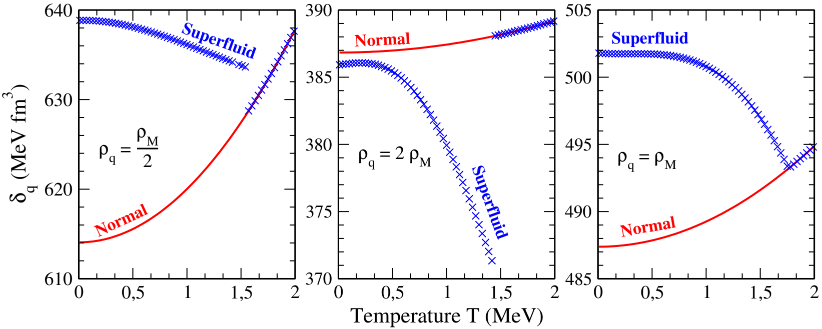


- Larger effect than T = 0

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[\text{phase}]{\text{superfluid}}$ δ_q decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy

  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

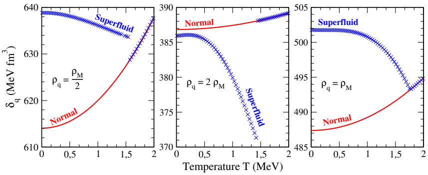


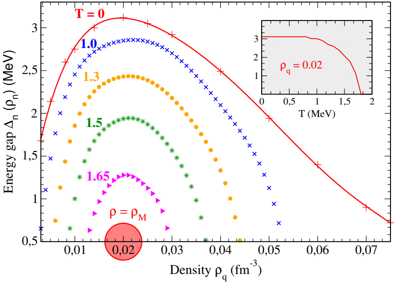
Larger effect than T = 0

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3}\frac{\epsilon_q^F}{\rho_q}\left[1 + \frac{\pi^2}{12}\left(\frac{T}{\epsilon_q^F}\right)^2\right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy

  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)





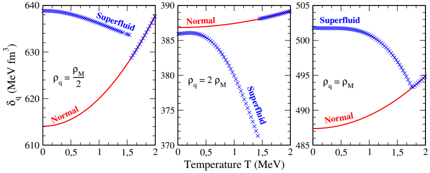
- Larger effect than T = 0
- Double discontinuity

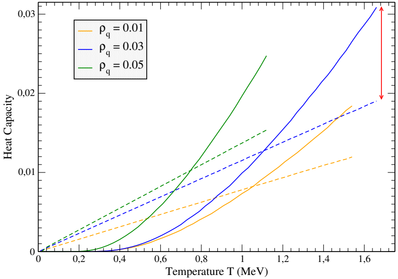
  $\Rightarrow$ n and p critical T

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3}\frac{\epsilon_q^F}{\rho_q}\left[1+\frac{\pi^2}{12}\left(\frac{T}{\epsilon_q^F}\right)^2\right] \xrightarrow[\text{phase}]{\text{superfluid}}$ δ_q decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy

  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)
- Heat capacity $\Rightarrow$ implications on the astrophysical context



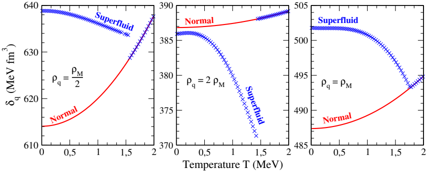


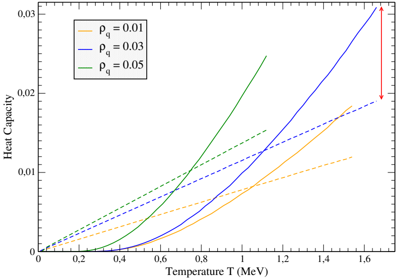
- Larger effect than T = 0
- Double discontinuity

  $\Rightarrow$ n and p critical T

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy
  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)
- Heat capacity $\Rightarrow$ implications on the astrophysical context



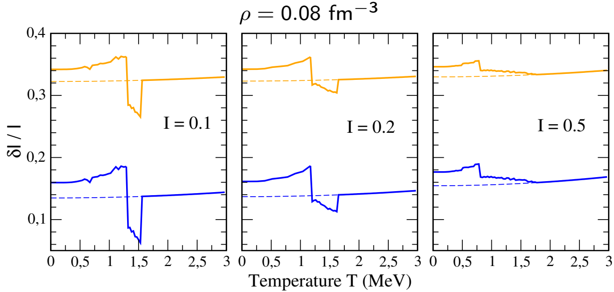


- Larger effect than T = 0
- Double discontinuity
  $\Rightarrow$ n and p critical T

Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy
  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

- Larger effect than T = 0
- Double discontinuity
  $\Rightarrow$ n and p critical T
- Jump $\sim \left\langle \frac{\delta I}{I} \right\rangle$
  $\Rightarrow$ sizable effects on the
  isotopic properties of clusters



Effect on chemical potential derivatives ($T \neq 0$)

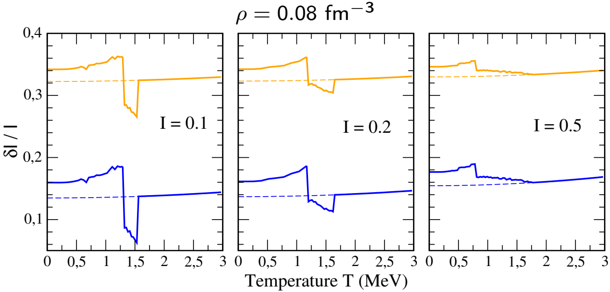
- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3} \frac{\epsilon_q^F}{\rho_q} \left[1 + \frac{\pi^2}{12} \left(\frac{T}{\epsilon_q^F} \right)^2 \right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy

  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

- Larger effect than T = 0
- Double discontinuity

  $\Rightarrow$ n and p critical T
- Jump $\sim \left\langle \frac{\delta I}{I} \right\rangle$

  $\Rightarrow$ sizable effects on the isotopic properties of clusters



Effect on chemical potential derivatives ($T \neq 0$)

- Normal phase: $\frac{\partial \epsilon_F^q}{\partial \rho_q} \simeq \frac{2}{3}\frac{\epsilon_q^F}{\rho_q}\left[1 + \frac{\pi^2}{12}\left(\frac{T}{\epsilon_q^F}\right)^2\right] \xrightarrow[\text{phase}]{\text{superfluid}} \delta_q$ decreases with T!
- Normal $\leftrightarrow$ superfluid: discontinuity on the 2nd derivatives of the energy

  $\Rightarrow$ 2nd order phase transition
- Compressibility $\Rightarrow$ jump depends on the density (disappears at $\rho_q = \rho_M$)

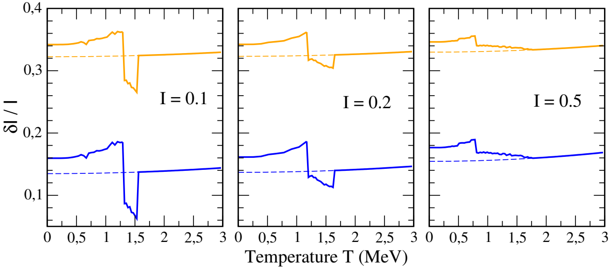
- Larger effect than T = 0
- Double discontinuity

  $\Rightarrow$ n and p critical T
- Jump $\sim \left\langle \frac{\delta I}{I} \right\rangle$

  $\Rightarrow$ sizable effects on the

  isotopic properties of clusters

$\rho = 0.08$ fm^{-3}



Conclusions

- Clusterization studies with pairing confirm the leading role of the symmetry energy in determining isotopic properties of density fluctuations
- At the transition temperature (from superfluid to normal phase) significant effects may appear for the asymmetry of the density oscillations
- $\Rightarrow$ Implications in the astrophysical context

Conclusions

- Clusterization studies with pairing confirm the leading role of the symmetry energy in determining isotopic properties of density fluctuations
- At the transition temperature (from superfluid to normal phase) significant effects may appear for the asymmetry of the density oscillations
- $\Rightarrow$ Implications in the astrophysical context

Conclusions

- Clusterization studies with pairing confirm the leading role of the symmetry energy in determining isotopic properties of density fluctuations
- At the transition temperature (from superfluid to normal phase) significant effects may appear for the asymmetry of the density oscillations
- $\Rightarrow$ Implications in the astrophysical context

Conclusions

- Clusterization studies with pairing confirm the leading role of the symmetry energy in determining isotopic properties of density fluctuations
- At the transition temperature (from superfluid to normal phase) significant effects may appear for the asymmetry of the density oscillations
- $\Rightarrow$ Implications in the astrophysical context

Thank You!