Properties of Bare Strange Stars Associated With Surface Electric Fields

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in collaboration with:
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Picanco Negreiros R., Weber F., Malheiro M., Usov V., *PRD* 80, 083006 (2009)

Picanco Negreiros R., Mishustin I., Schramm S., Weber F.,
PRD (in press) arXiv:1008.0277v2

FIAS Frankfurt Institute for Advanced Studies

HIC for FAIR Helmholtz International Center

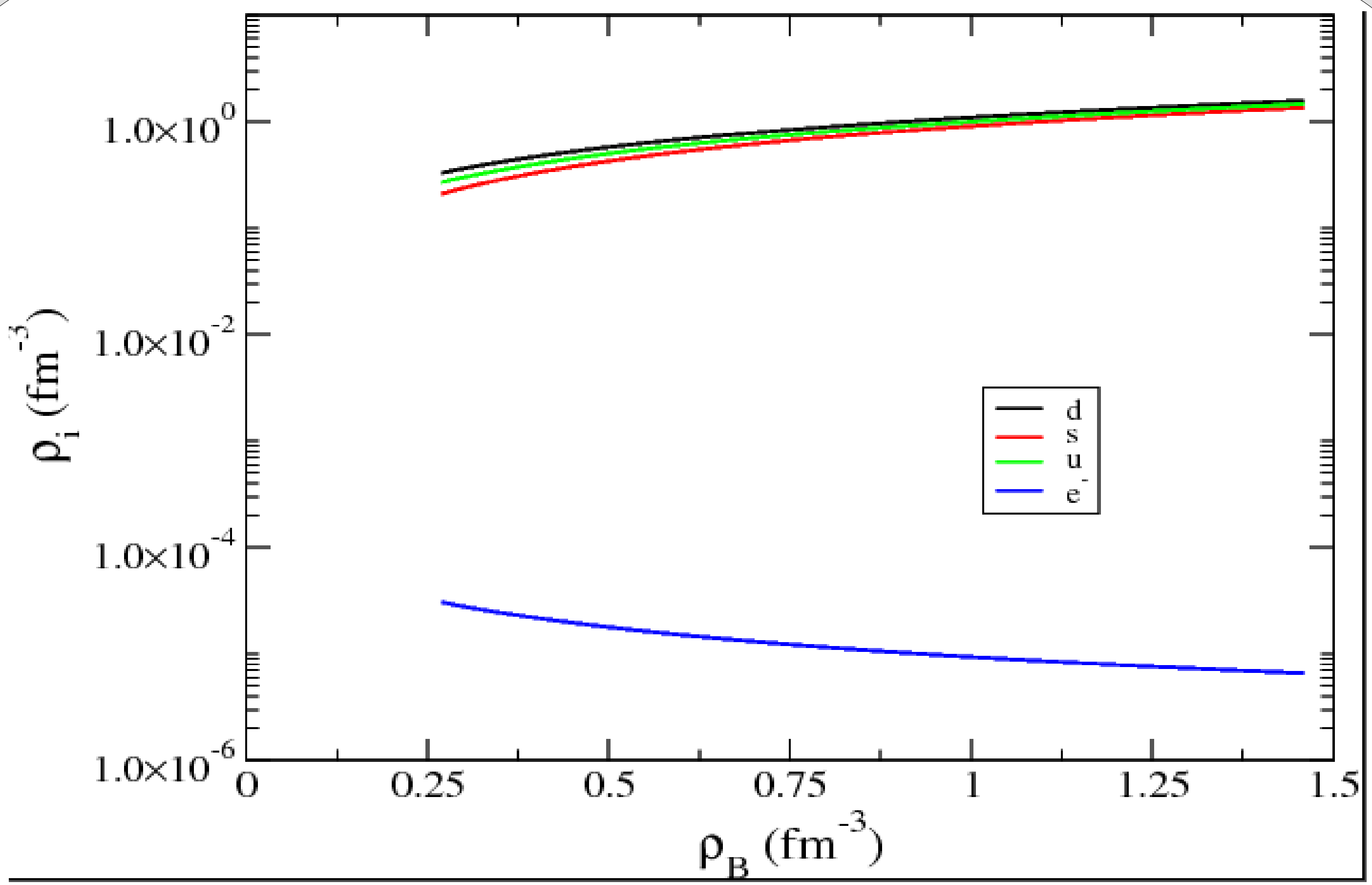
MODE-SNR-PWN Workshop

Bare Strange Stars

- Crustless compact stars composed of absolutely stable quark matter.
- Consists of roughly the same number of up, down and strange quarks.
