Quarks hadron-confined in Compact Stars?

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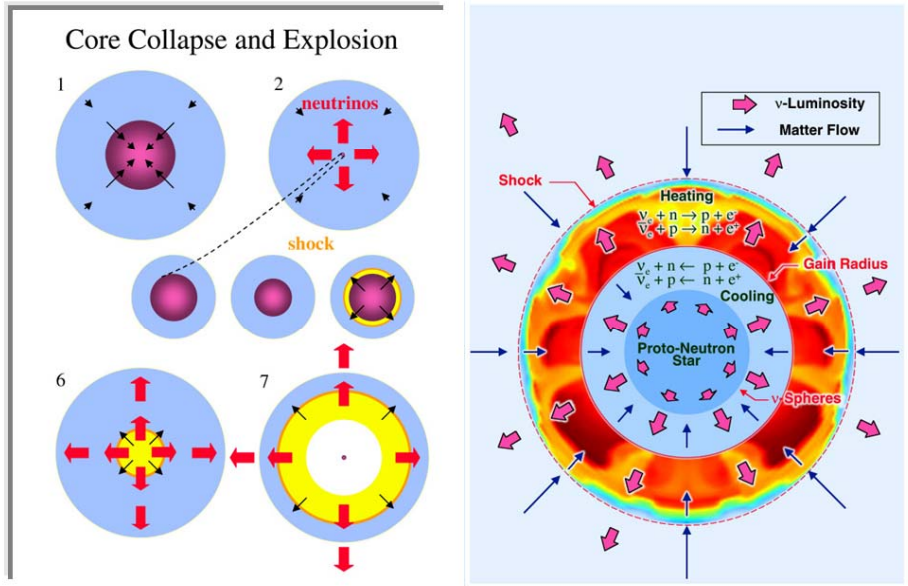
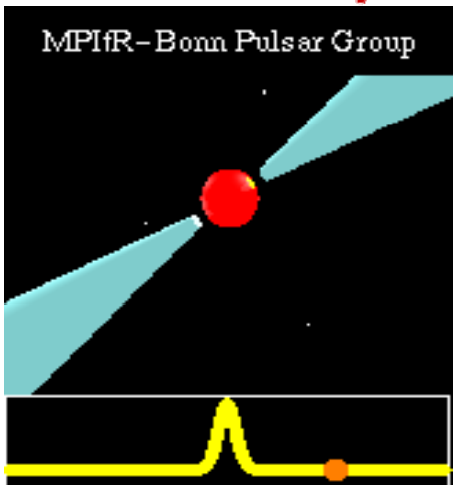
Summary

- Baryonic matter at $>\sim\rho_0$: an alternative
- Questions for our discussions
  - Quark clustered (hadron-like confined)?
  - Causality in quark-cluster matter?
  - EoS of quark-cluster matter: why stiff?
  - Evidence for self-bound on surface?
  - Light-flavour symmetry restoration?
- Conclusion & Outlook

Quarks in the Universe:
compressed again!





EoS of pulsar is meaningful for both:

- QCD at low-E
- Understanding cosmic events

Baryonic matter at >~ρ_0: an alternative

- My answer: condensed matter of quark clusters

Hadron star: quarks confined *gravity-bound*

Quark star: quarks de-confined *self-bound on surface*

Hybrid/mixed star: quarks de-con./con. *gravity-bound*

Quark-cluster star: quarks localized *self-bound on surface*

★ An essential question:
Quarks de-confined or not?
- Hadron matter: ***hyperon puzzle***
- Quark matter: ***asymptotic freedom***

★ The peculiarity of quark-cluster star:
Quarks hadron-confined in clusters
- Self-bound: M-R curves similar to QS
- Global rigidity: extra energy release

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Quark clustered (hadron-like confined)?

