Maximum Mass and Radial modes of hybrid star in presence of Magnetic field

Nihar Ranjan Panda
Institute of Physics

Talk Outline

- Introduction
- Magnetic field in hadronic phase
- Magnetic field in quark phase
- Mixed phase
- Radial modes
- Summary

Introduction

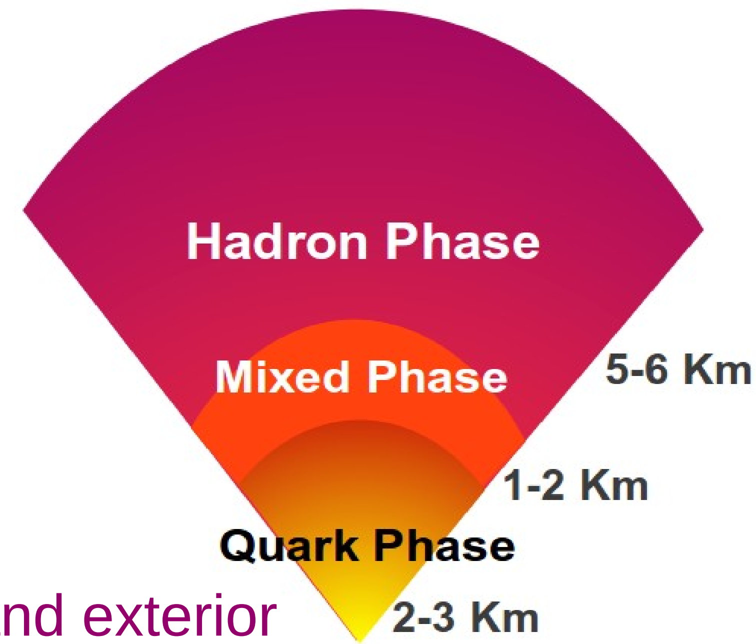
Compact stars which has only nuclear matter, basically neutron and proton are called Neutron stars .

$M_n \approx 1.5 - 2.1 \ M_0 , R \approx 10\text{-}15\, km , \rho \approx 5 - 10 \rho_{nuclear}$

Since central density of neutron star exceeds nuclear saturation density so it may contain deconfined quark matter.

Those are made up of quark matters are broadly divided into strange quark star and hybrid star

HYBRID STAR



Hybrid stars are NS having interior quark phase and exterior hadron phase having a mixed phase in between them .

$\textbf{Surface magnetic field} = 10^{14} - 10^{15} G , \ \textbf{Central magnetic field} = 10^{17} - 10^{18} G$

The high magnetic field modifies the properties of nuclear and deconfined quark matter of hybrid star

Magnetic field in hadronic phase

For the beta equilibrated matter : $\mu_i = b_i \mu_B + q_i \mu_e$

For charge neutrality condition : $\rho_c = \sum_i q_i n_i$

For the magnetic field along Z-direction : $A^{\mu} \equiv (0, -yB, 0, 0)$, $\vec{B} = B\hat{k}$

$$B = B_s + B_0 \{1 - e^{-\alpha (n_b/n_0)^{\gamma}}\}$$

Single particle energy eigenvalue in presence of magnetic field

$$E_i = \sqrt{p_i^2 + m_i^2 + 2\nu q_i B}, \text{ where } \nu = 2n + s + 1$$

Total energy density of the system :

$$\varepsilon = \frac{1}{2} m_\omega^2 \omega_0^2 + \frac{1}{2} m_\rho^2 \rho_0^2 + \frac{1}{2} m_\sigma^2 \sigma_0^2 + \frac{1}{2} m_{\sigma^*}^2 \sigma^{*2} + \frac{1}{2} m_\varphi^2 \varphi_0^2$$

$$+ \frac{3}{4} d\, \omega_0^4 + U(\sigma) + \sum_b \varepsilon_b + \sum_l \varepsilon_l + \frac{B^2}{8\pi^2}$$

$$P = \sum_i \mu_i n_i - \varepsilon$$

Magnetic field in quark phase

Thermodynamic potential in presence of strong magnetic field at zero temperature:

$$\Omega_i = -\frac{2 g_i |q_i| B}{4\pi^2} \sum_{\nu} \int_{\sqrt{m_i^2 + 2\nu |q_i| B}}^{\mu} dE_i \sqrt{E_i^2 - m_i^2 - 2\nu |q_i| B}$$

