Strangeon Matter:
from stars to nuggets

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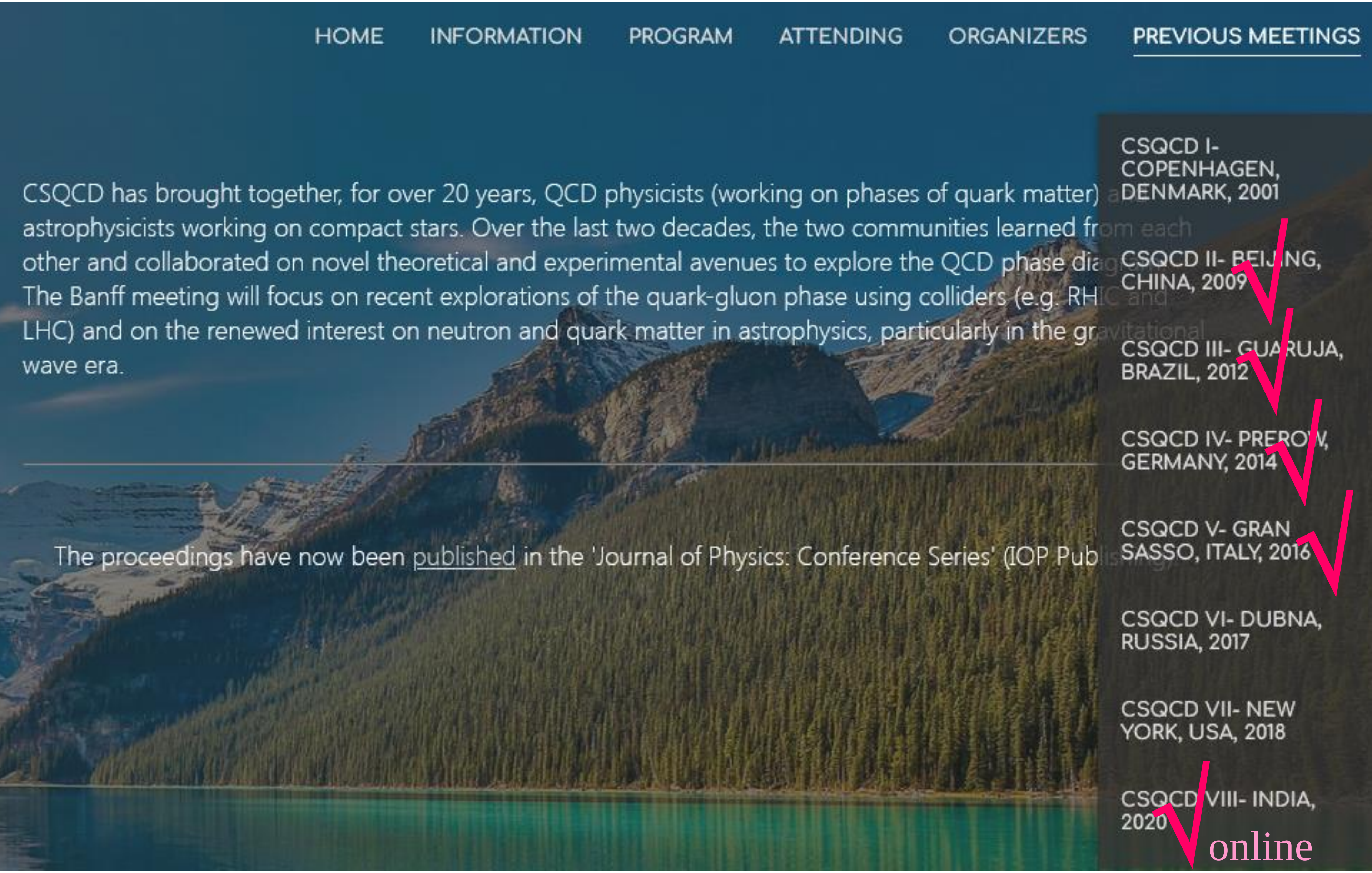
Compact Stars in the QCD phase diagram, CSQCD X

Oct. 7-11, 2024; YITP, Kyoto University

CSQCD IX: August 1-5 2022, Banff, Alberta, Canada



http://www.quarknova.ca/CSQCDIX/

What's the nature of pulsars?

RHIC(sQGP?)

GRB (XRF)?

The physics of (***cold***) matter at supra-nuclear density:

A big challenge

QCD diagram?

SGRs/AXPs?

FRB

Core-collapse supernovae?

Compact stars in the QCD phase

May 20-24, 2009
Peking University, Beijing, China

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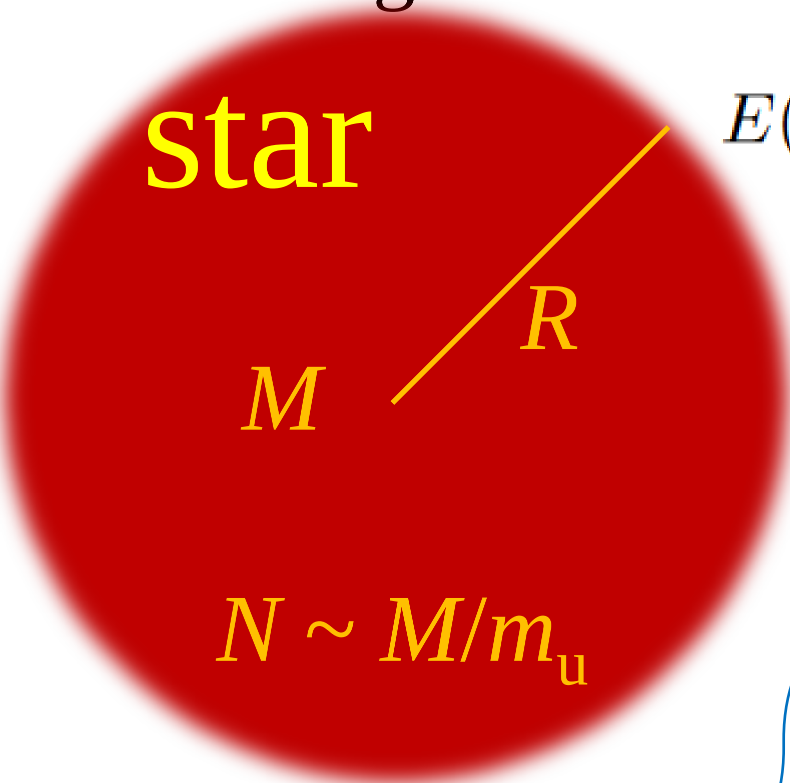
Cosmic ***energy-scale***: the stars

