

Matter in extreme conditions



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Outline

- **The QCD phase diagram**
- **Compact stars**
- **Pion stars**

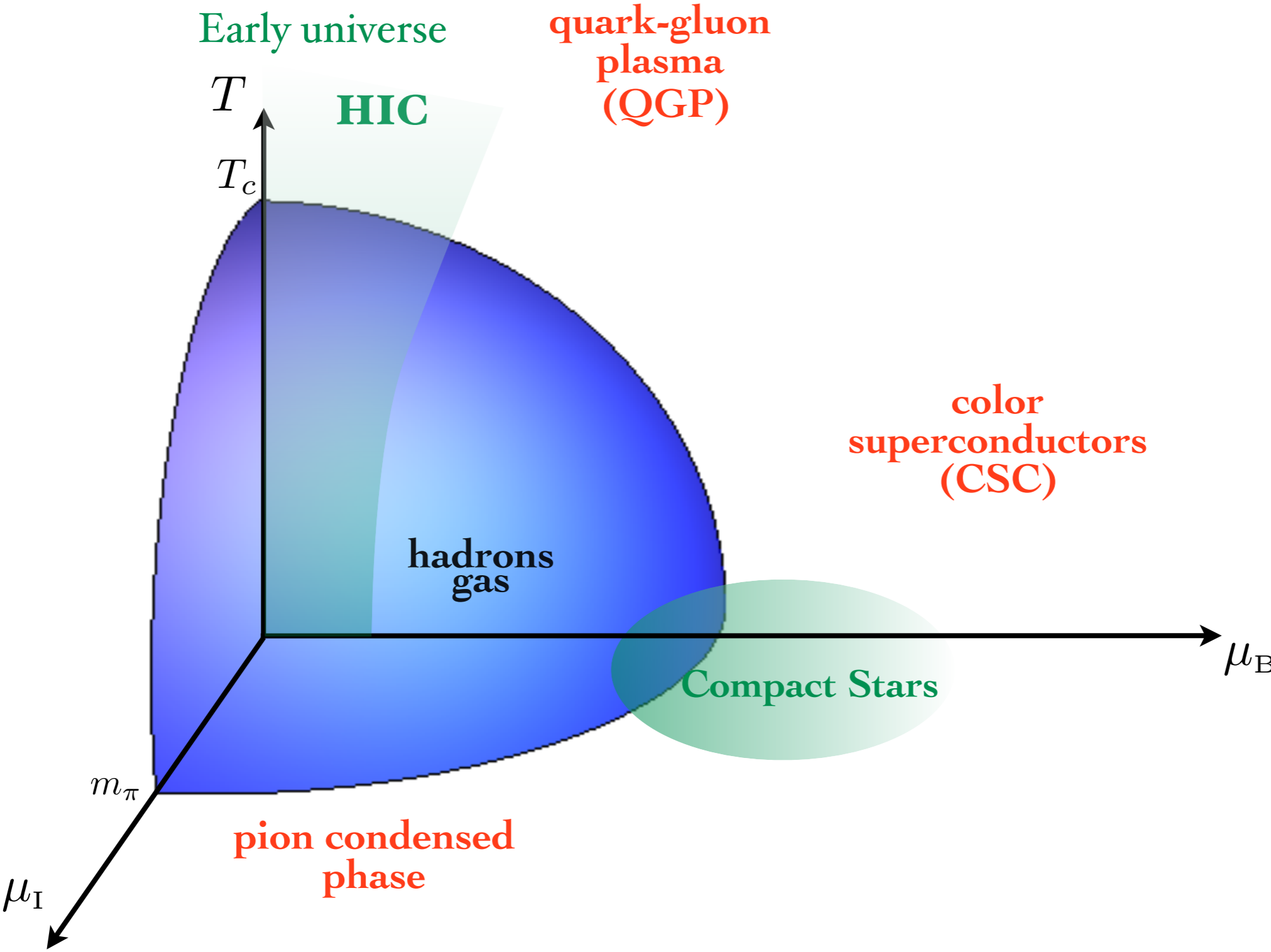
Some references

Phys.Rev.D 110 (2024) 2, L021301

Phys.Rev.D 103 (2021) 7, 076003

Rev.Mod.Phys. 86 (2014) 509-561

Phases of Matter



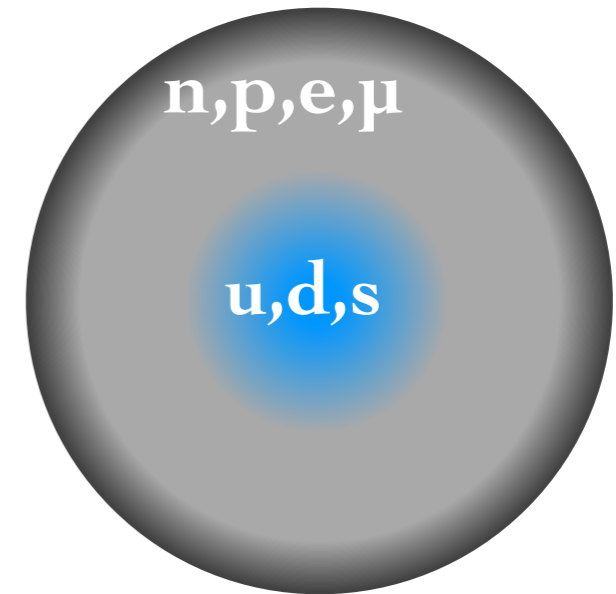