- *Clustering*? pressure-free → in "low ρ" regime
- *Interaction*? DSE approach of NQCD…

- Fermi gas at a few ρ_0:

  $\mu \approx (3\pi^2)^{1/3}\,\hbar c n^{1/3} \sim 0.4\text{GeV} < 1\text{GeV}$

- Fischer & Alkofer (2002)

$$\alpha(x) = \frac{\alpha(0)}{\ln(e + a_1 x^{a_2} + b_1 x^{b_2})}$$

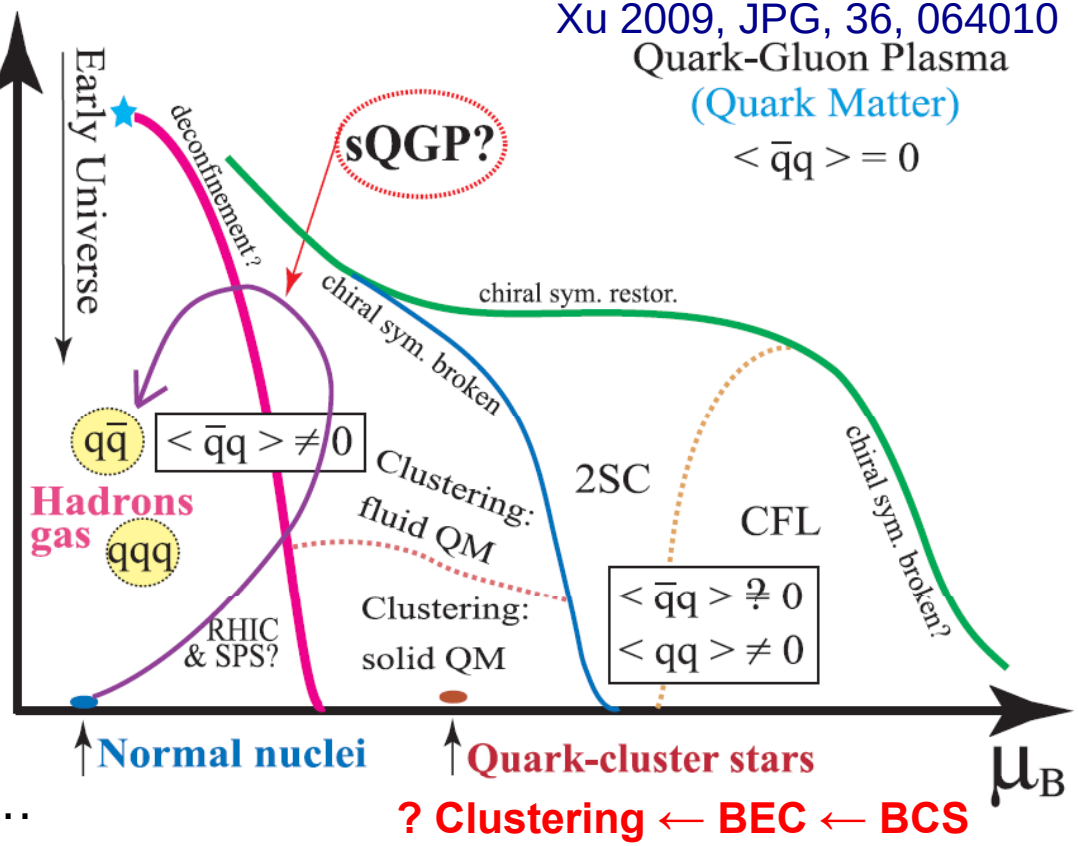
  ~ 2 at even $10\rho_0$!

- If Coulomb-like color interaction

  $E_q \sim \alpha_s^2 m_q c^2 \simeq 300\alpha_s^2$ MeV $> \mu$

  $\Rightarrow$ Fermi gas is dangerous?