- The strong interaction matters for stars!



$$E(M) = \varepsilon \frac{M}{m_{\rm u}} + E_{\rm g} \simeq (\varepsilon - \frac{GMm_{\rm u}}{R})\frac{M}{m_{\rm u}}$$

$$R \simeq \frac{GMm_{\rm u}}{\varepsilon} \simeq 1.5\ {\rm km}\ \frac{M}{M_\odot} \frac{1\ {\rm GeV}}{\varepsilon}$$

- $\varepsilon \sim$ keV $\Rightarrow R \sim 10^9$ m: Main-sequence
- $\varepsilon \sim$ MeV $\Rightarrow R \sim 10^6$ m: White dwarf
- $\varepsilon \sim 10^2$MeV $\Rightarrow R \sim 10^5$ m: Neutron S.
- $\varepsilon \to \infty \Rightarrow R \to 0$: Black hole

CSQCD focuses on NS

Cosmic ***energy-scale***: the stars

- so... what's the consequences of scale of ~ 10^2 MeV?

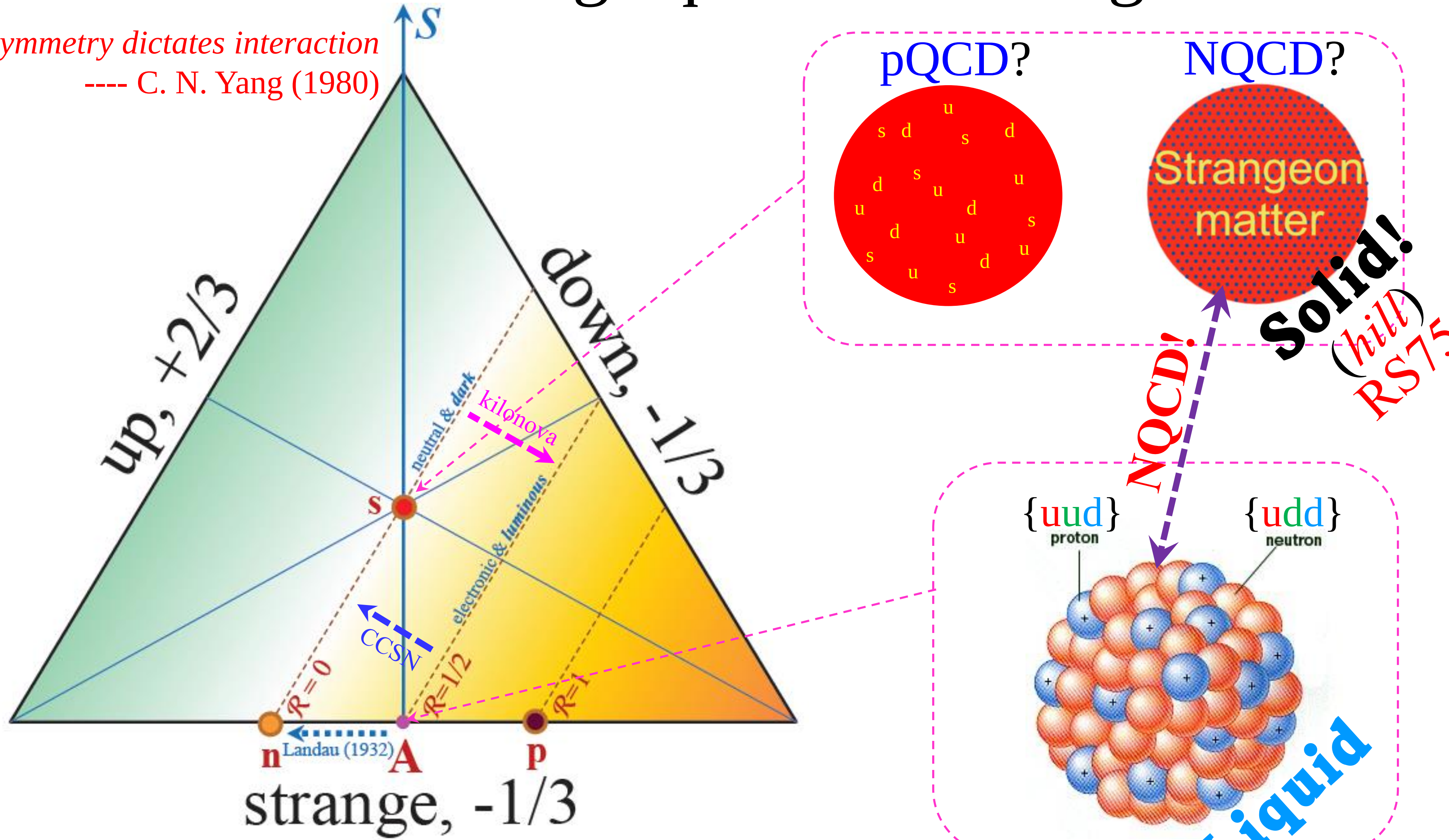
{ Non-perturbative QCD: free quarks? (atomic nuclei@*P*=0)
{ Strangeness matters here: three{*uds*}-flavours…

It is convenient to take advantage of **a triangle diagram**!

Cosmic ***energy-scale***: the stars

- Neutron star? Strange quark s.? Strangeon s.?

Symmetry dictates interaction
---- C. N. Yang (1980)



Cosmic ***energy-scale***: the stars

- Strangeon star model was proposed > 20 years…

THE ASTROPHYSICAL JOURNAL, 596:L59–L62, 2003 October 10

SOLID QUARK STARS? **= strangeon star?**

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School of Physics, Peking University, Beijing 100871, China
Received 2003 July 9; accepted 2003 August 22; published 2003 September 15

ABSTRACT

It is conjectured that cold quark matter with very high baryon density could be in a solid state, and strange stars with low temperatures should thus be solid stars. The speculation could be close to the truth if no peculiar polarization of thermal X-ray emission (as in, e.g., RX J1856) or no gravitational wave in postglitch phases are detected in future advanced facilities or if spin frequencies beyond the critical ones limited by *r*-mode instability are discovered. The shear modulus of solid quark matter could be $\sim 10^{32}$ ergs cm^{-3} if the kilohertz quasi-periodic oscillations observed are relevant to the eigenvalues of the center star oscillations.

