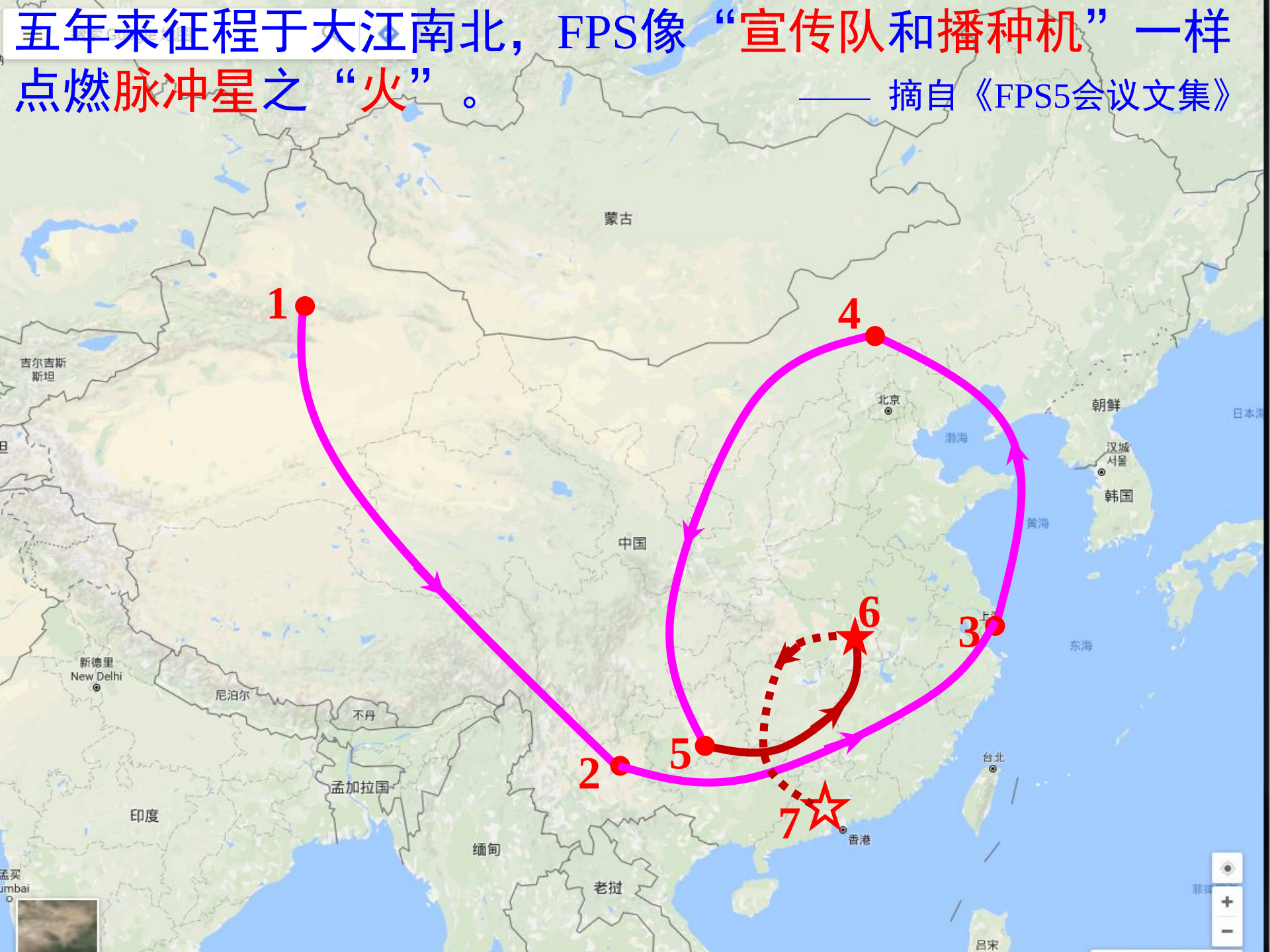
五年来征程于大江南北，FPS像“宣传队和播种机”一样点燃脉冲星之“火”。

—— 摘自《FPS5会议文集》



Strangeness
in Compact Stars

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[2]Kavli Institute for Astronomy and Astrophysics

"FPS6"

June 28-30, 2017; HUE, Wuhan

Summary

- Why *strangeness* in compact stars?
- *Strangeness* manifested in the form of
  - Hyperon
  - Strange quark matter
  - Strangeon
- Conclusions

Summary

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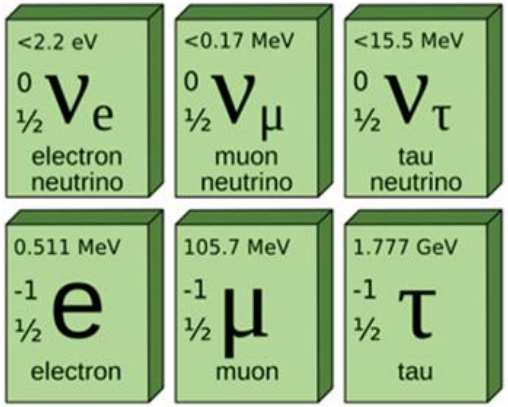
Why strangeness in compact stars?