- Relatively small number of electrons are needed for charge neutrality.
- Possibly in a color superconductor state.
- Higher concentration of electrons in the low density regions (surface) due to massive strange quarks suppression.
- Ultra high electric fields (10^{16-18} V/cm) on the surface.

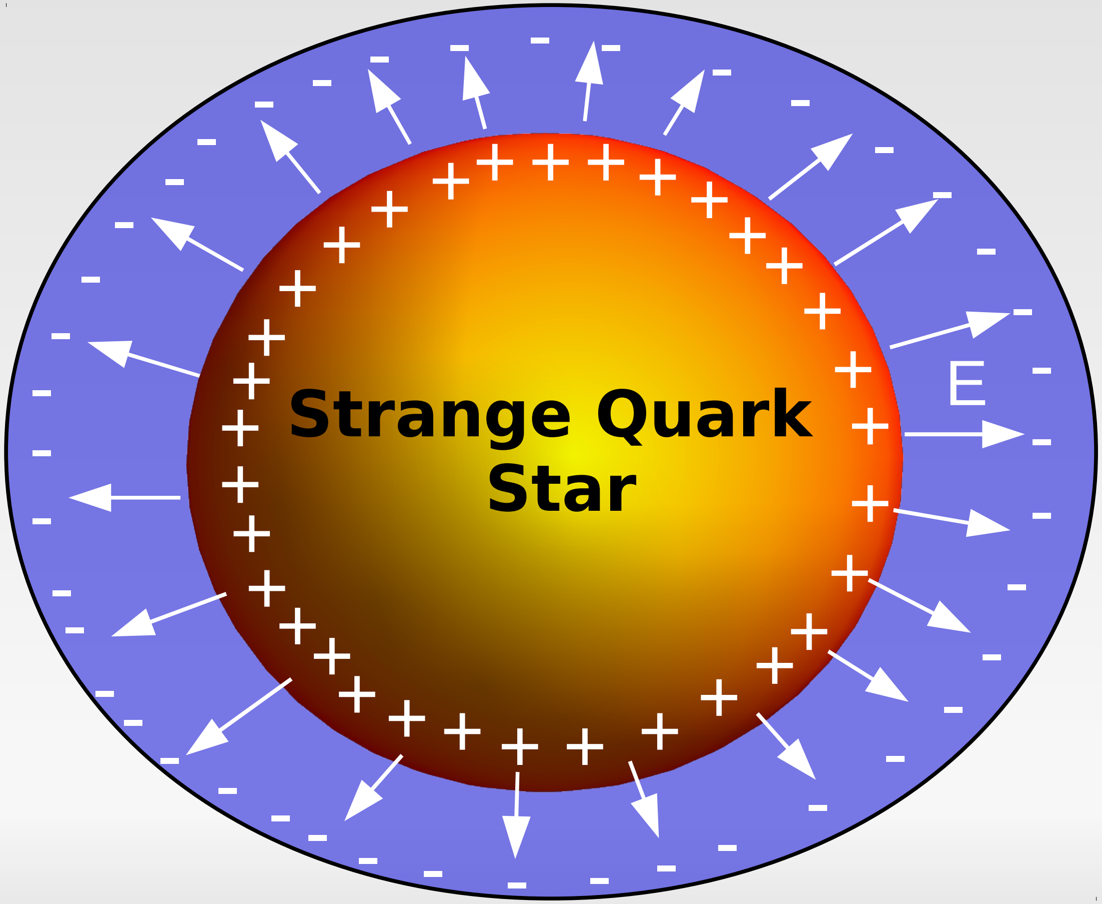
Bare Strange Star Composition

- Composition and Equation of State (EoS) computed in the framework of the MIT Bag model with first order corrections in α_c



Surface Electric Field

- Suppression of strange quarks near the surface increases the quantity of electrons.
- Electrons, are allowed to move to the outside of the star, establishing an electric field.