Subject headings: dense matter — elementary particles — pulsars: general — stars: neutron

1. INTRODUCTION

The gauge theory of strong interaction, quantum chromodynamics (QCD), is still developing; nevertheless, it is well known to have two general properties: asymptotic freedom at

2. CAN QUARK MATTER BE SOLID?

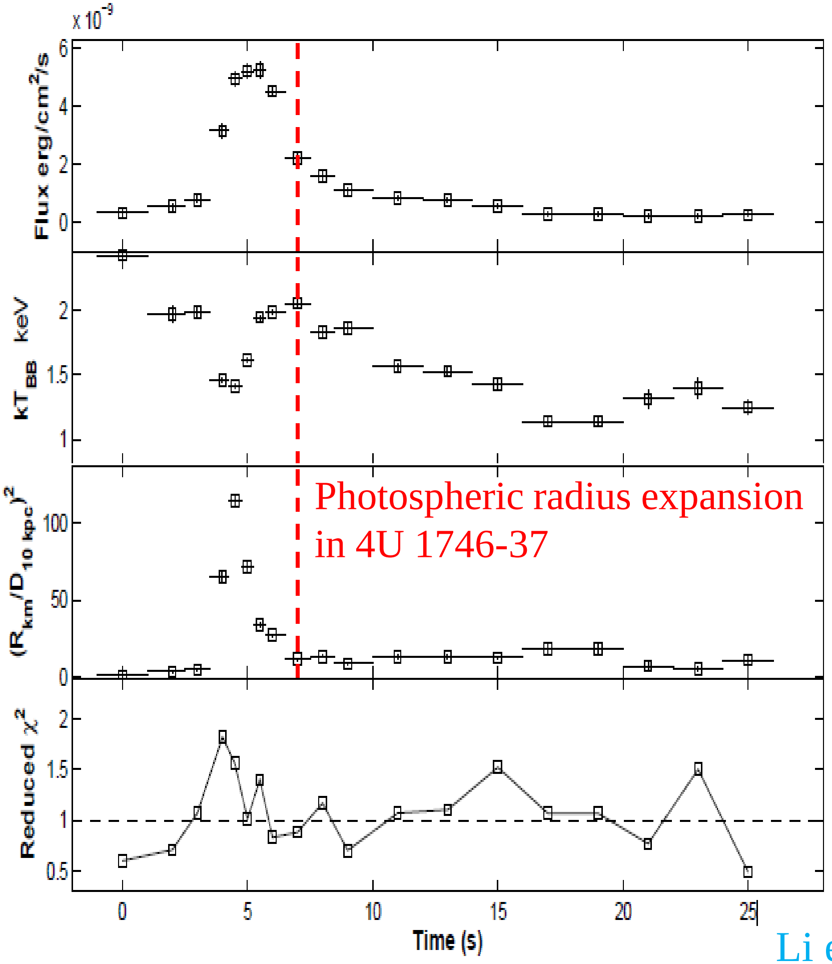
There are virtually two ingredients that affect the formation of the quark cluster in quark-gluon plasma: Pauli's exclusion principle and interactions. Suppose we "turn off" the interactions

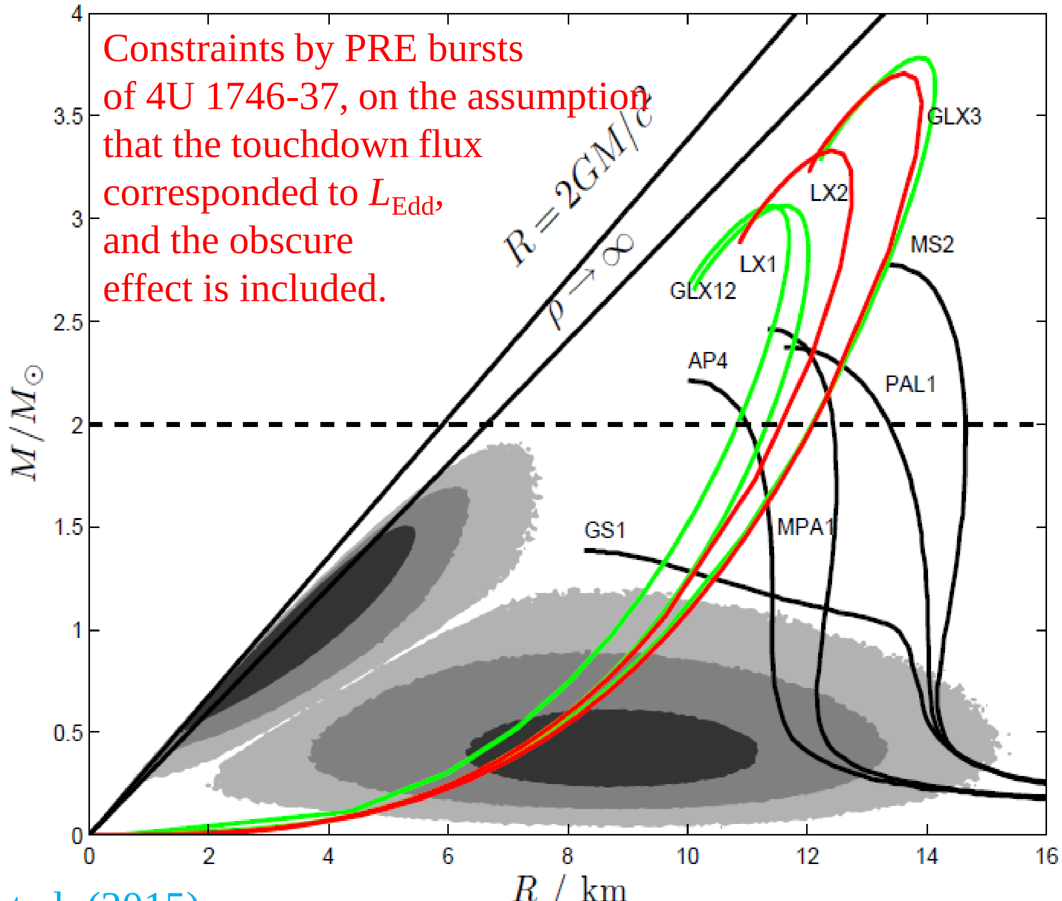
Strangeon Matter:

from **Stars**

Strangeon matter: *from* **stars**

- Mass-radius constrained by PRE bursts?





