Quark Stars: Features and Findings

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05/17/06

Argonne National Laboratory

Hot Quarks 2006, Villasimius, Sardinia, Italy

Outline

- Strange Quark Stars

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- Comparison to neutron stars

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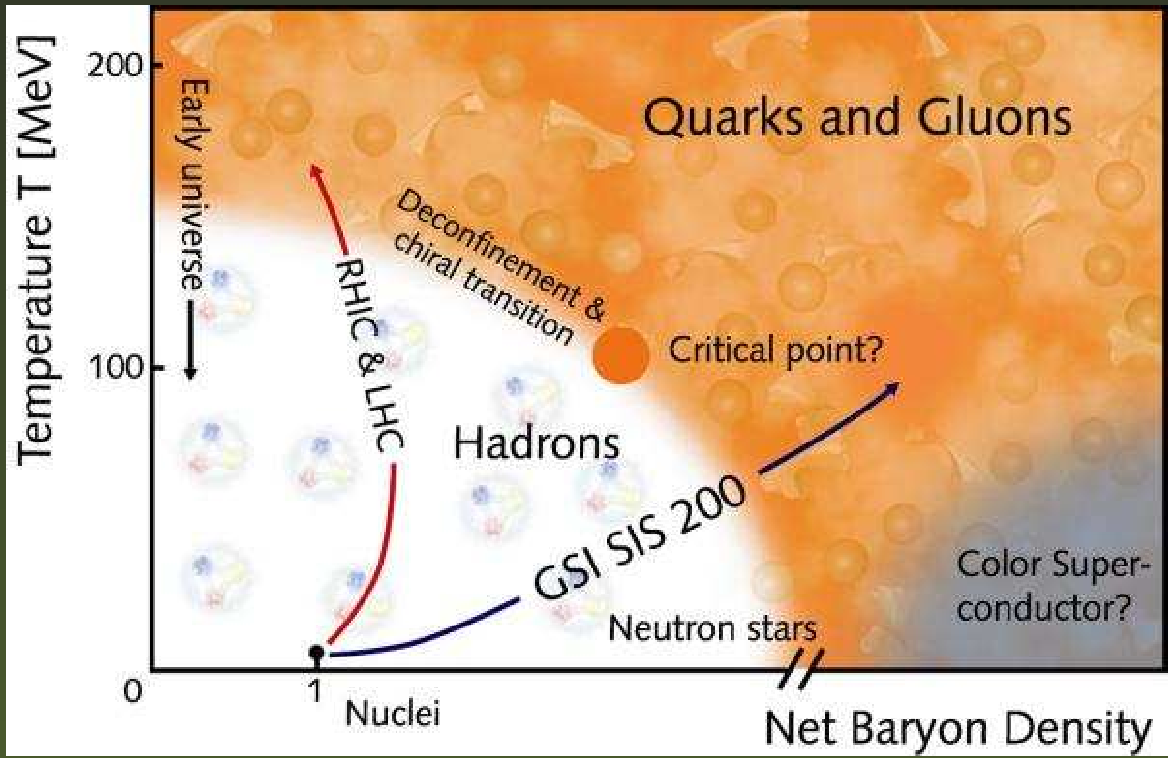
- Observational signatures
- Connection with heavy-ions

Strange Quark Stars



Hybrid Stars: Neutron stars with quark core

Bare Quark Stars: Absence of thick nuclear crust

Equation of state

$$\boxed{P = \frac{1}{3}(\epsilon - 4B) \ \leftarrow \ EOS(\alpha_s = 0, m_s = 0)}$$

TOV equations:

$$\frac{dM(r)}{dr} = 4\pi r^2 \epsilon(r), \qquad \frac{dP(r)}{dr} = -\frac{GM(r)\epsilon(r)}{r^2}$$