- A quark-cluster state expected …



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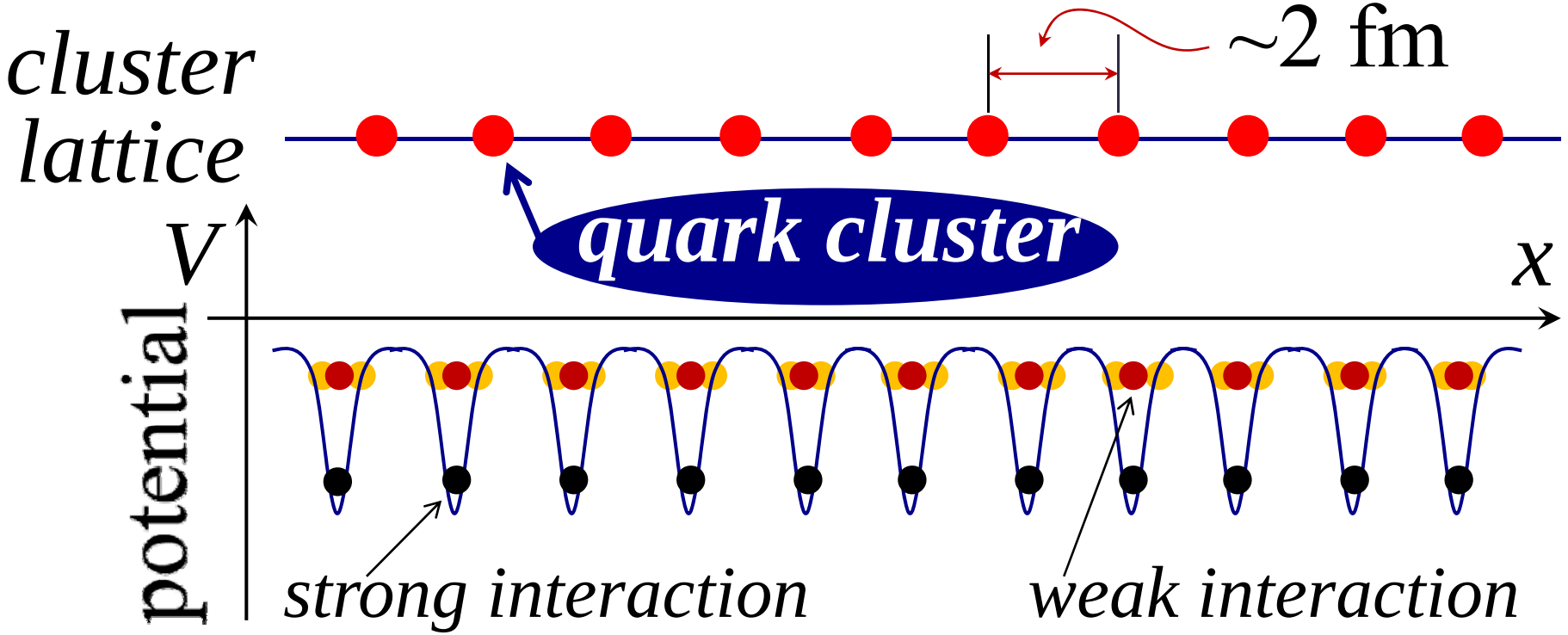
Causality in quark-cluster matter?

- Superluminal? c_s is in fact difficult to calculate



- A convenient way to calculate EoS of quark-cluster condense matter would be in ***potential representation*** as translational symmetry breaks there, similar to the case of condense matter physics.

$c_s = \sqrt{\mathrm{d}P/\mathrm{d}\epsilon}$ only measures ***stifness***, nothing with sound speed!

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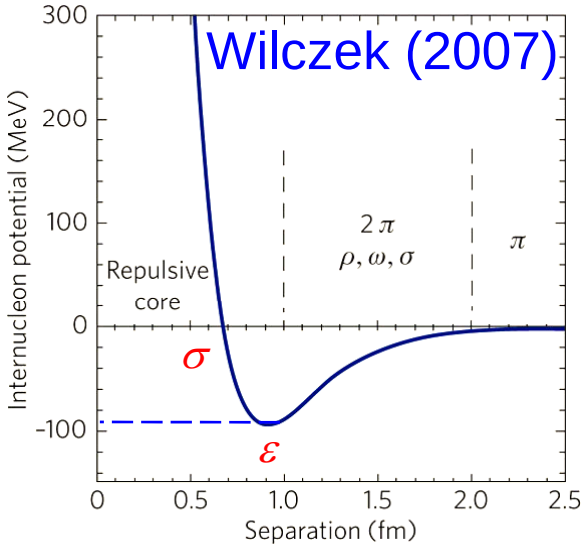
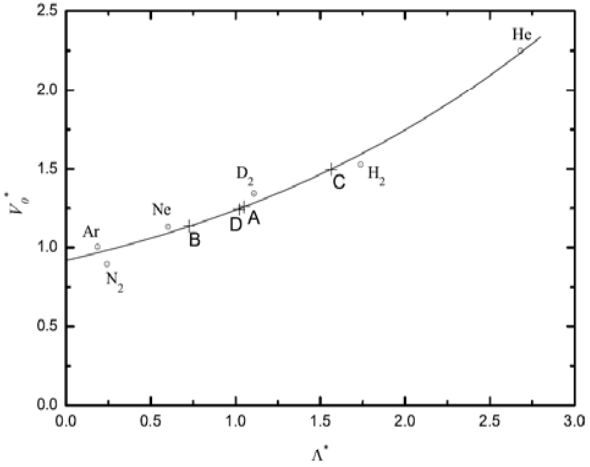
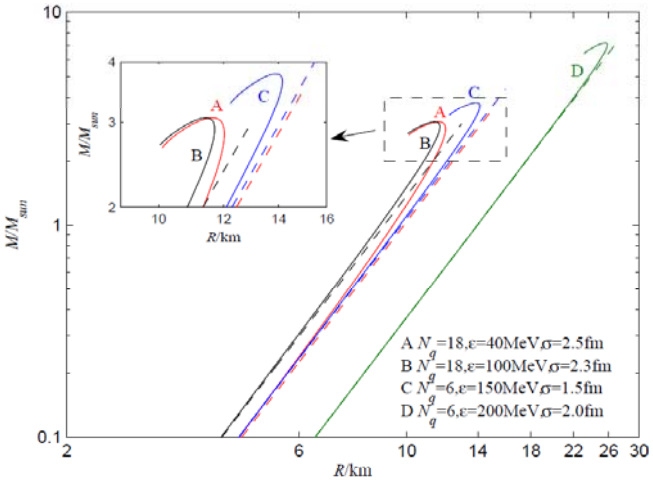
EoS of quark-cluster matter: why stiff?