Li et al. (2015)

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- My talk in CSQCD4: 2014…

On the status of the world's largest radio telescope FAST

(*Five-hundred-meter Aperture Spherical radio Telescope*)

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School of Physics, Peking University

(北京大学物理学院)

Compact Stars in the QCD phase diagram (CSQCD IV)

Sept. 26 - 30, 2014; Prerow, Germany

CSQCD4 http://www.phy.pku.edu.cn/~xurenxin/ R. X. Xu

Strangeon matter: *from* **stars**

- Now, FAST plays an essential role!

running since 2019…

FRB (poln *L*/*V*), ~1/3 of radio pulsars

nHz-GW!

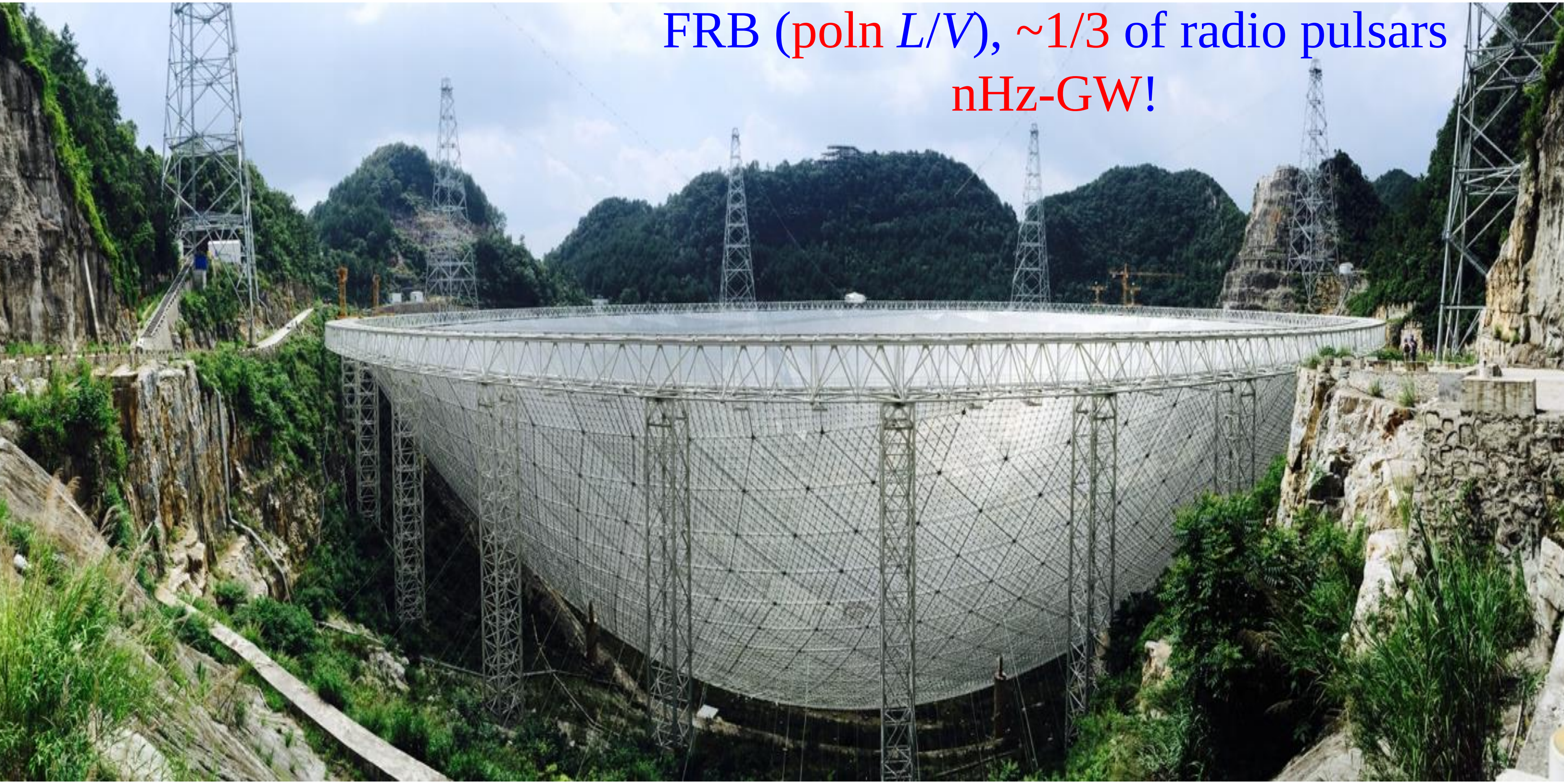

Fig. 1 Panoramic view of FAST (obtained in June of 2017).

