COLLECTIVE MODES IN A SUPERFLUID NEUTRON GAS WITHIN QUASIPARTICLE RPA

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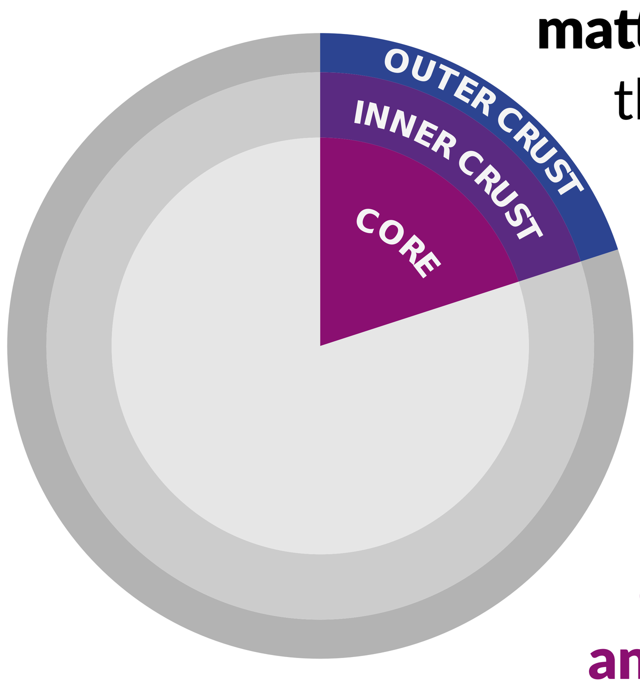
NEUTRON STARS BASICS

Neutron stars are compact, only a **few kilometers**, and **heavy**, more than the mass of the Sun. In consequence the **neutron star matter is under extreme conditions**, and the star becomes a macroscopic laboratory for nuclear physics. Furthermore, the star is not homogeneous, but composed of an **outer crust**, an **inner crust** and a **core**.