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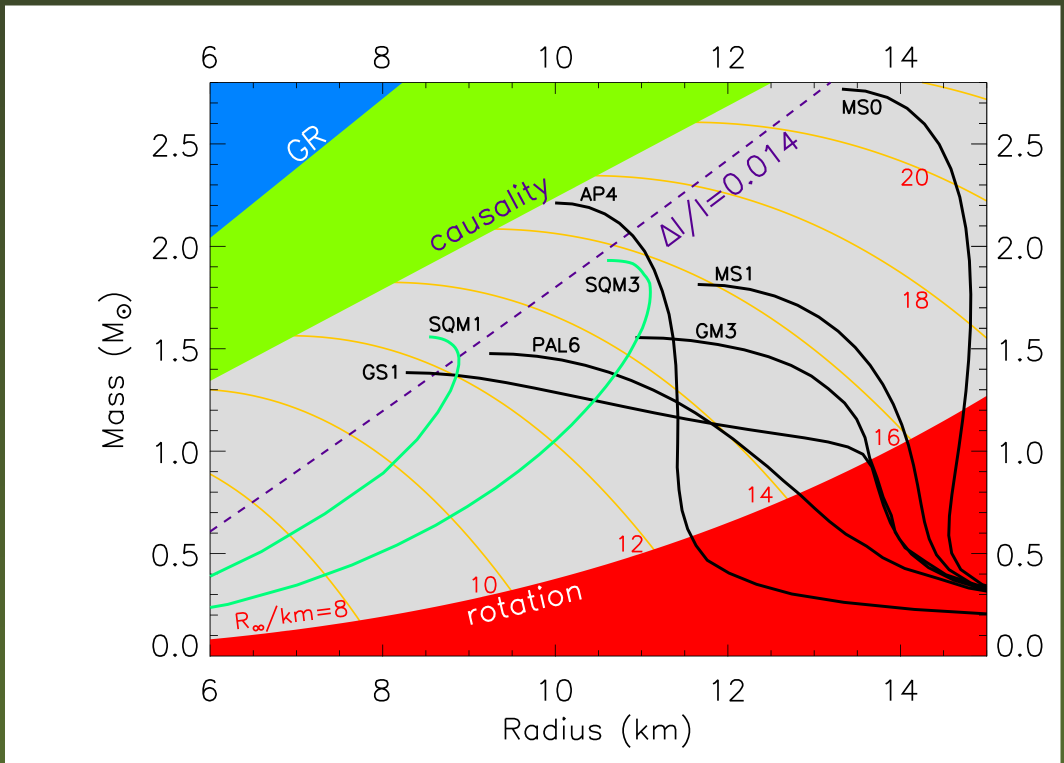

Observational signals I

Can We Detect Quark Matter inside Neutron Stars?

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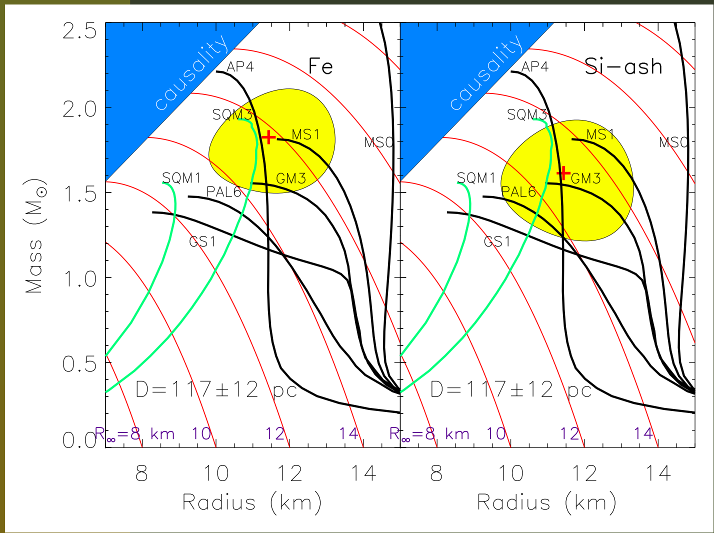