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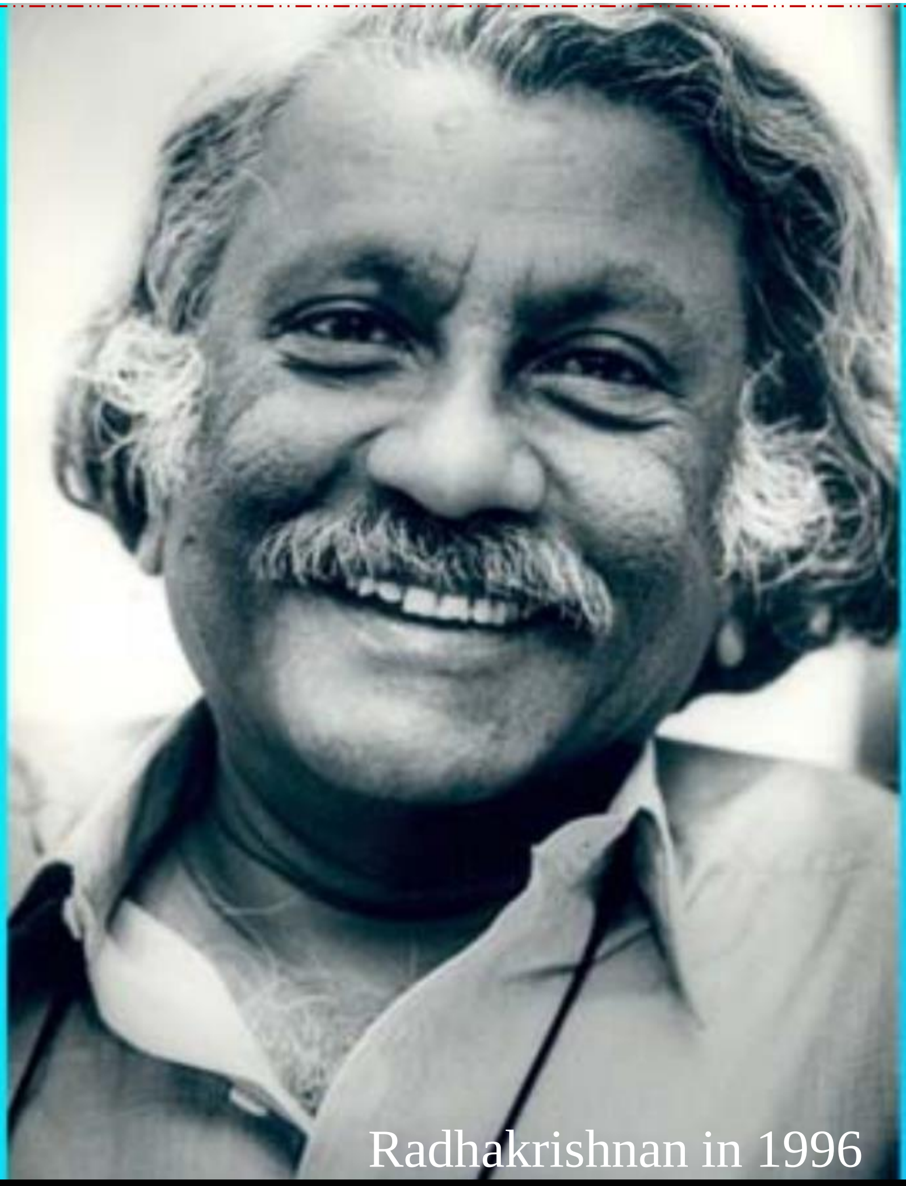
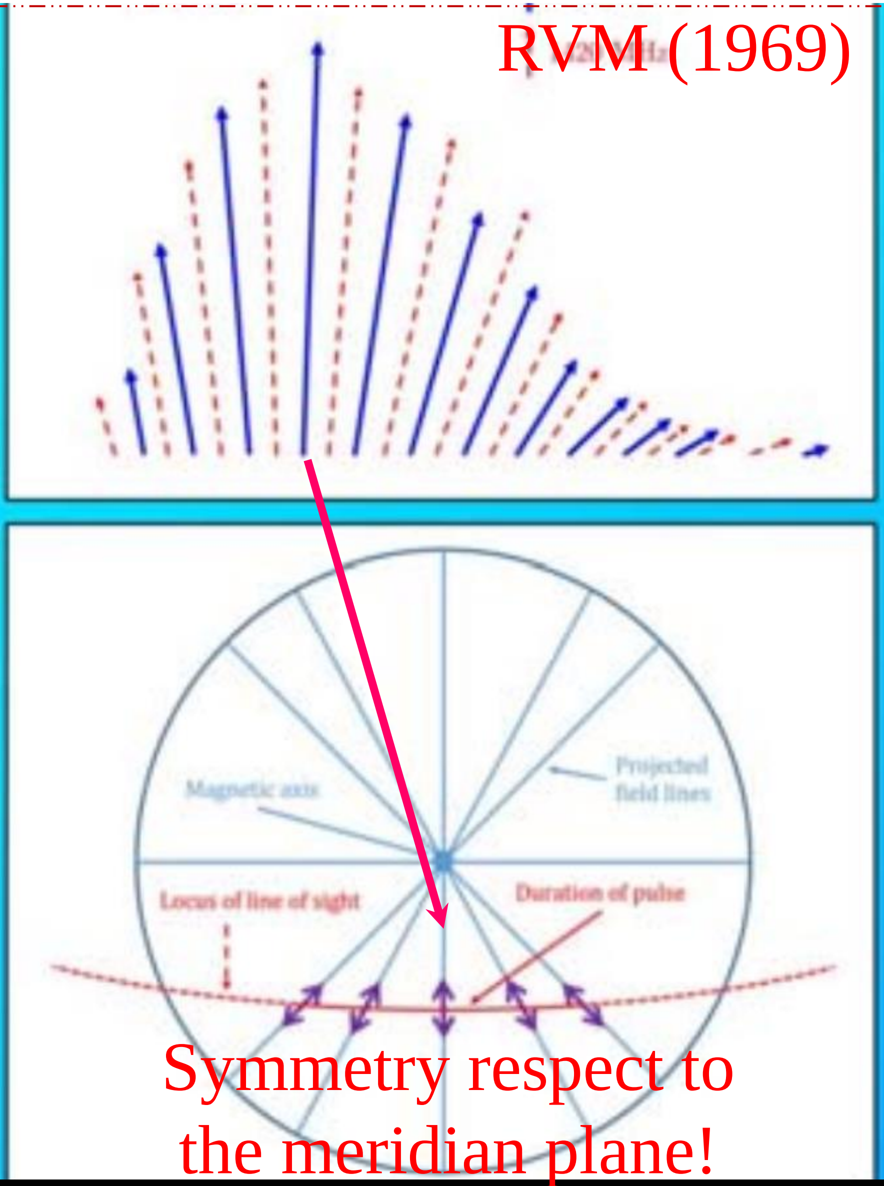


Radhakrishnan in 1996

from Manchester (2017)



RVM (1969)

Symmetry respect to the meridian plane!