Taxonomy of compact stars

Neutron star



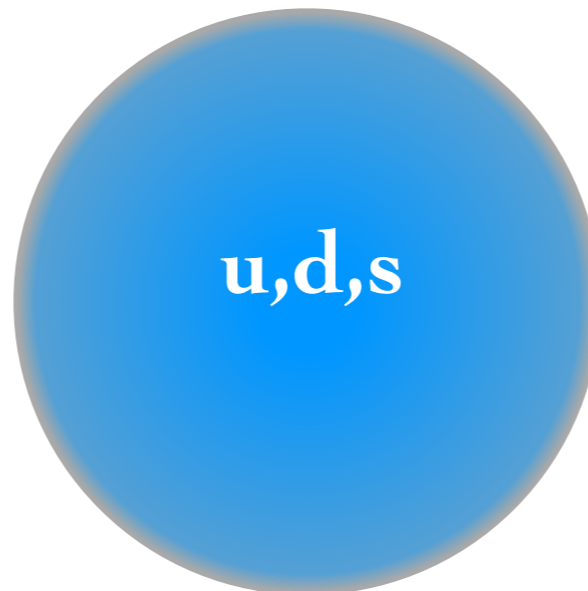
$$R \sim 10 \text{ km} \quad M = 1 - 2 M_{\odot}$$

Hybrid star



$$R \sim 10 \text{ km} \quad M = 1 - 2 M_{\odot}$$

Strange star



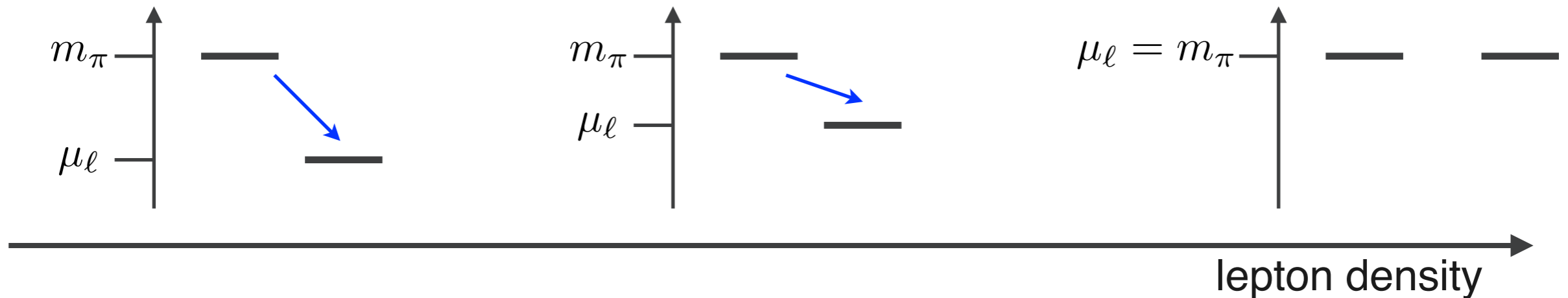
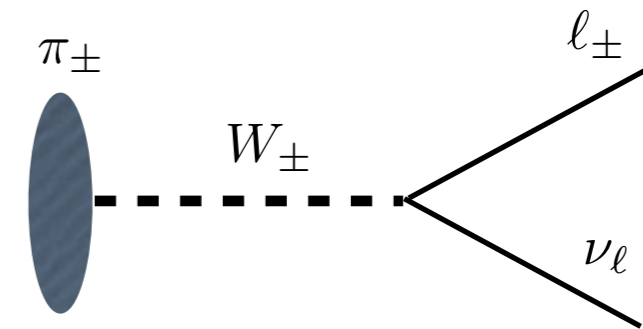
$$R \sim 0 - 10 \text{ km} \quad M < 3 M_{\odot}$$