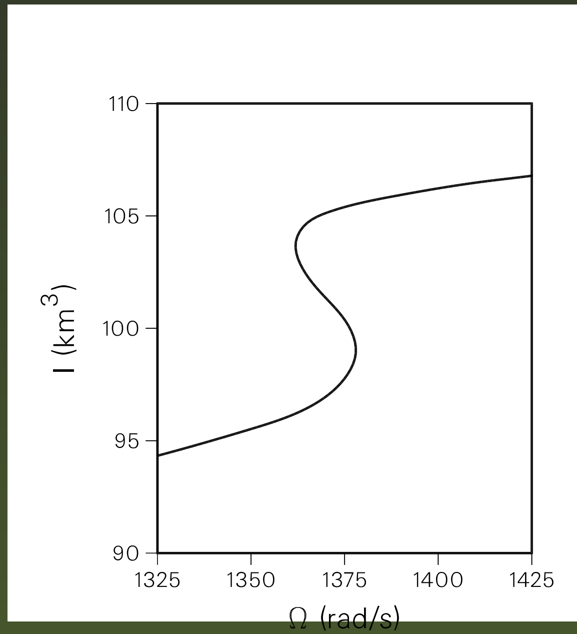

Equation of state different..

overlap in observed region.

Moment of inertia different..

low odds of detection.

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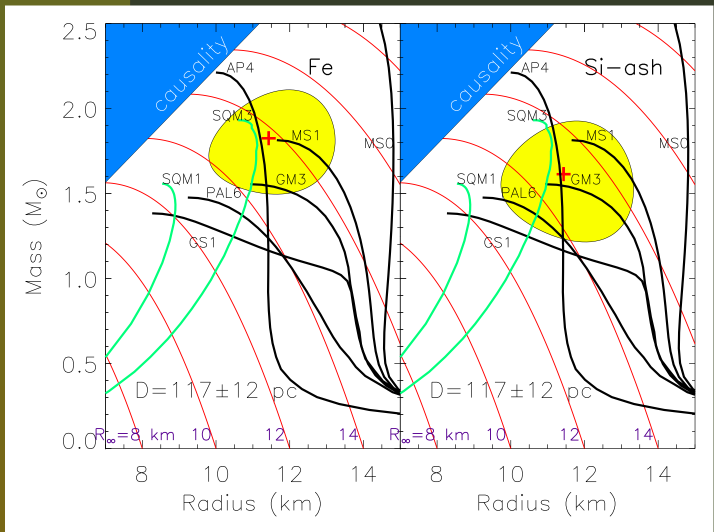