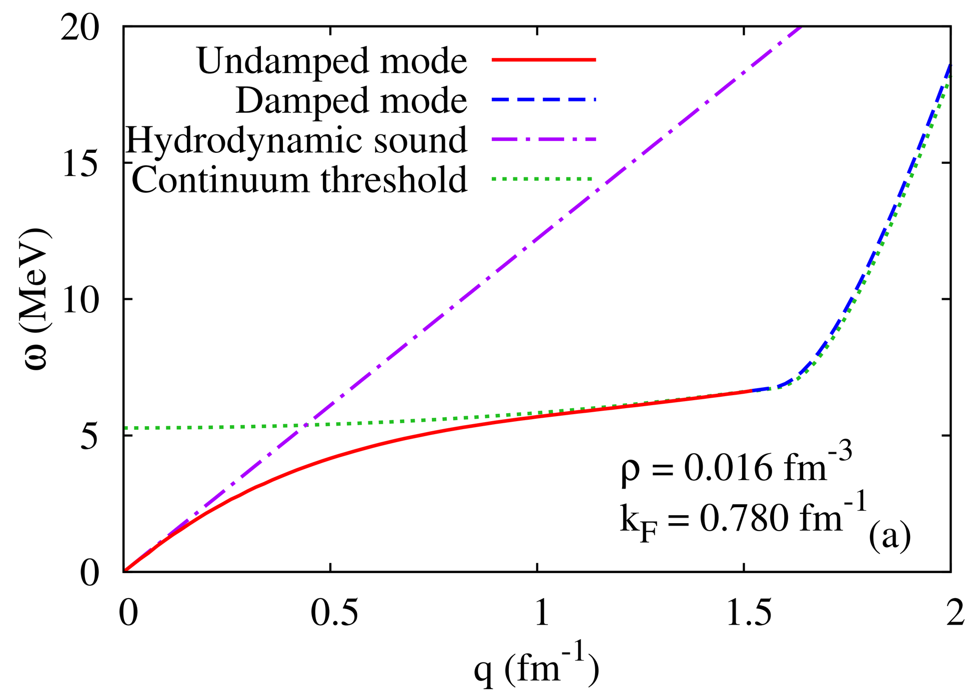


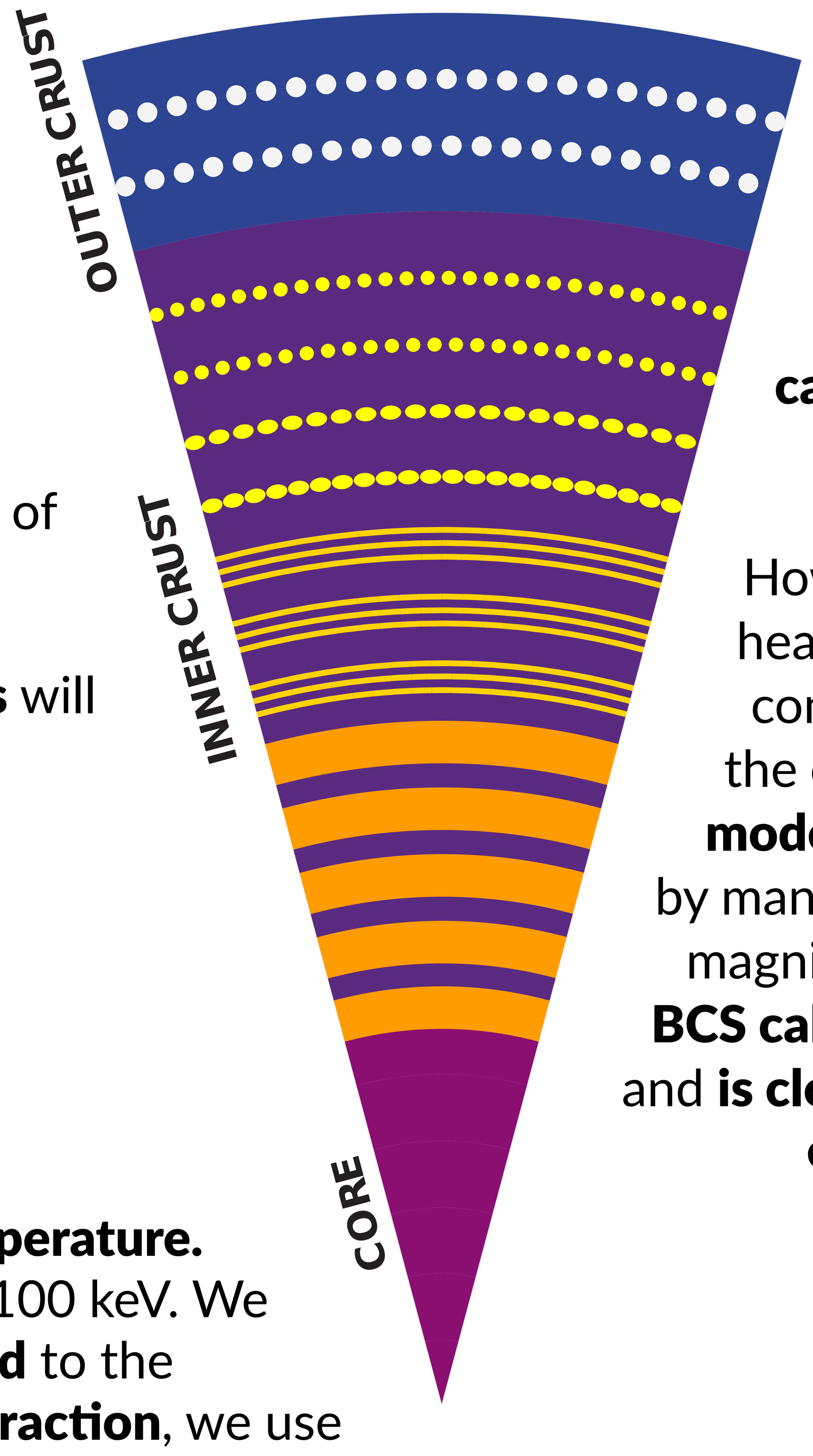
We focus our study on the inner crust, where we expect a neutron gas and complex geometries.