Taking density dependance MIT bag model

$$\varepsilon = \sum_i \Omega_i + B_G + \sum_i n_i \mu_i , \quad P = -\sum_i \Omega_i - B_G$$

$$B_G(n_b) = B_\infty + (B_g - B_\infty) \exp\left[-\beta \left(\frac{n_b}{n_0}\right)^2\right]$$

Mixed phase

Performing Glendenning construction and taking the Gibb's condition

$$P_{HP}(\mu_{e.}\mu_{B}) = P_{QP}(\mu_{e.}\mu_{B}) = P_{MP}$$

$$\chi\rho_c^{QP} + (1-\chi)\rho_c^{HP} = 0$$

$\chi = 1$: Quark Phase

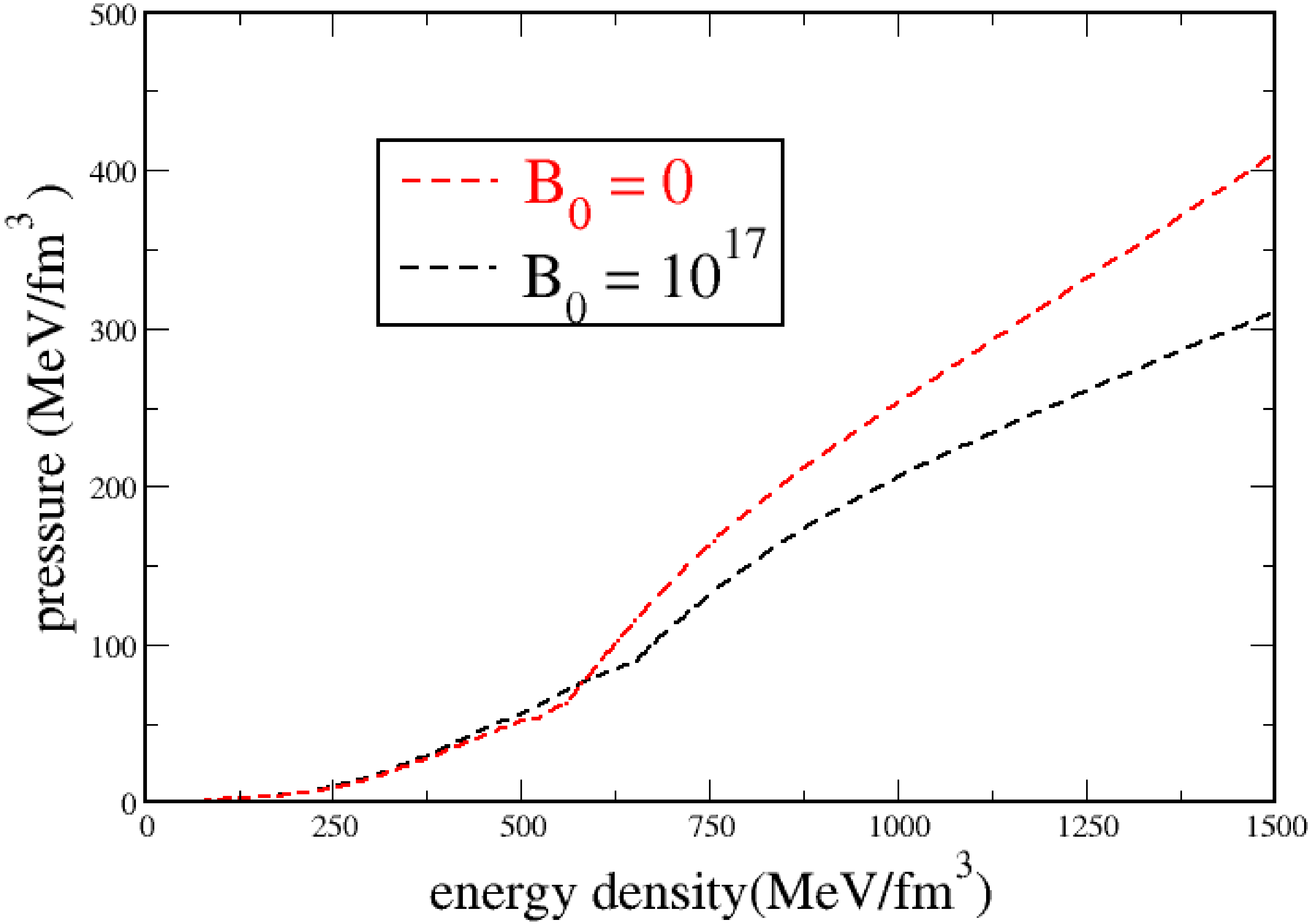
$\chi = 0$: Hadron Phase

$$\varepsilon_{MP} = \chi\varepsilon_{QP} + (1-\chi)\varepsilon_{HP}$$

$$n_{MP} = \chi n_{QP} + (1-\chi) n_{HP}$$

Results

Energy density vs Pressure



Radial Modes

$$X\frac{d^2\xi}{dr^2}+Y\frac{d\xi}{dr}+Z\xi=\sigma^2\xi$$

$\xi(r)$ is the Lagrangian fluid displacement $c\sigma$ is the characteristic eigenfrequency

The function X, Y, Z depend on equilibrium profile of pressure $'P'$ and enrgy density $'\varepsilon'$ and metric functions $\lambda(r)$ and $\nu(r)$

TOV equations : $$\frac{dm(r)}{dr}=4\pi r^2\epsilon(r)$$

$$\frac{dP(r)}{dr}=\frac{-Gm(r)\epsilon(r)}{r^2}\frac{[1+P(r)/\epsilon(r)][1+4\pi r^3P(r)/m(r)]}{1-2Gm(r)/r}$$

$$\lambda(r)=\ln(1-2Gm/rc^2) \qquad \frac{d\nu(r)}{dr}=\frac{2G}{r^2c^2}\frac{(m+4\pi r^3P/c^2)}{1-2Gm/rc^2}$$

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Contd....

$$\xi(r=0)=0$$

$$\delta P(r) = -\xi \frac{dP}{dr} - \Gamma P \frac{e^{\nu/2}}{r^2} \frac{\partial}{\partial r}\left(r^2 e^{\nu/2} \xi\right)$$