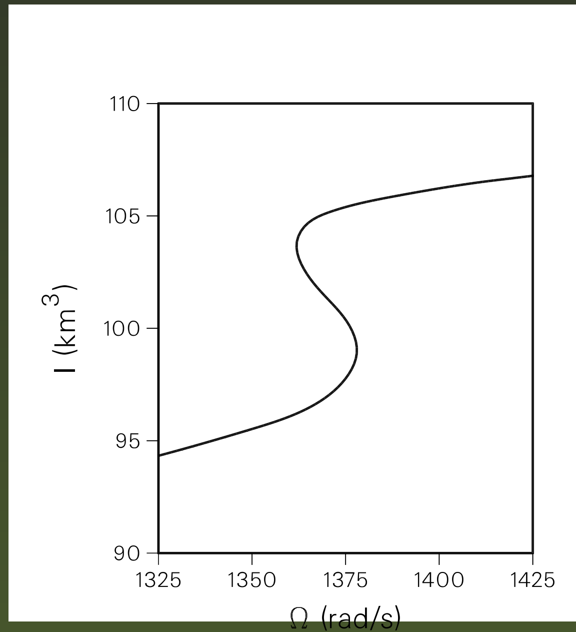

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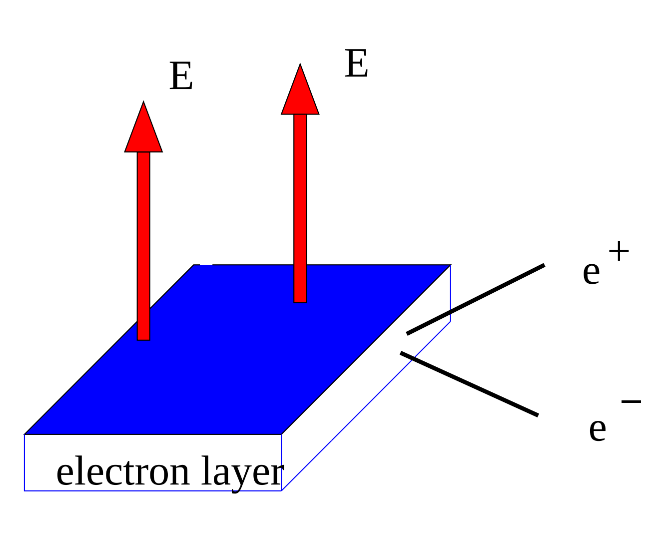
As at RHIC, we may need a combination of signatures

Observational Signals II

e^+e^- Pair creation at the Star's Surface

..due to superstrong Electric field at surface!

(Usov et al, Astrophys. J. **609** (2004))



$$l_e \sim 10^3\text{fm}, \quad E \sim 5 \times 10^{16}\ \text{V cm}^{-1}$$

$$E_{\rm cr} = \frac{m_e^2 c^3}{e\hbar} \simeq 1.3 \times 10^{16} \text{V cm}^{-1}$$

$$R_\pm \simeq 1.7 \times 10^{50} \left(\frac{E}{E_{\rm cr}}\right)^2 \text{cm}^{-3}\ \text{s}^{-1}$$

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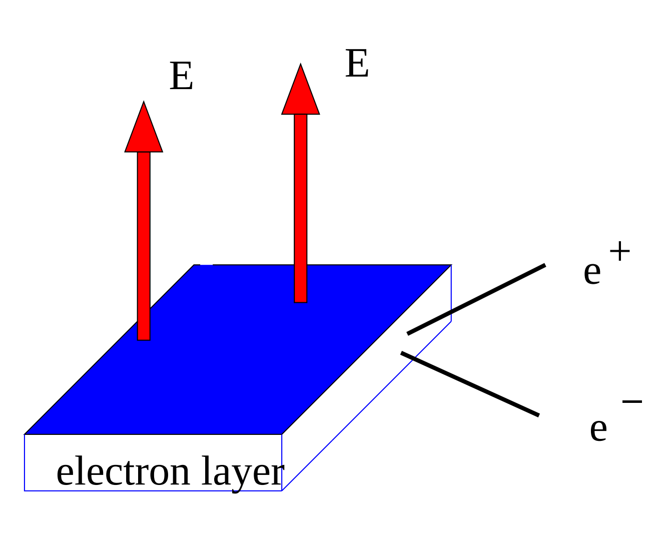