Alcock, C., Farhi, E., Olinto, A. *ApJ* 310, 261 (1986)
Usov, V. *PRD* 70, 14 (2004)

Surface Electric Field: microscopic description

- Given by the solution of the following Poisson equation

$$\nabla^2 \mu_e = 4\pi e^2 (n_q - \mu_e^3 / 3\pi^2)$$

↓

$$E = 10^{16-18} \text{ V/cm}$$

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Surface Electric Field: macroscopic description

- Solution of Einstein's equation of general relativity

$$T_\nu{}^\mu = (p+\epsilon)u_\nu u^\mu + p\,\delta_\nu{}^\mu + \frac{1}{4\pi}\left(F^{\mu l}F_{\nu l} + \frac{1}{4\pi}\delta_\nu{}^\mu F_{kl}F^{kl}\right)$$

→ Energy-Momentum Tensor (EOS)

$$\frac{dP}{dr} = -\frac{2G\left(m + \frac{4\pi r^3}{c^2}\left(p - \frac{Q^2}{4\pi r^4 c^2}\right)\right)}{c^2 r^2\left(1 - \frac{2Gm}{c^2 r} + \frac{GQ^2}{r^2 c^4}\right)}(p+\epsilon) + \frac{Q}{4\pi r^4}\frac{dQ}{dr}$$

→ TOV equation (General Relativistic Hydrostatic equilibrium)

$$\frac{dm}{dr} = \frac{4\pi r^2}{c^2}\epsilon + \frac{Q}{c^2 r}\frac{dQ}{dr}$$

→ Stellar mass

$$\frac{dQ}{dr} = \frac{r^2\sigma\, \exp\left(-((r-r_g)/b)^2\right)\exp(\Lambda/2)}{2(\sqrt{\pi}b^3/4 + r_g b^2 + \sqrt{\pi}r_g^2 b/2)}$$

→ Relativistic Gauss's Law

Structure Equations

- Solution of Einstein's equation of general relativity

$$T_{\nu}{}^{\mu} = (p+\epsilon)u_{\nu}u^{\mu} + p\,\delta_{\nu}{}^{\mu} + \frac{1}{4\pi}\left(F^{\mu l}F_{\nu l} + \frac{1}{4\pi}\delta_{\nu}{}^{\mu}F_{kl}F^{kl}\right)$$