Pion condensation

Stabilization

The pion decay can be Pauli blocked by a large lepton chemical potential

pion decay in vacuum



Energy spectrum splitting Stark-like effect

$$E_{\pi^0} = \sqrt{m_{\pi}^2 + p^2}$$

$$E_{\pi^-} = +\mu_I + \sqrt{m_{\pi}^2 + p^2}$$

$$E_{\pi^+} = -\mu_I + \sqrt{m_{\pi}^2 + p^2}$$

$$m_{\pi^+}^{\text{eff}} = m_{\pi} - \mu_I$$



At $\mu_I = m_{\pi}$ a massless mode appears:
pion condensation

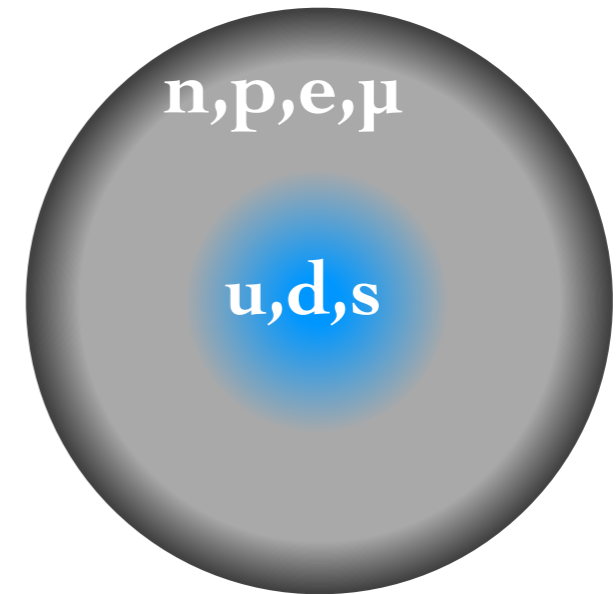
One more guy

Neutron star



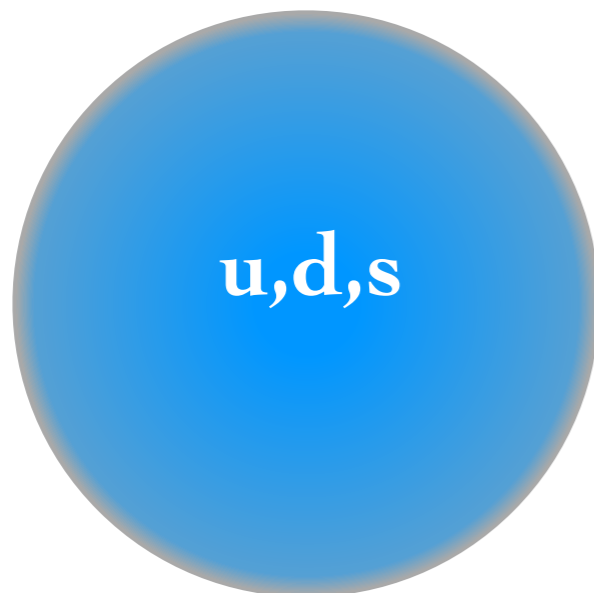
$R \sim 10 \text{ km}$ $M = 1 - 2 M_{\odot}$

Hybrid star



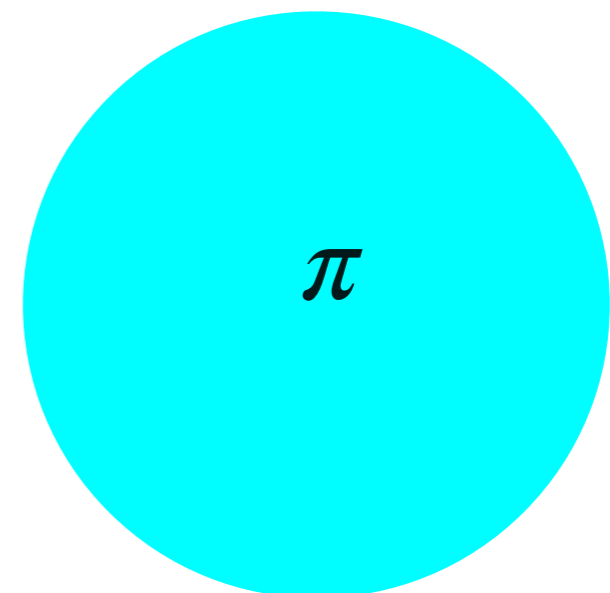
$R \sim 10 \text{ km}$ $M = 1 - 2 M_{\odot}$