- Non-relativistic ***ideal*** q-clusters → stiff EoS
  - Heisenberg's relation ⇒ momentum $p \propto n^{1/3}$
  - kinetic energy $\varepsilon_k \propto np^2 \propto n^{5/3}$,
  - pressure $P = n^2\partial(\varepsilon_k/n)/\partial n \propto n^{5/3}$(NR EoS of WD): very stiff EoS!
- Non-relativistic and ***repulsive*** → stiff EoS
  - A corresponding-state approach (Guo, Gao & Xu, CPC, 2013) $P^* = f(V^*, T^*, \Lambda^*)$







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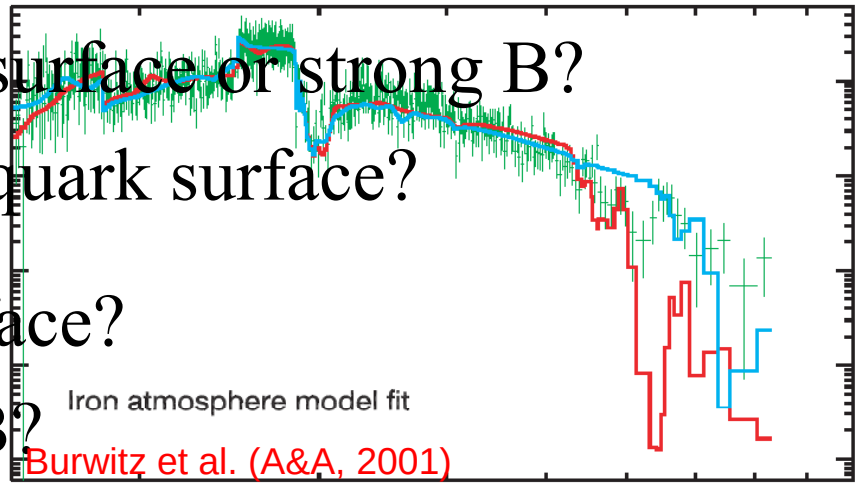
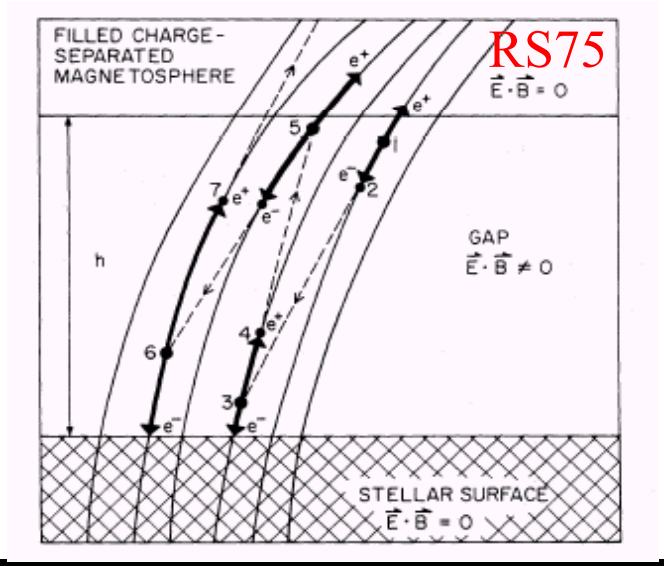
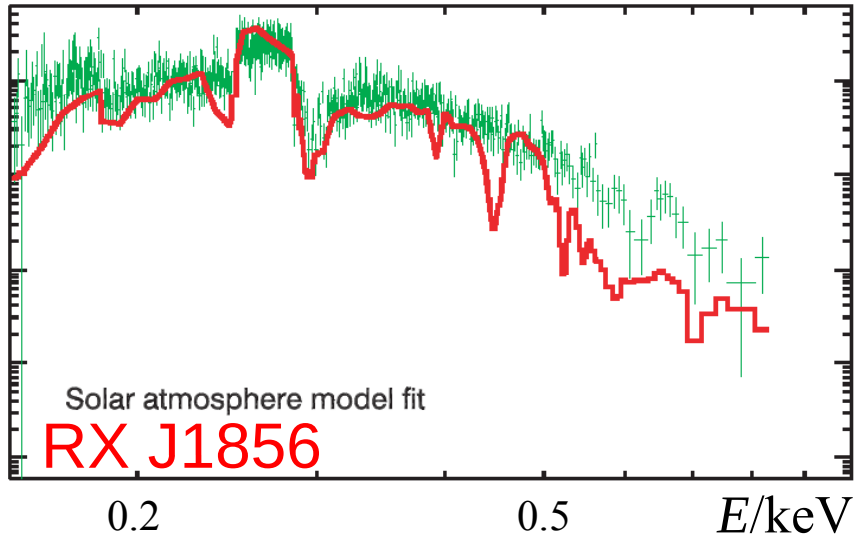
Evidence for self-bound on surface?