Strangeon matter: *from* **stars**

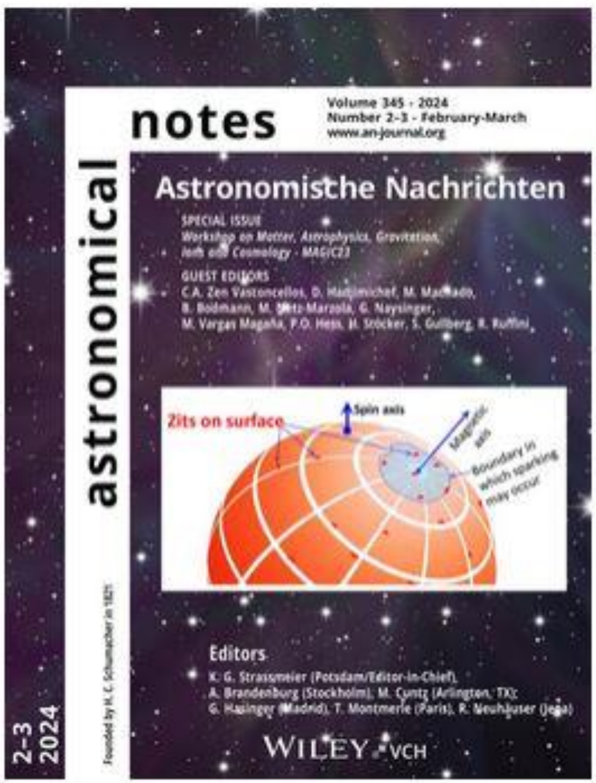
COVER PICTURE

Free Access

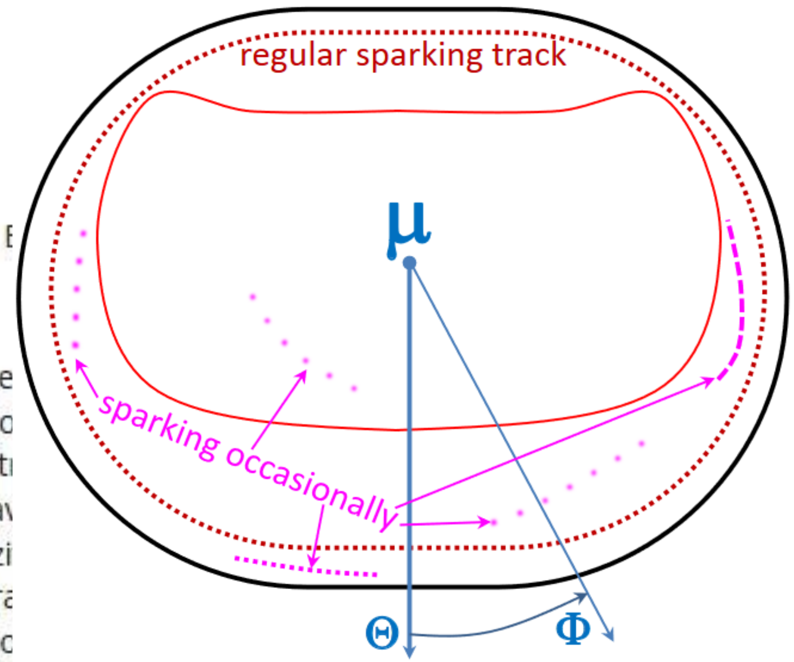
Cover Picture: Astron. Nachr. 2/2024

Zhengli Wang, Jiguang Lu, Jingchen Jiang, Shunshun Cao, Weiyang Wang, E

e249012 | First Published: 24 March 2024



It has been proposed that the matter could be 'an', strangeo nucleons but with negative st strangeon star should not hav be covered with small hills ('zi spots in this schematic illustra pulsar surface might be respo magnetospheric activity and the mysterious coherent radio emission, as discussed in the contribution by Xu and Wang, this issue, p. e230153. Zits may also be responsible for the significantly non-symmetrical sparking discovered in the 110-min polarization observation of pulsar PSR B0950+08 targeted with China's Five-hundred-meter Aperture Spherical radio Telescope, FAST. Details can be found in the contribution by Wang et al., this issue, e240010.



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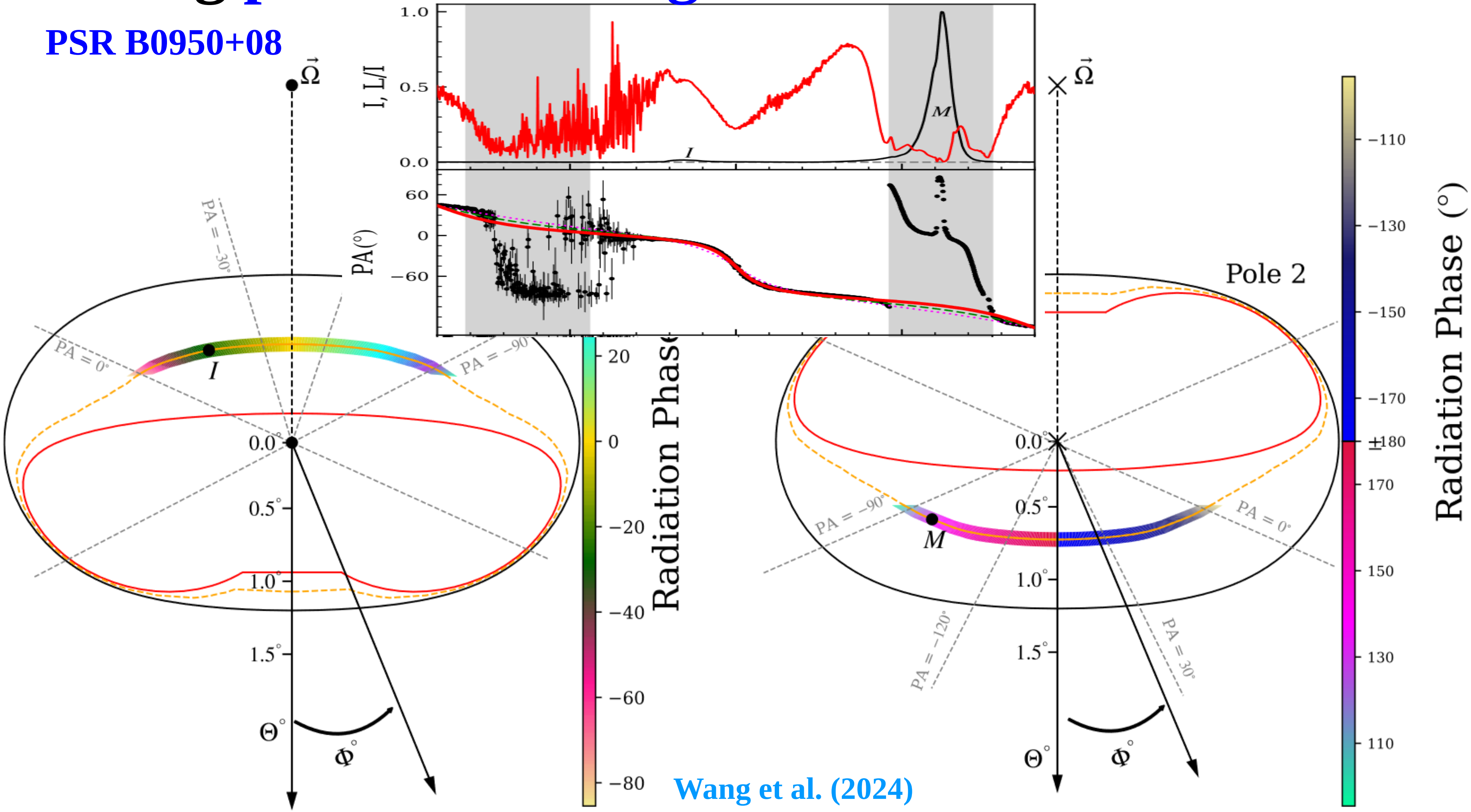
- **Strong particle-binding and "zits" on PSR surface**