$$\delta P(r=R)=0$$

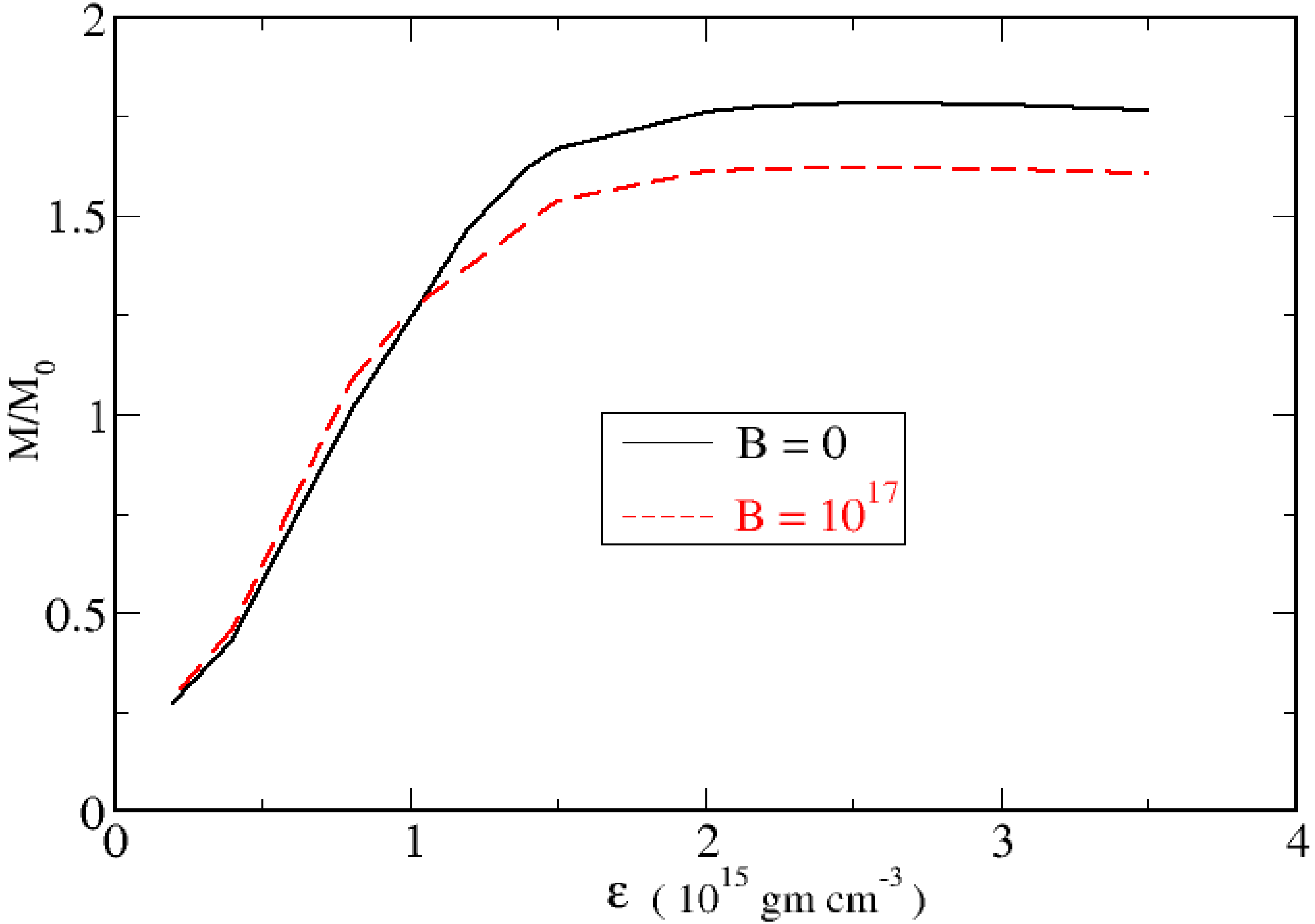
$$\sigma_0^2 < \sigma_1^2 < \sigma_2^2 < \ldots\ldots < \sigma_n^2$$

Hence if fundamental radial mode of a star is stable ($\sigma_0^2 > 0$), then all radial modes are stable