- Besides mass, clear signals could from surface
  - ***Subpulse drifting***: self-bound surface or strong B?
  - ***Bi-drifting***: strong self-bound quark surface?
  - ***Nonatomic spectra***: quark surface?
  - ***Clean fireball*** for SNE & GRB?







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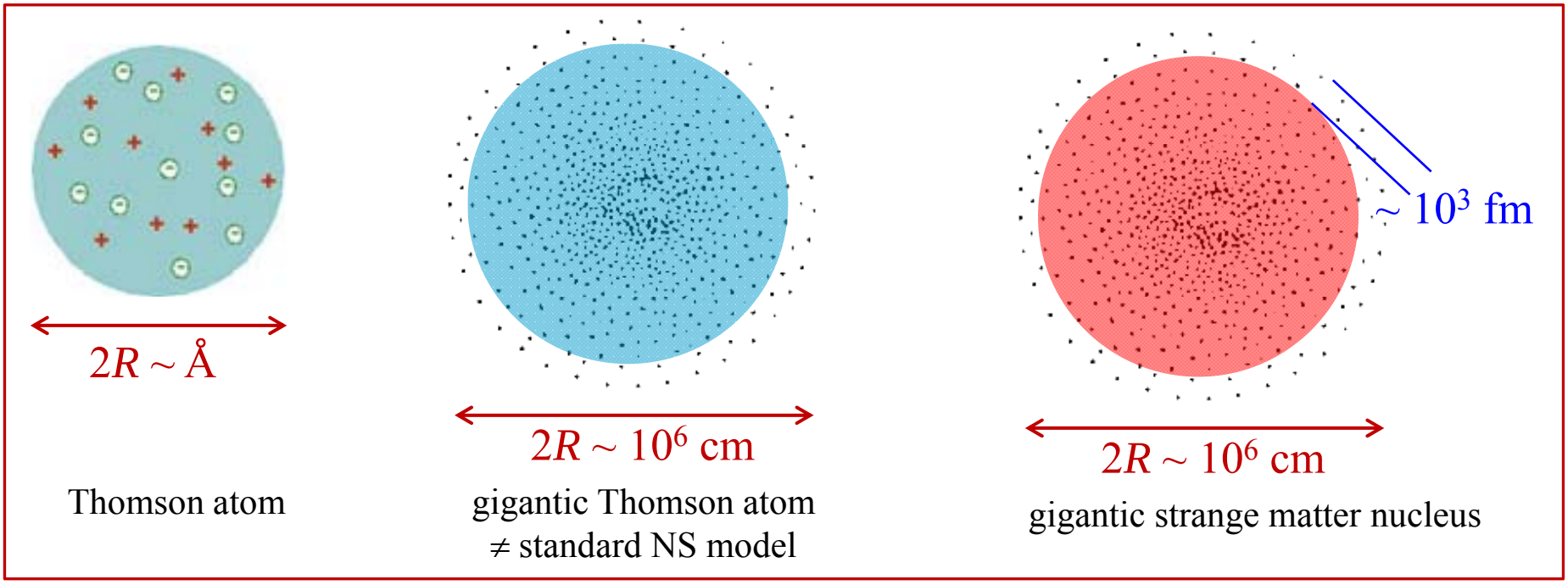
Light-flavour symmetry restoration?