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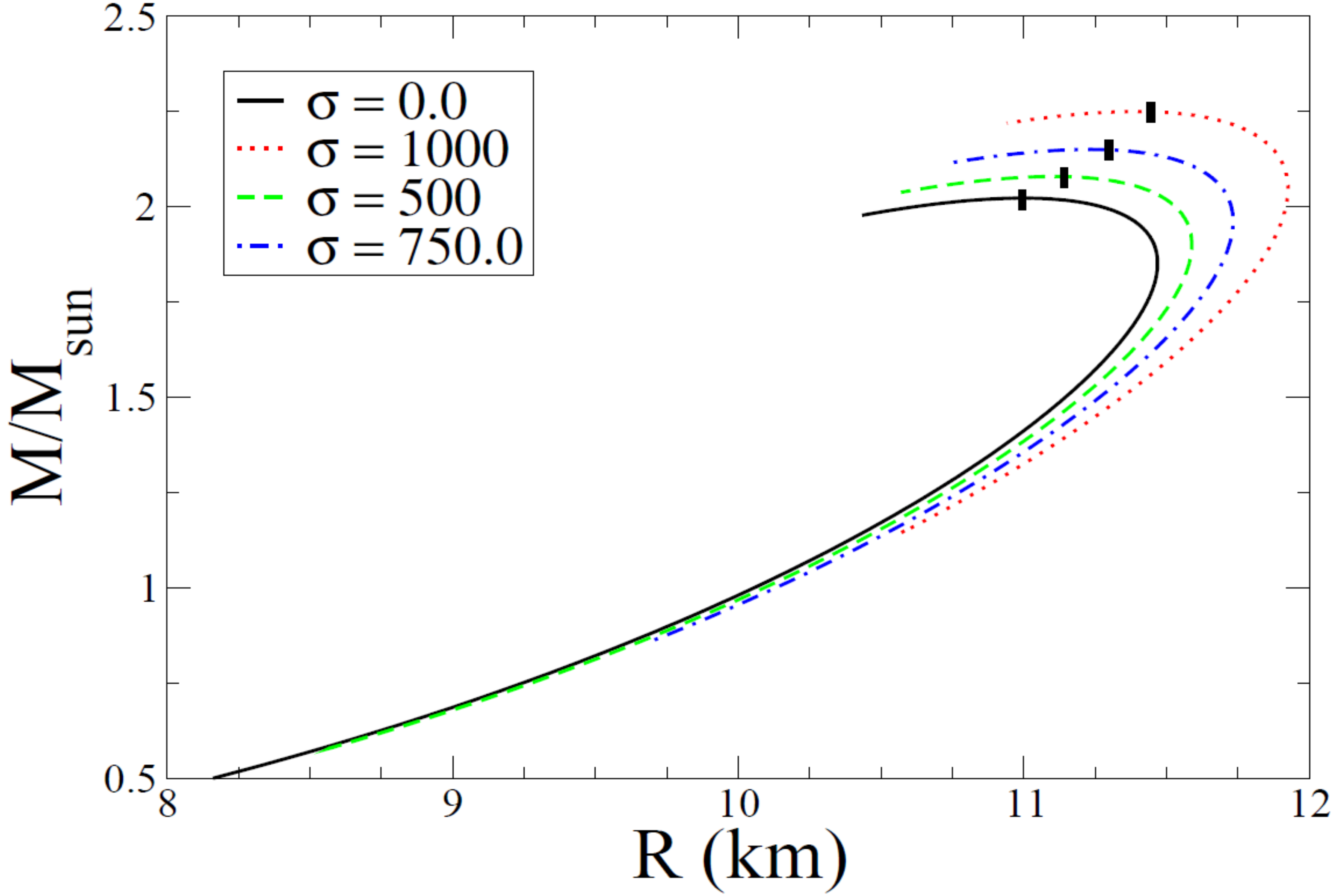
Relativistic Gauss's Law

Mass-Radius diagram of CHARGED strange quark stars

- Stellar mass for positively charged quark star's core



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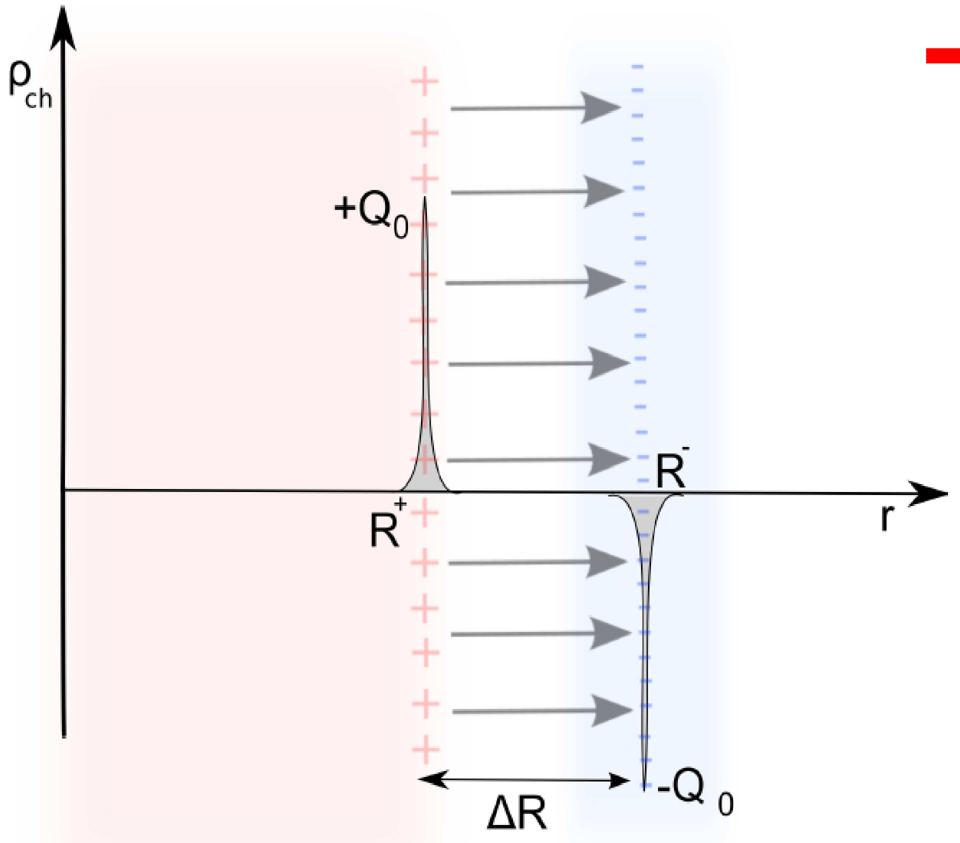
Stellar Structure of NEUTRAL Quark Stars