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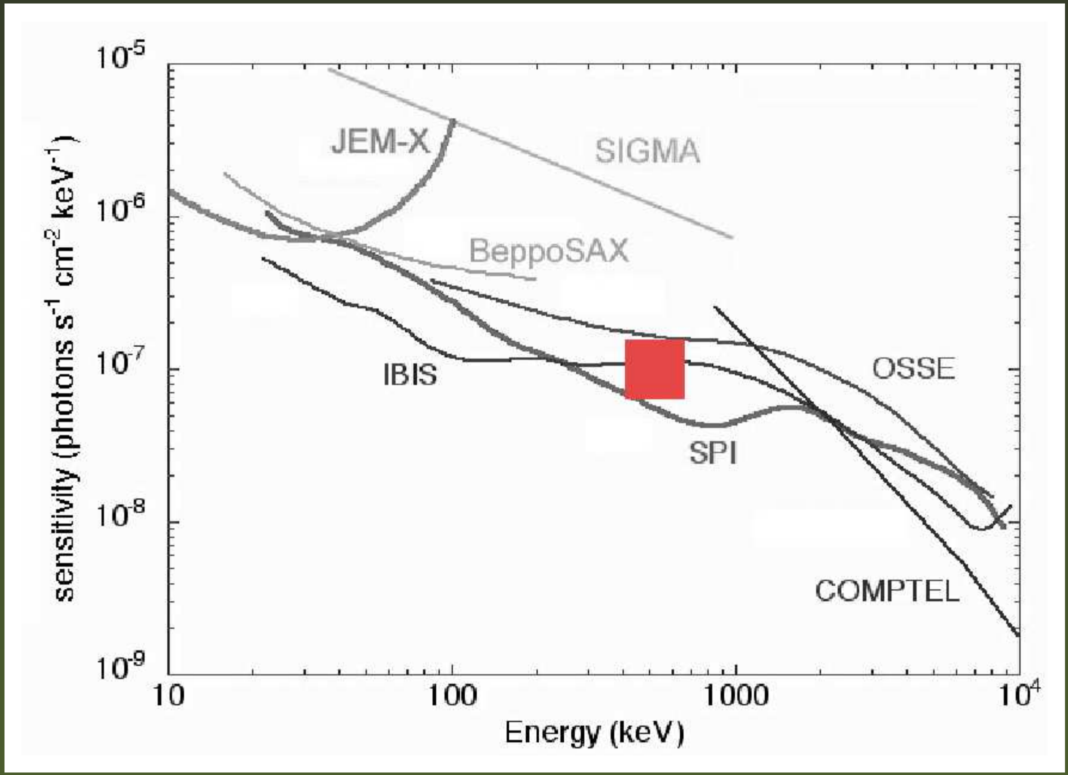
e^+e^- annihilation can lead to super-Eddington Photon Luminosities.

Surface photon emission

emission is controlled by surface layers.



Mean energy of photons is $\sim \mathrm{MeV}$ (Gamma-rays)

Mixed phase crust

Surface energy should be small enough:

$$\epsilon_{s+C} + G_M \leq G_H$$

Surface tension of quark droplet:

$$\sigma \leq 36 \; \left(\frac{m_s}{150\ \mathrm{MeV}}\right)^3 \frac{m_s}{\mu}\ \mathrm{MeV/fm^2}$$

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Mixed phase $\mu \simeq 300$ **MeV**, $m_s = 150$ **MeV**