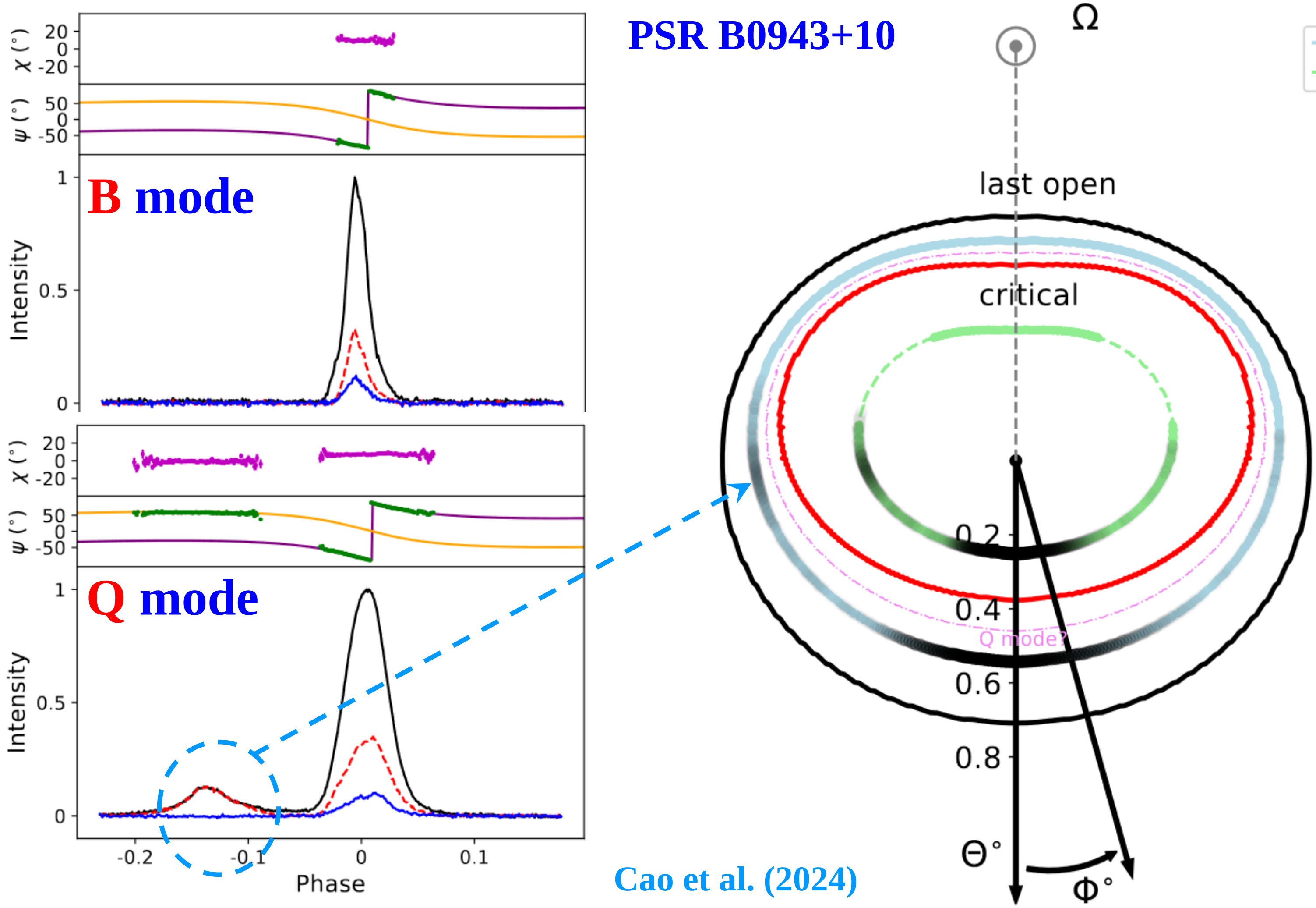
PSR B0950+08



Wang et al. (2024)

Strangeon matter: *from* **stars**

- **Strong particle-binding and "zits" on PSR surface**



Strangeon Matter:

to **Nuggets**

Strangeon matter: *to* **Nuggets**

- A *gigantic* nucleus anticipated by Landau (1932)

ON THE THEORY OF STARS.

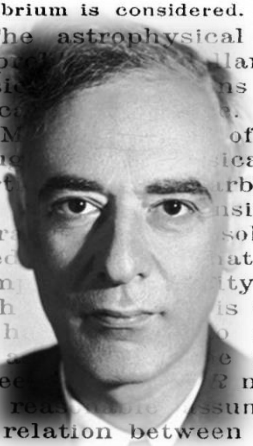
By L. Landau.

(Received 7 January 1932).

From the theoretical point of view the physical nature of Stellar equilibrium is considered.

The astrophysical methods usually applied in attacking the p… lar structure are characterised by making physi… ns chosen only for the sake of mathematic… By this is characterised, for instance, Mr. M… of the impossibility of a star consisting throu… ical ideal gas; this proof rests on the assert… rbitrary L and M, the fundamental equations … nsisting of classical ideal gas admit, in gener… solution. Mr. Milne seems to have overlooke… hat this assertion results only from the assum… ity being constant throughout the star, which … is made only for mathematical purposes and h… do with reality. Only in the case of this … e radius R disappears from the relation betwee… R necessary for regularity of the solution. Any rea… sumptions about the opacity would lead to a relation between L, M and R, which relation would be … from the physical criticisms put forward against Eddington's mass-luminosity-relation.

It seems … able to try to attack the problem of stellar structure by methods of theoretical physics, i. e. to investigate the physical nature of stellar equilibrium. For that purpose we must at first investigate the statistical equilibrium of a given mass without generation of energy, the condition for which equilibrium being the minimum of free energy F (for given temperature). The part of free energy due to gravitation is negative and inversely proportional to some



Lev Davidovich Landau
(1908-1968)

we have no need to suppose that the radiation of stars is due to some mysterious process of mutual annihilation of protons and electrons, which was never observed and has no special reason to occur in stars. Indeed we have always protons and electrons in atomic nuclei very close together, and they do not annihilate themselves; and it would be very strange if the high temperature did help, only because it does something in chemistry (chain reactions!). Following a beautiful idea of Prof. Niels Bohr's we are able to believe that the stellar radiation is due simply to a violation of the law of energy, which law, as Bohr has first pointed out, is no longer valid in the relativistic quantum theory, when the laws of ordinary quantum mechanics break down (as it is experimentally proved by continuous-rays-spectra and also made probable by theoretical considerations).[1] We expect that this must occur when the density of matter becomes so great that atomic nuclei come in close contact, forming one gigantic nucleus.