- Stellar mass of GLOBALY neutral quark stars



$$\rho_{\rm ch} = +K\,\frac{\delta(r-R^+)}{4\pi r^2} - K\,\frac{\delta(r-R^-)}{4\pi r^2}$$

$$m_{\mathcal{E}} = \int_0^r \frac{Q(r')^2}{2r'^2}\,dr' + \frac{Q(r)^2}{2r}$$

$$\frac{M_{\mathcal{E}}}{M_\odot} = 3.12^{-61}\ R_s^4\ E^2\ \frac{\Delta R}{R^+\ R^-}$$

Electromagnetic Mass

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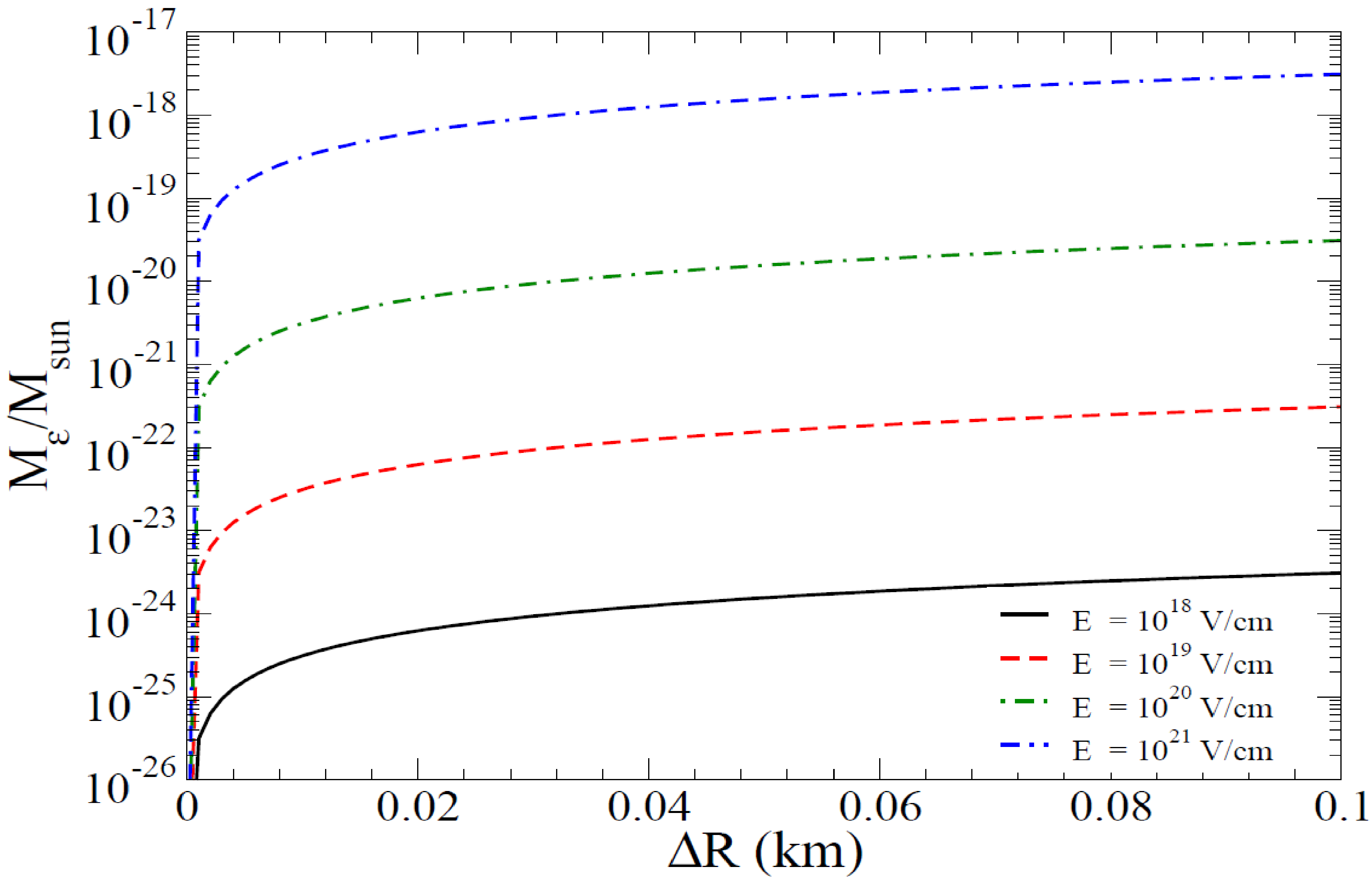
Electromagnetic mass