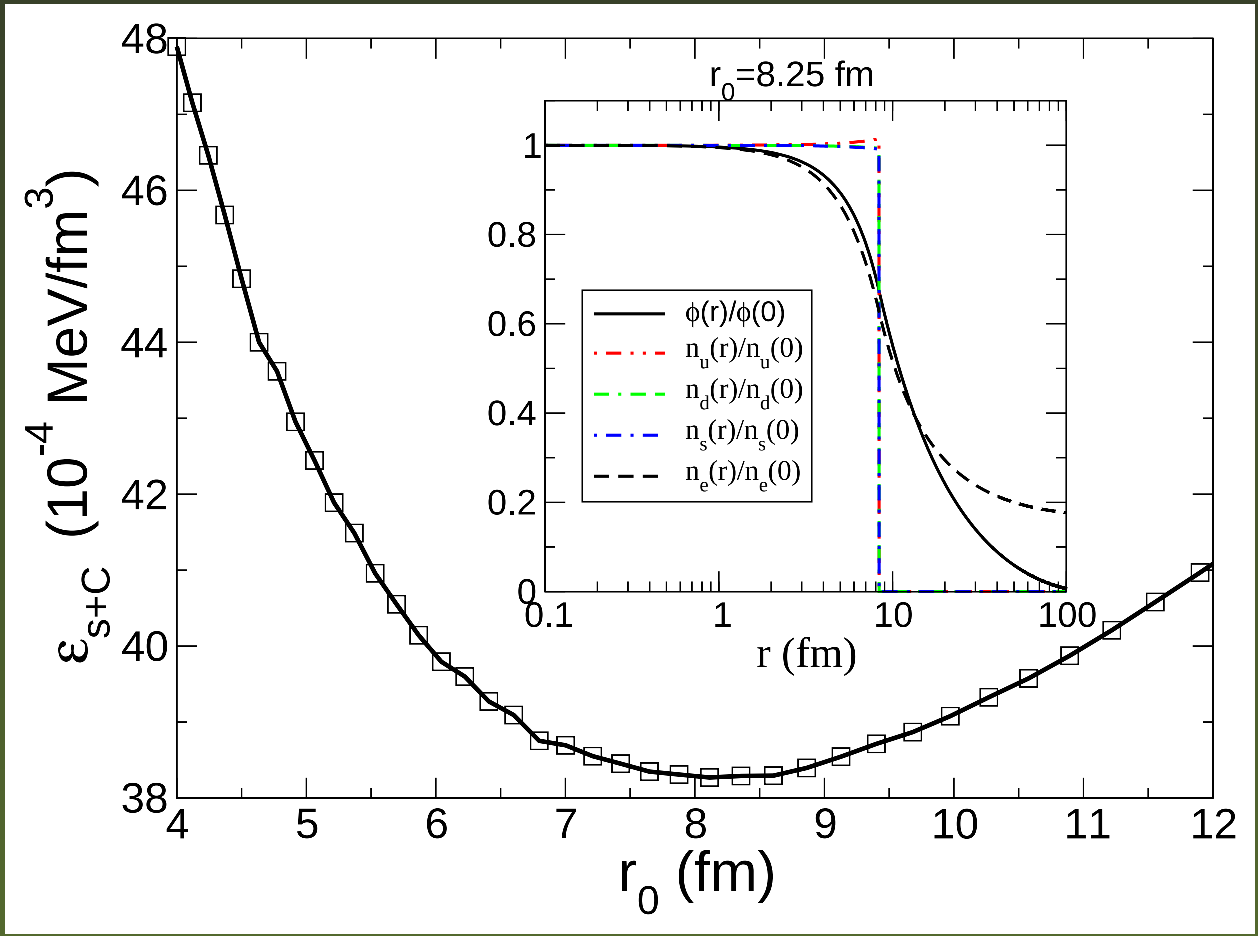
Homogeneous phase

$\mu \simeq 300$ **MeV**, $m_s = 130$ **MeV**

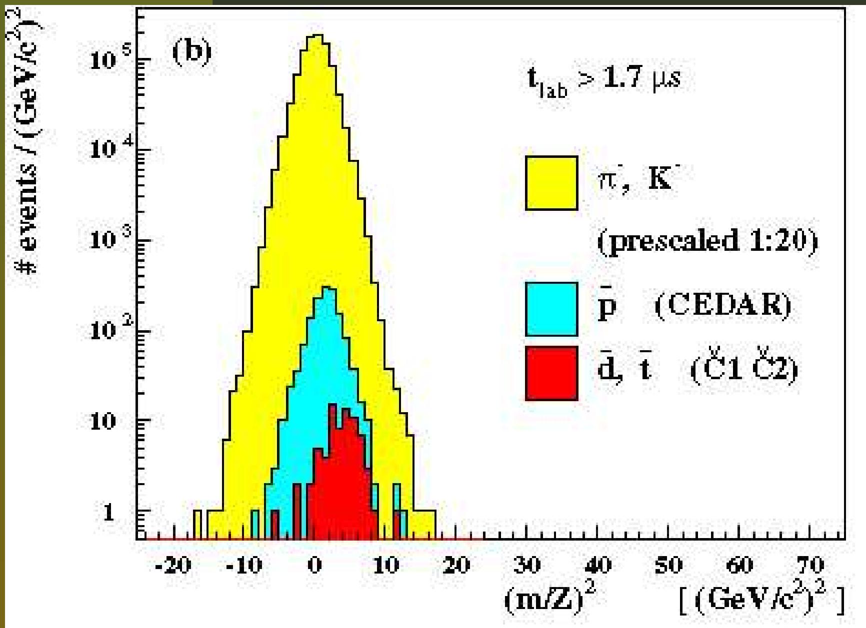
A surface of quark nuggets?