- 3-symmetry: an extension of ***B-W conjecture***
  - Energy scale $E_{\text{scale}} \sim 400\text{MeV} > \Delta m_{\{\text{s, ud}\}} \sim 100\text{MeV}$
  - Electrons contribute negligible energy, if not:

    electron Fermi energy: $E_{\text{F}} \sim \hbar c n_{\text{e}}^{1/3} \sim 10^2$ MeV!
  - to eliminate E_{F} by neutronization or strangeness?



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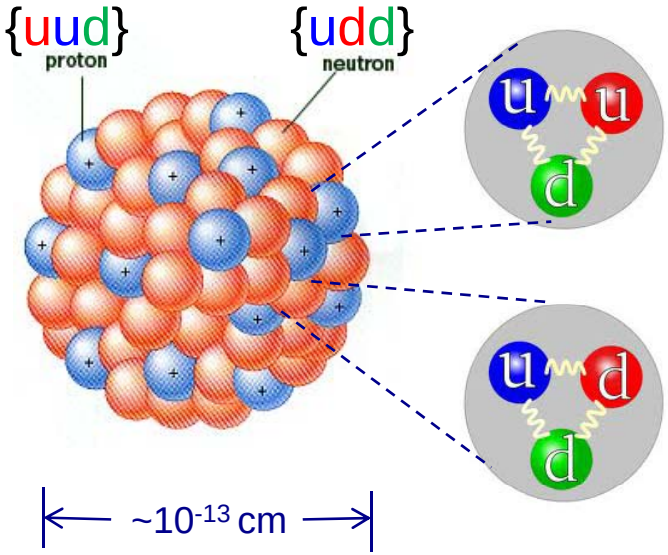
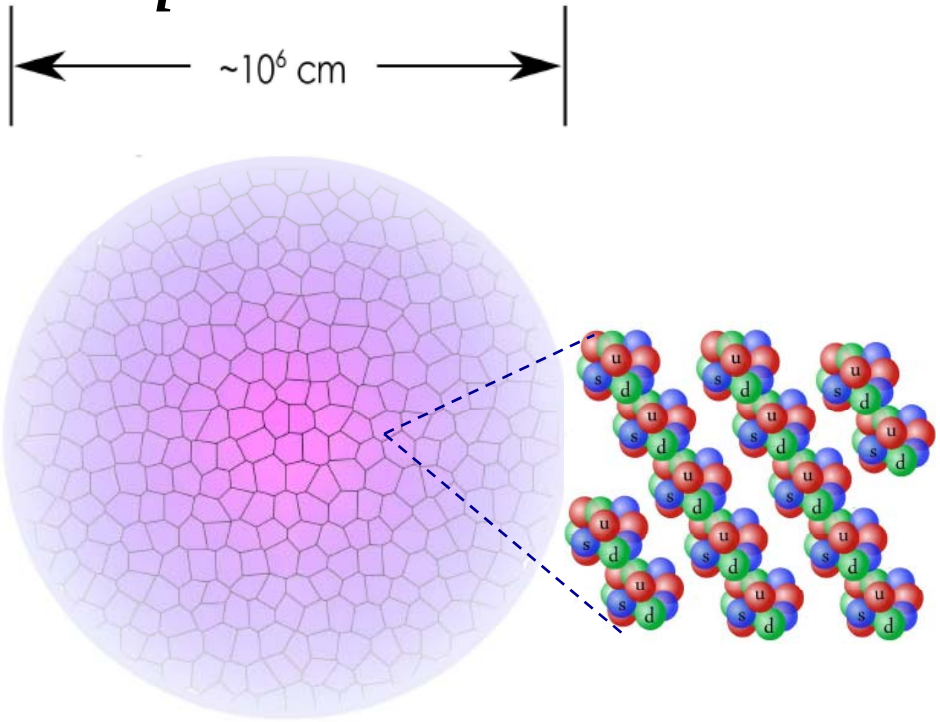
Conclusion & Outlook