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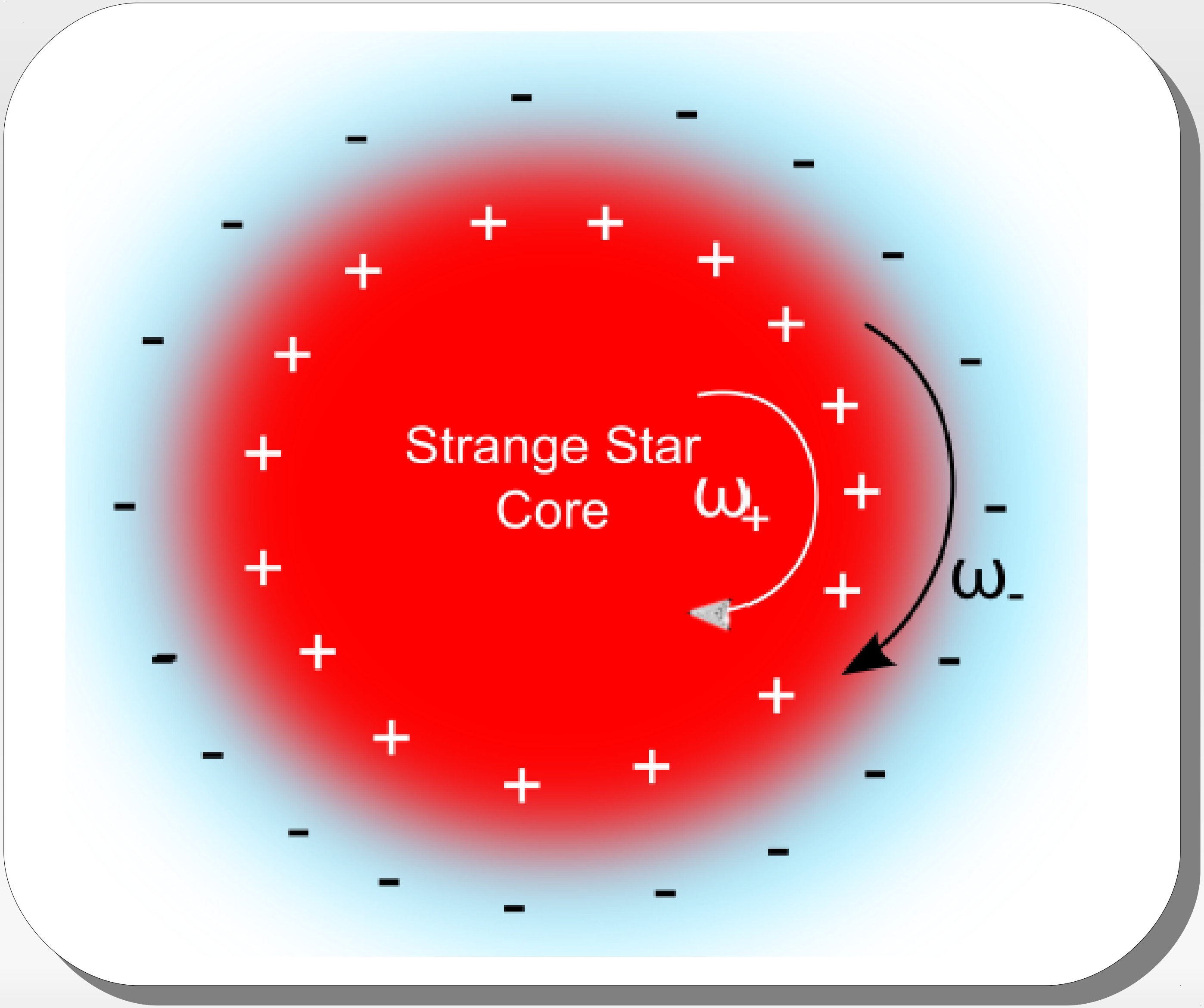
What if the star is rotating?