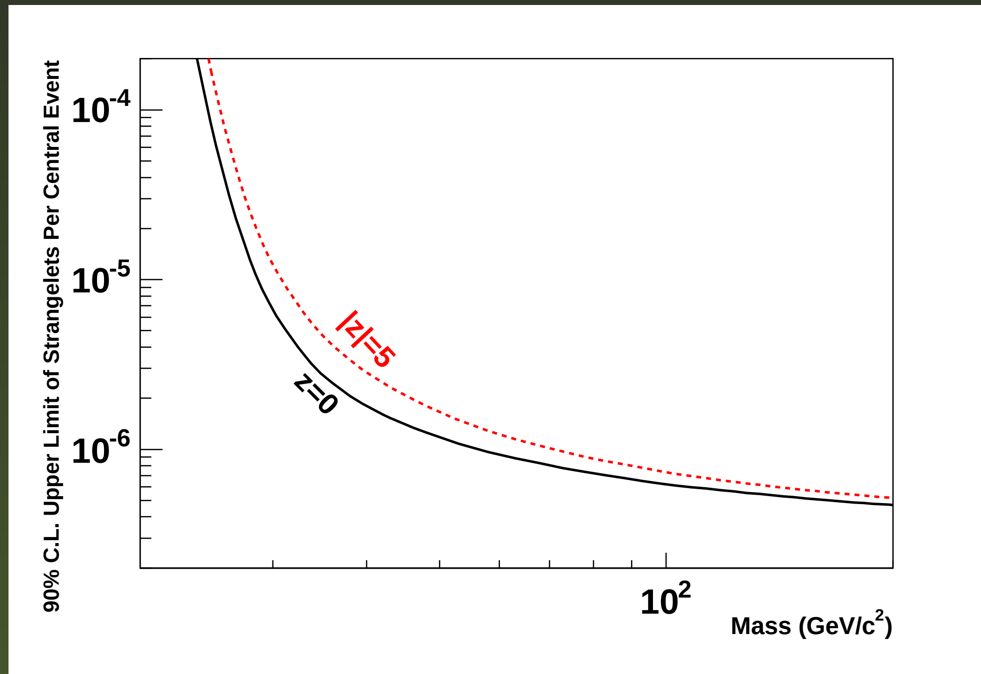
mixed phase: Quark nuggets + Electron sea

$\boxed{\Delta R \simeq 0.1 \text{ km}}$, Opt. nugget size (σ_T, μ_q): $\boxed{\approx 8 \text{ fm}}$



Help from heavy-ion collisions





Strangelet search at CERN-SPS

$\leq 10^{-10}$ strangelets/collision

created by coalescence

Strangelet search at RHIC

$\leq 10^{-6}$ strangelets/collision

distillation of QGP?

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- Neutron stars may contain such matter but may remain hidden inside neutron star cores
- A Bare Quark Star has a distinctive surface; it cools also by emitting photons – spectral identification by INTEGRAL satellite possible
- Quark stars can have a crust – we need accurate determinations of QCD parameters at high density
- *No "smoking gun" for quark stars so far, but not ruled out yet!*

Collaborators

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