COLLECTIVE MODE

We obtained the **collective mode (Anderson-Bogoliubov mode) dispersion relation** by using the **QRPA** formalism. This result is compared to the **linear dispersion relation** obtained from **hydrodynamics.**

We observe that **at low momenta**, the **QRPA** follows the **linear trend** of hydrodynamics. **Then** it deviates until entering into the **continuum.**





INNER CRUST

The **transition between** the **inner crust and the outer crust** corresponds to the **appearance of a neutron gas.** Indeed the **density** of the medium **shifts the β-equilibrium** towards the production of neutrons. In consequence, the **excess of neutrons** will be **released** in the medium **as a gas**.

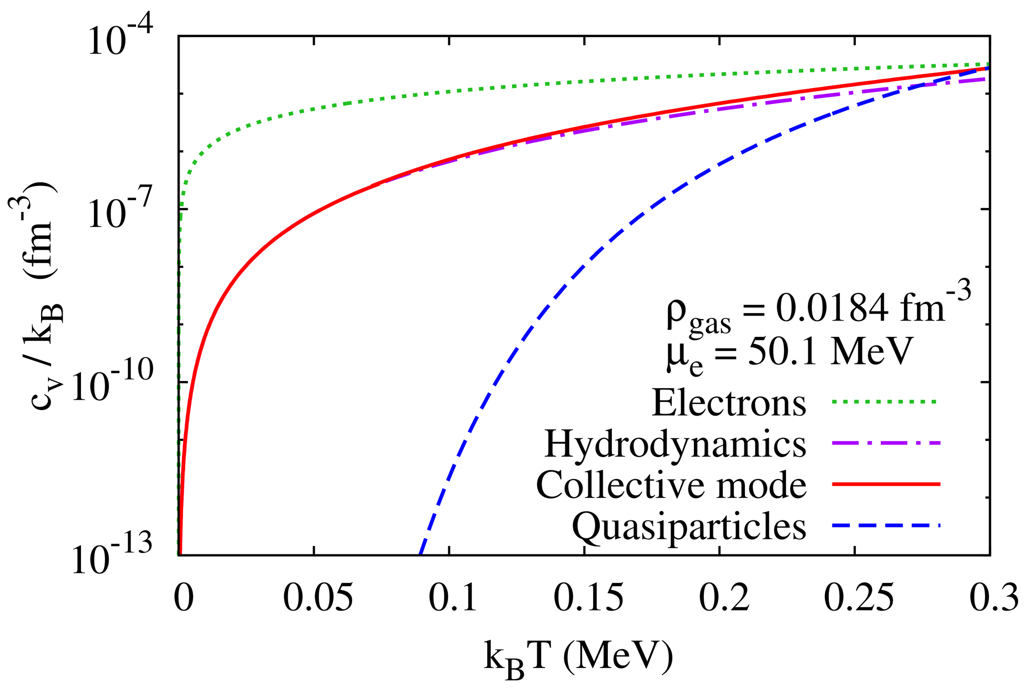
$$N \to P\ e^-\ \bar{\nu}_e$$

$$P\ e^- \to N\ \nu_e$$

HEAT CAPACITY

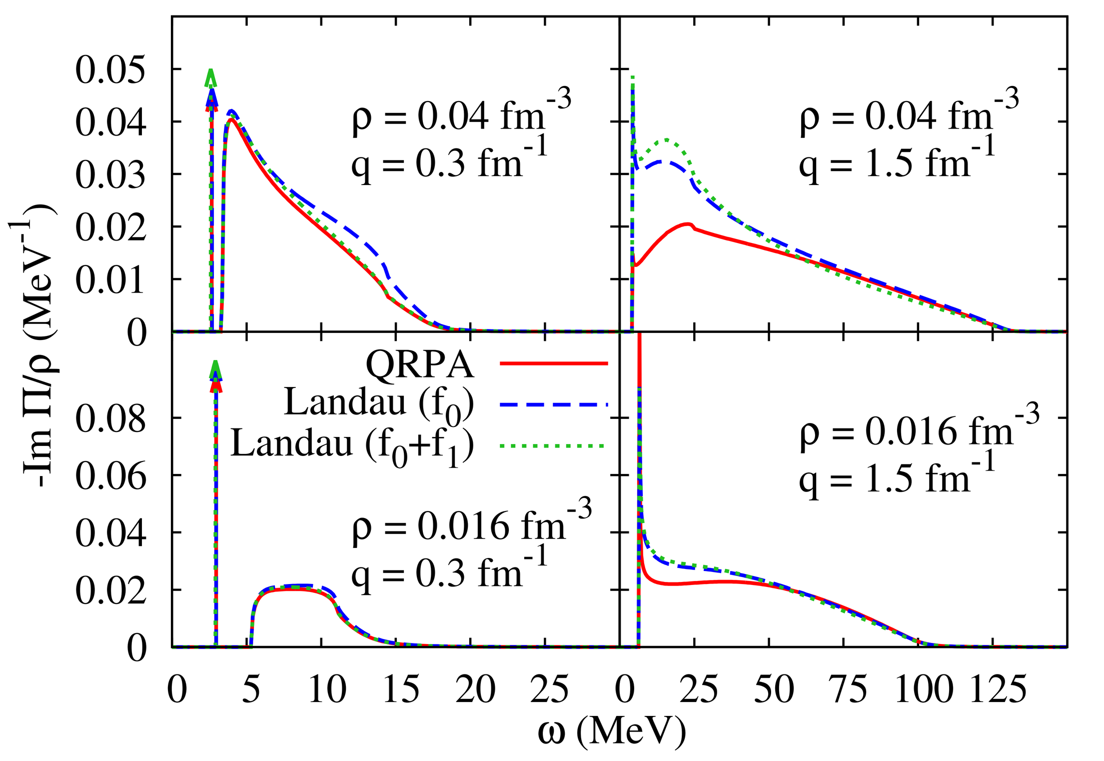
The **collective mode** contributes to the **heat capacity** of the inner crust. From the point of view of **the BCS theory**, the heat capacity comes from the **neutron quasi-particles,** and from the **electrons**.

However the heat capacity coming from **the collective mode exceeds** by many order of magnitudes the **BCS calculations** and **is close to the electrons.**



RESPONSE FUNCTIONS