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Differential rotation near the surface

Surface Current →

$$I = \sigma\,(\omega_+ - \omega_-)$$

Dipole Field →

$$\vec{B} = \frac{1}{3}\,\mu_0\,\sigma\,(\omega_+ - \omega_-)\,\frac{R^4}{r^3}\,(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta})$$

↓

$$B_{\rm p} = E(\omega_+ - \omega_-)R \times 7.4104 \times 10^{-9}\ {\rm G}$$
$$B_{\rm eq} = E(\omega_+ - \omega_-)R \times 3.7052 \times 10^{-9}\ {\rm G}$$

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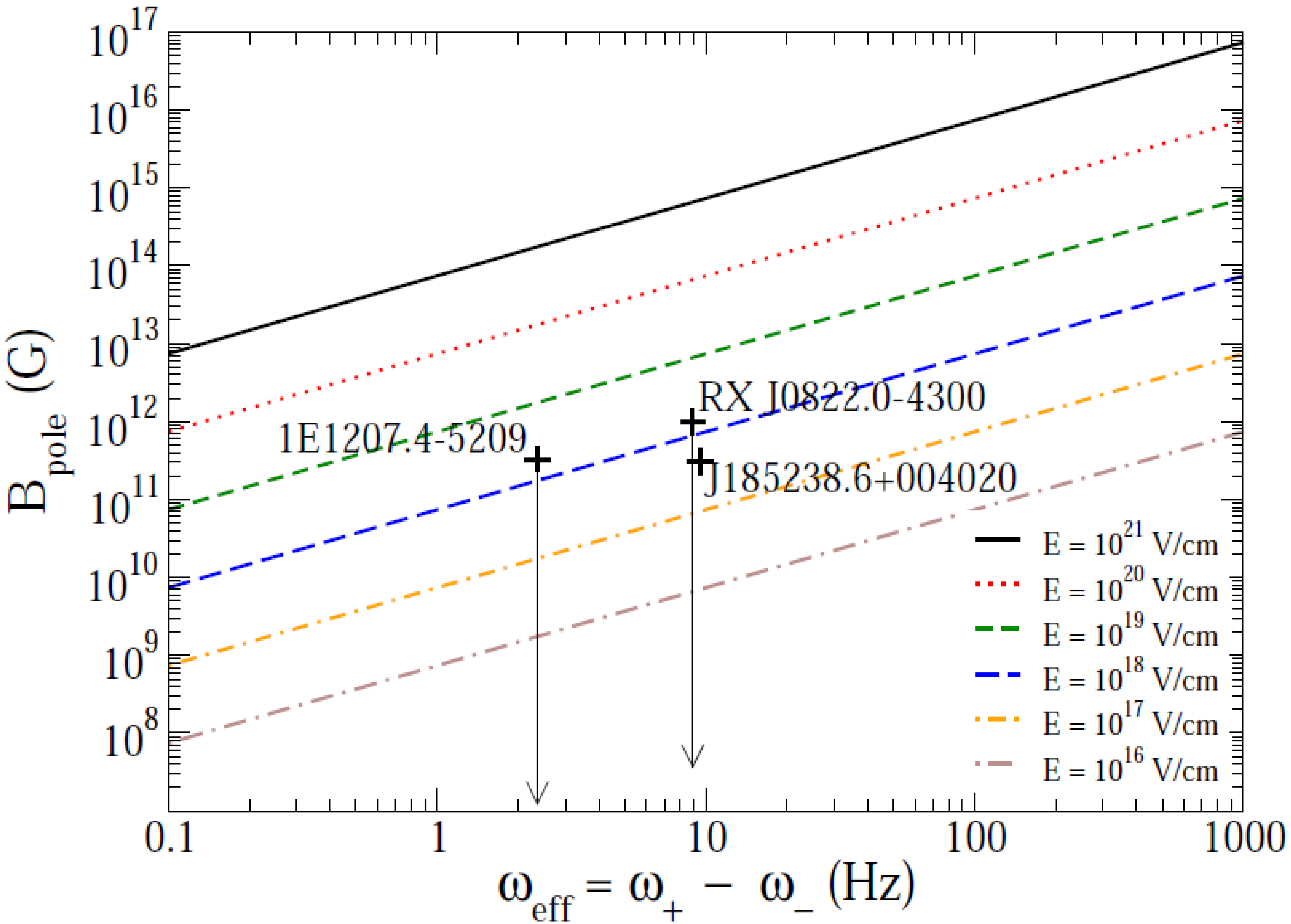
Magnetic field strength at the pole