Strange star



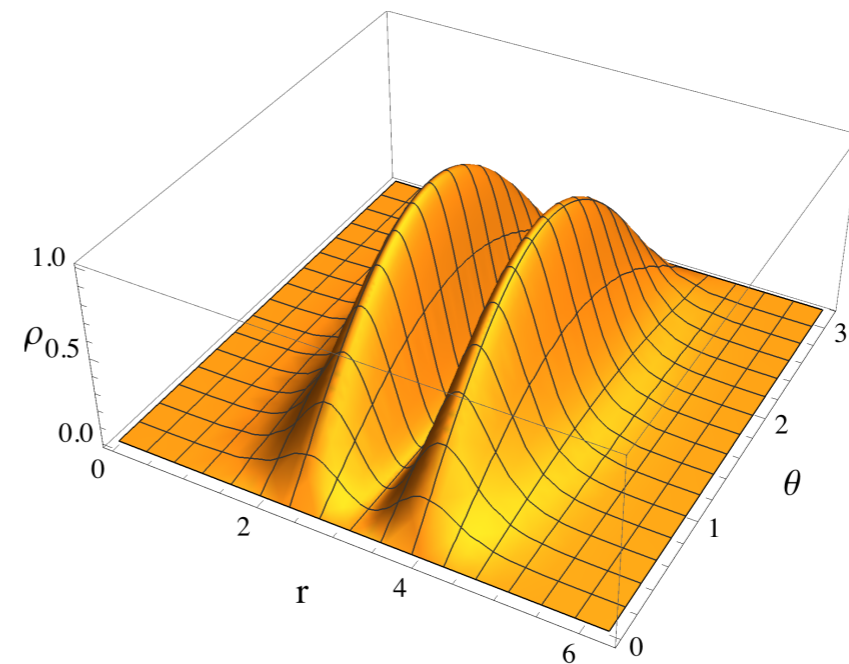
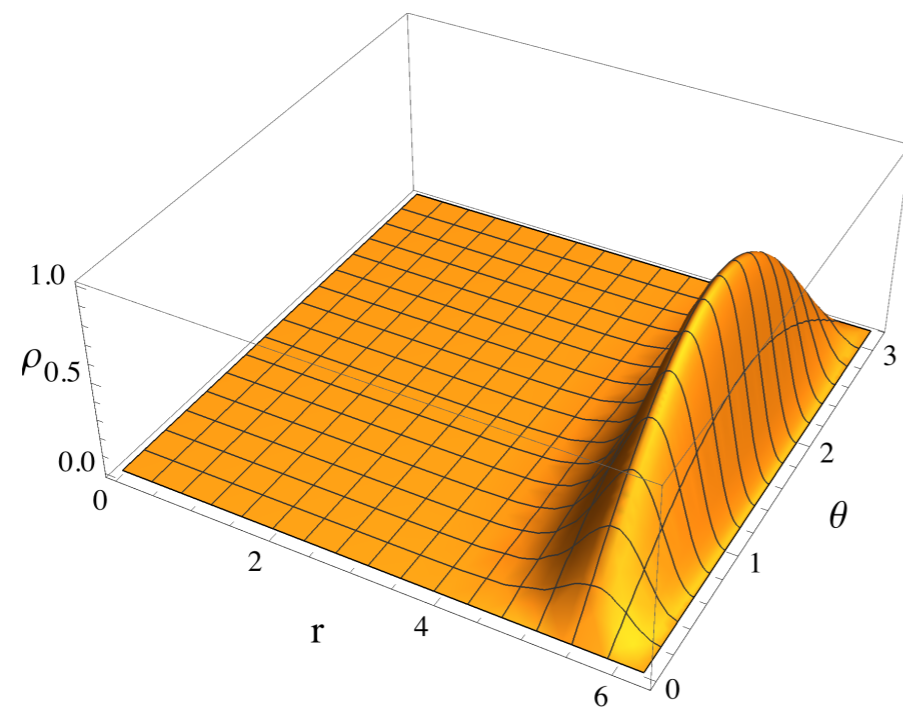
$R \sim 0 - 10 \text{ km}$ $M < 3 M_{\odot}$

Pion stars



Supersolid of pions

Periodic structure of baryons in a superfluid of charged pions



F. Canfora, S. Carignano, M. Lagos, MM, A. Vera
Phys.Rev.D 103 (2021) 7, 076003

Thanks for your attention!