- ***Quark-cluster star*** is condensed matter of quark clusters, which *distinguishes from both neutron and conventional quark stars*.



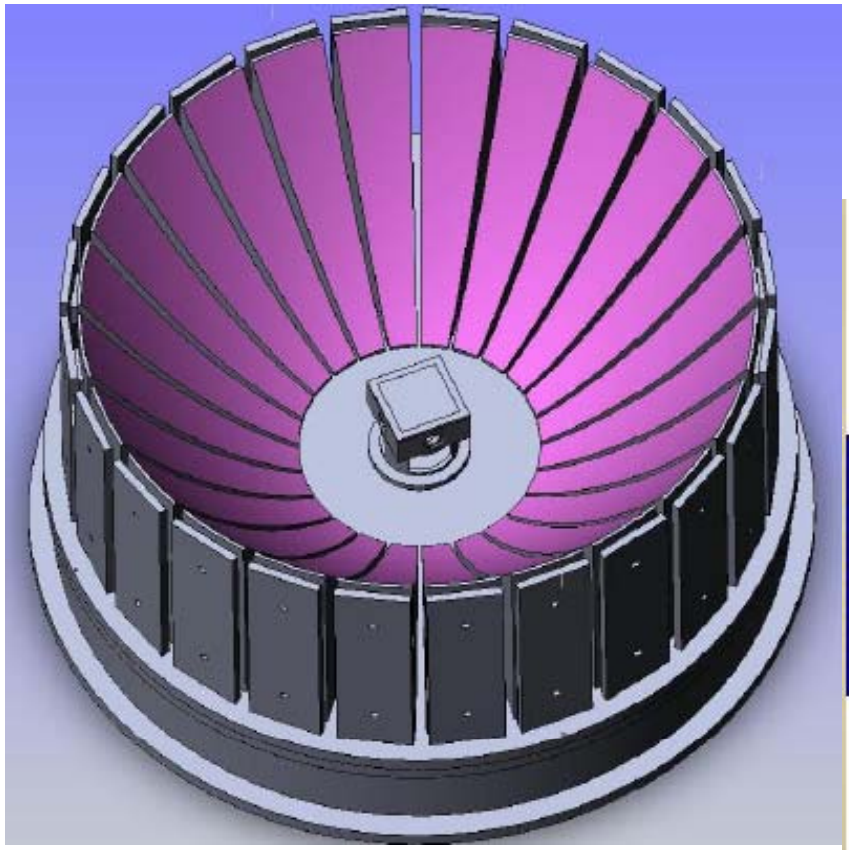
Neutrons are stable inside nuclei.