On these general lines we can try to develop a theory of stellar structure. The central region of the star must consist of a core of highly condensed matter, surrounded by matter in ordinary state. If the transition between these two states were a continuous one, a mass $M < M_0$ would never form a star because the normal equilibrium state (i. e. without pathological regions) would be quite stable. Because, as far as we know, it is not the fact, we must conclude that the condensed and non-condensed states are separated by some unstable states in the same manner as a liquid and its vapour are, a property which could be easily explained by some kind of nuclear attraction. This would lead to the existence of a nearly discontinuous boundary between the two states.

The theory of stellar structure founded on the above considerations is yet to be constructed, and only such a theory can show how far they are true.

February 1931, Zurich.

[1] L. Landau und R. Peierls, ZS. f. Phys. 69, 56, 1931.

How *gigantic* is gigantic?

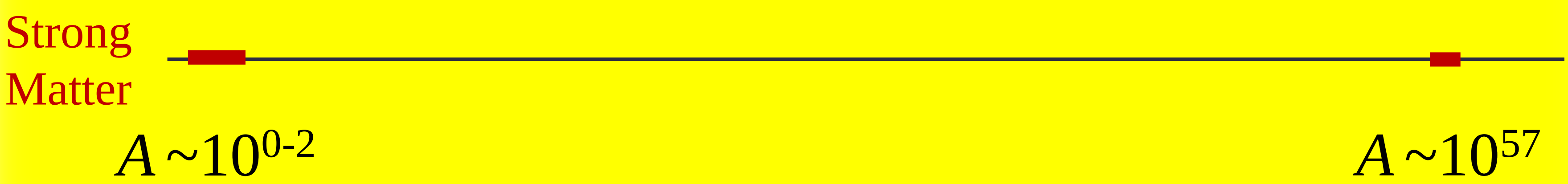
Have a guess of *A*: only ~10^{57}?

Landau L. 1932, *Sov. Phys.*, 1, 285

Strangeon matter: *to* **Nuggets**

- Huge mass-gap for condensed matter bound by the strong force (***strong matter***)!

A mass-spectrum speculated:

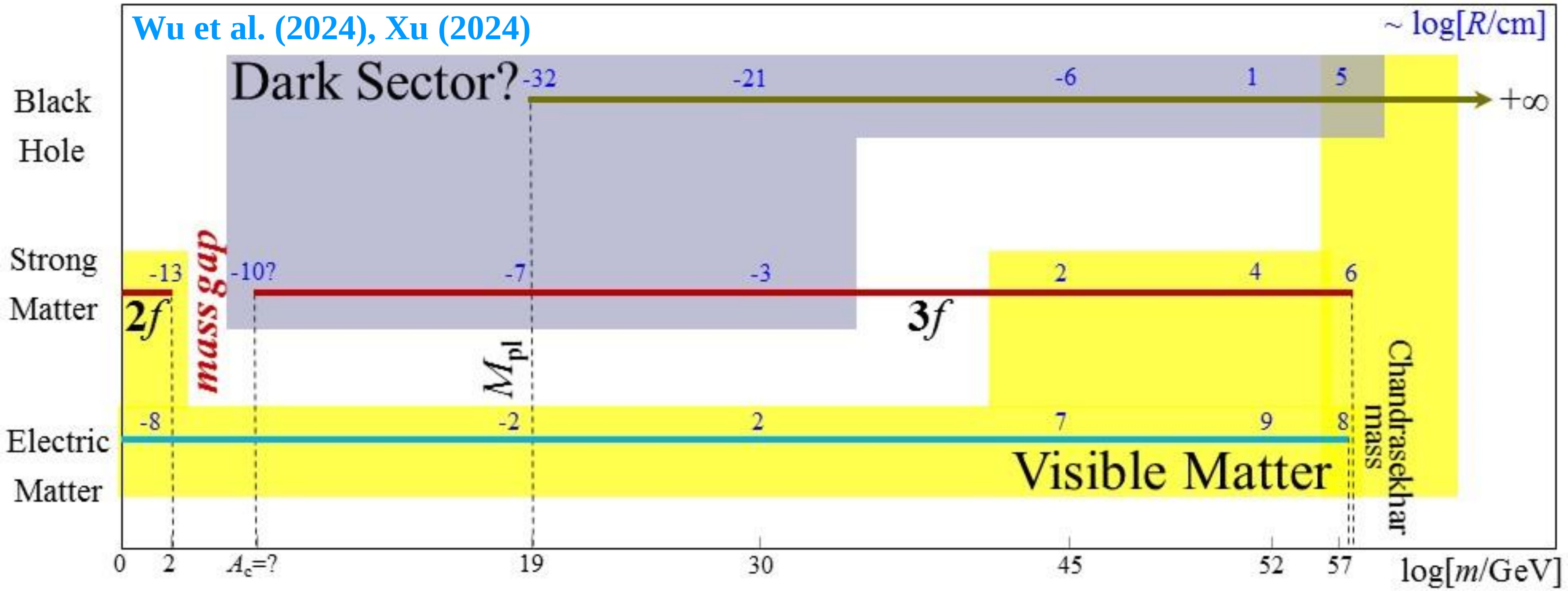


Really? we argue that the mass-gap would narrower considerably *if* Nature favors flavour symmetry!

Strangeon matter: *to* **Nuggets**

A world conjectured in the "**old**" physics:
standard model of particle physics
electric, *strong*, and *singular*!

(condensed matter power off, without energy supply)



Summary

- We proposed that pulsar-like compact stars are *strangeon* stars if Nature really loves symmetry, and with FAST's polarization observation, non-symmetric sparking is found, which could imply *hills* on the surface of strangeon star.

- Strangeon *nuggets* with baryon number $A > 10^{5\sim9}$ could exist, to be manifested in the form of "*dark*" matter, but it is challenging to detect.

- Let's test the model further with FAST and…

THANKS!