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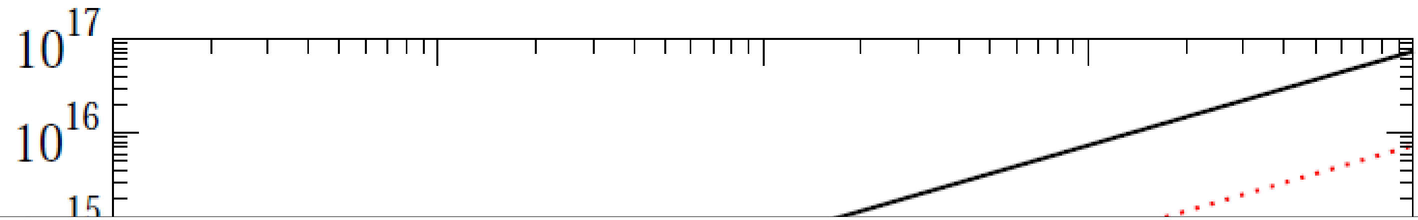

CCO	Ω (Hz)	B (10^{11} G)
RX J0822.0-4300	8.928	< 9.8
1E 1207.4-5209	2.3584	< 3.3
CXOU J185238.6+004020	9.5238	3.1

Halpern, J. P., Gotthelf E. V., *ApJ* 709, 436 (2010)

$\omega_{eff} = \omega_+ - \omega_-$ (Hz)

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Possible heating mechanism

- Considering the distance between the electron layer and the strange star core, one should expect friction heating.

- Our estimates indicate heating of the order of

$$H = 5.279 \times 10^9 \text{ erg s}^{-1}$$

- More elaborate, microscopic calculations are required.

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Conclusions and Outlook

- We have studied the surface properties of bare strange stars in details.
- Only in the case that the strange star possess a net charge that the surface electric field will increase the gravitational mass.
- In the event that the electron layer and the strange matter core rotate at different frequencies, a dipolar magnetic field will be established.
- For the electrostatic properties predicted for bare strange stars, we have found that the magnitude of the magnetic field is in agreement with observed data for Central Compact Objects (CCO's).
- This scenario might also leads to internal heating. Our calculations estimates heating of the order of 10^7 erg/s. More detailed calculations are needed.
- Although, pairing does not in principle spoil the model, we still need consider superconducting states. This needs to be addressed carefully, and we save that for future investigations.

Thank you!