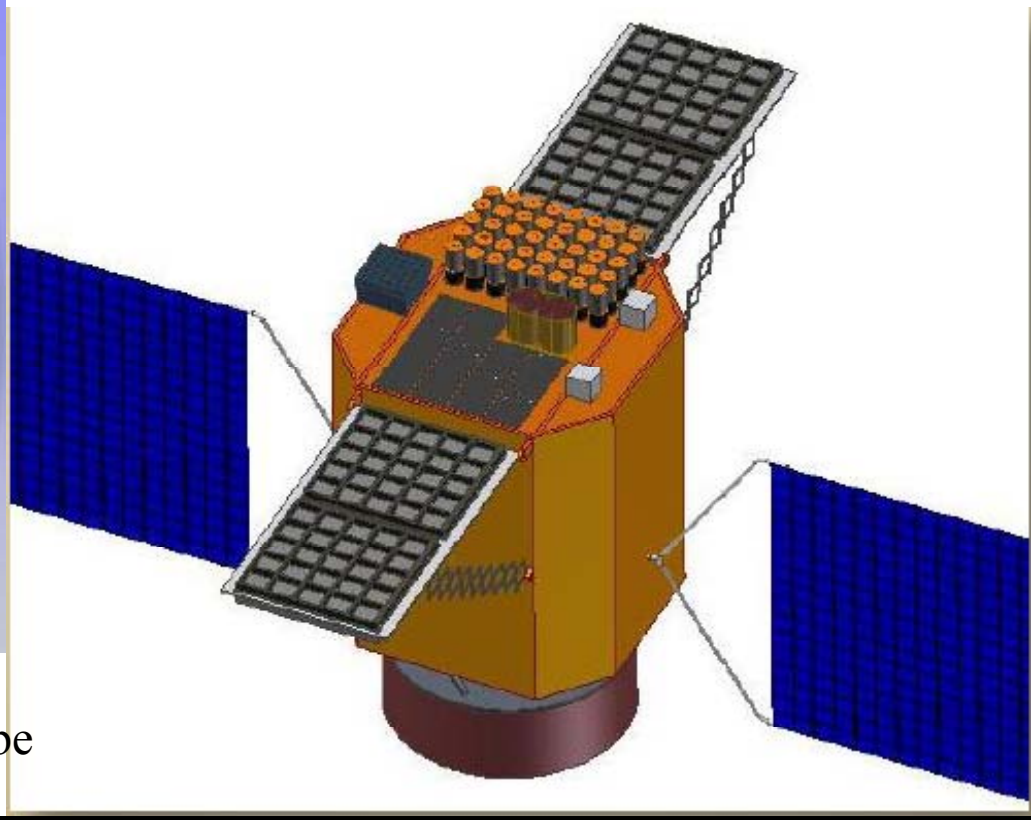
Quark-clusters, as multi-quark particles, don't decay in compact stars.

Conclusion & Outlook

- To teach us more? by X-ray ***polarization*** …



X-ray **T**iming and **P**olarization

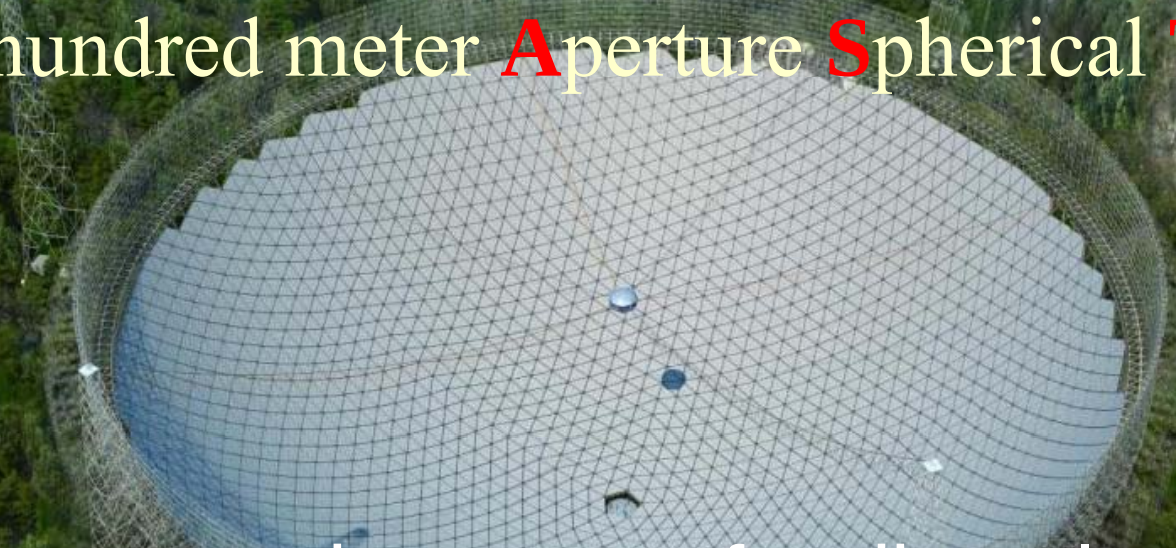


Lightweight **A**symmetry and **M**agnetism **P**robe

Conclusion & Outlook

- To teach us more? by ***radio*** …
  - To detect weak but best pulsars by FAST to be built in China (~2016)

Five hundred meter **A**perture **S**pherical **T**elescope



- To measure the mass of radio pulsars
- To measure the inertial of momentum of NS
- To find sub-ms radio pulsars