The period of oscillation $= \dfrac{2\pi}{c\,\sigma}$

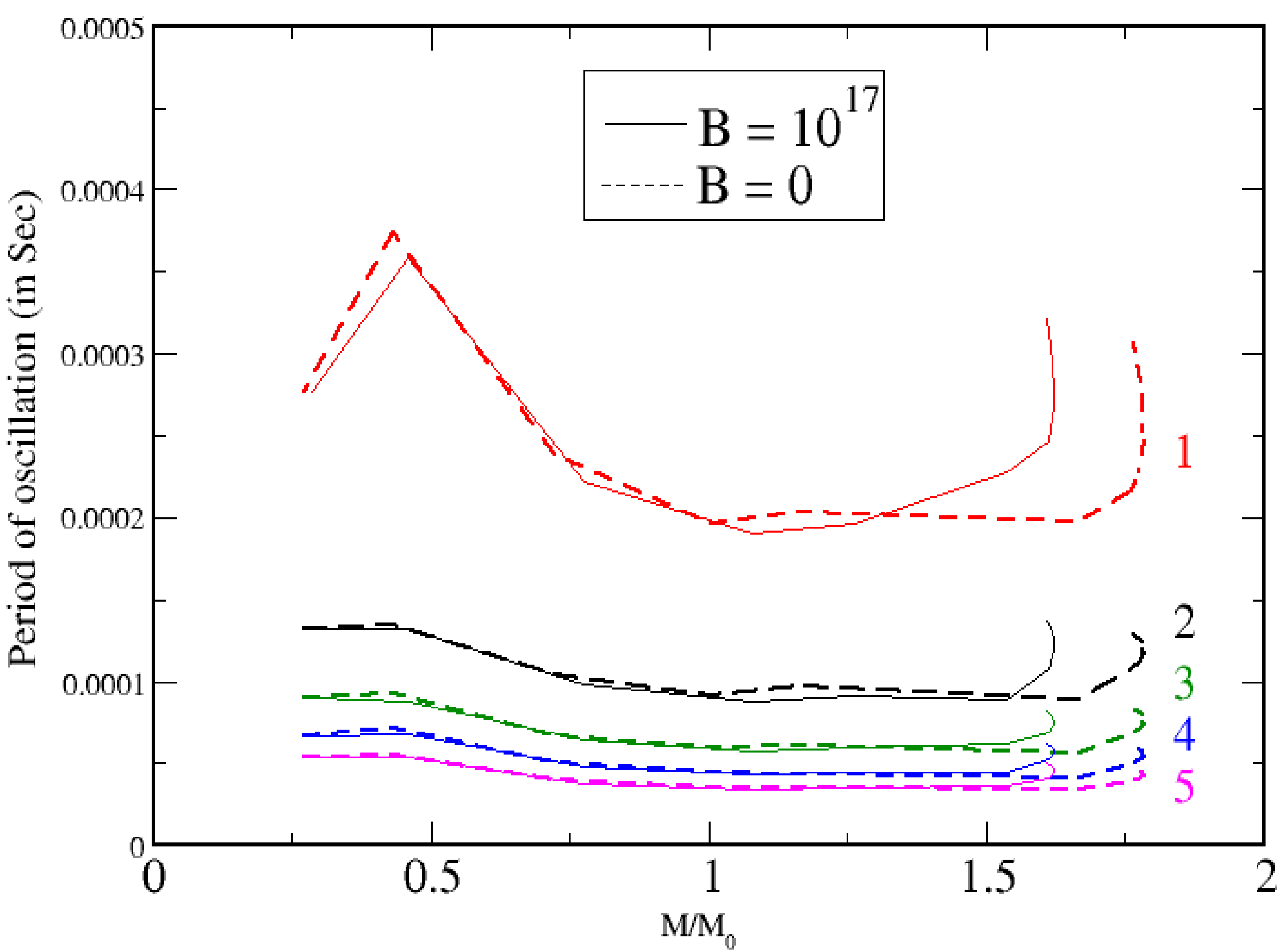
Results

Density vs. Gravitational mass



Results

Gravitational mass vs. Period of osillation



Summary

- The effect of magnetic field is much more pronounced in quark matter .
- The period of oscillation shows a kink around the point where mixed phase starts,in primary as well as in the higher modes. Which is the distinct signature of quark matter onset in neutron star.
- The presence of magnetic field increases period of oscillation of fundamental as well as in higer mode at maximum mass but the effect is significant in fundamental mode.
- The presence of magnetic field broadens the mixed phase region .

Collaborators: P. K. Sahu, K. Mohanta

Thank You