We perform the **QRPA calculations at zero temperature.** Typically the neutron star temperature is about 100 keV. We use a **separable interaction** for the **pairing, fitted** to the realistic **V_{low-k}**. Concerning the **particle-hole interaction**, we use the **complete form** of the **residual interaction** derived from the **Skyrme functional**.



We compare our results **to** the **Landau approximation.** As illustrated in the left figure, we observe that QRPA **does not modify** the **collective mode energy**, but the strength. **However**, at high transferred momentum, **far from the Landau assumption**, the **response functions** are **different.**

CONCLUSION

→ Derivation of the **complete form of the residual interaction from a Skyrme functional.**

→ Evaluation of the **contribution** of the **Anderson-Bogoliubov mode** to the heat capacity.

→ Different **shapes** of the response functions when **compared to the Landau approximation.**
Applications for the neutrino mean-free path.

→ **Good agreement between QRPA and hydrodynamics** at low momenta.
Applications for neutron star dynamics.

→ The **collective mode exceeds** by many order of magnitude the **BCS contribution** and **reaches** the contribution of **the electrons**.
To be included in cooling models.

REFERENCES

Collective modes in a superfluid neutron gas within the quasi-particle random phase approximation
N.M., M. Urban, Physical Review C 90, 065805 (2014)

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