- Physics (standard): **particles** and **interactions**

Building blocks

quark:

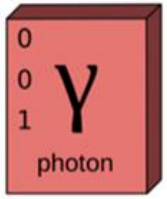
lepton:



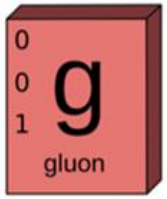
Higgs: H

Fundamental forces

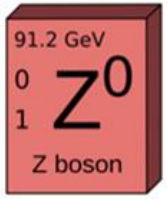
EM:

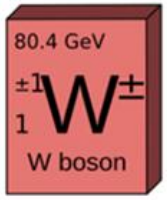


strong:



weak:





gravity: G

Why strangeness in compact stars?

- Why are we ***loving*** strangeness? the scale-energy…

For compact star with mass $M\sim1.5M_\odot$ and radius $R\sim10$km, the separation between quarks is $\Delta\ell$, order of 0.5 fm:

$$\Delta\ell \approx (3M/m_p)^{-1/3}R \approx (3M_\odot/m_p)^{-1/3}10\text{km} = 0.5\ \text{fm}.$$

From Heisenberg's uncertainty relation, $\Delta\ell\cdot\Delta p \approx \hbar$, one has an energy scale for dense matter inside compact star:

$$E_{\text{scale}} \approx \hbar c/\Delta\ell \approx 0.2\text{GeV}\cdot\text{fm}/0.5\ \text{fm} = 0.4\ \text{GeV}.$$

Therefore, we may confidently expect that strangeness would not be negligible because

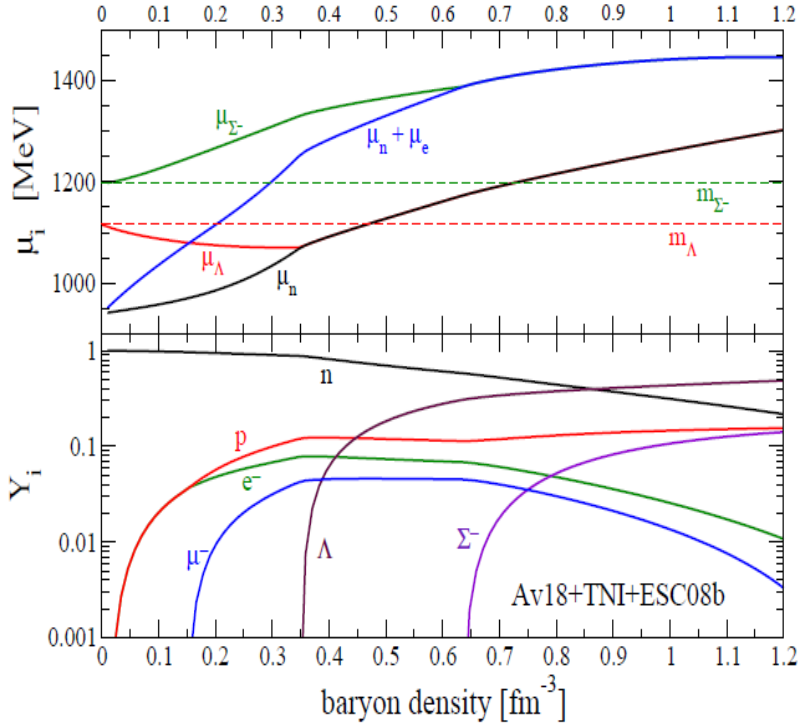
$$E_{\text{scale}} \gg (m_s - m_{ud})c^2!$$

Summary

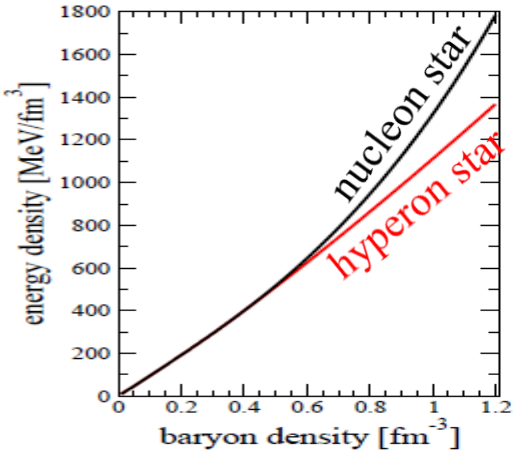
- Why strangeness in compact stars?
- Strangeness manifested in the form of
  - **Hyperon**
  - Strange quark matter
  - Strangeon
- Conclusions

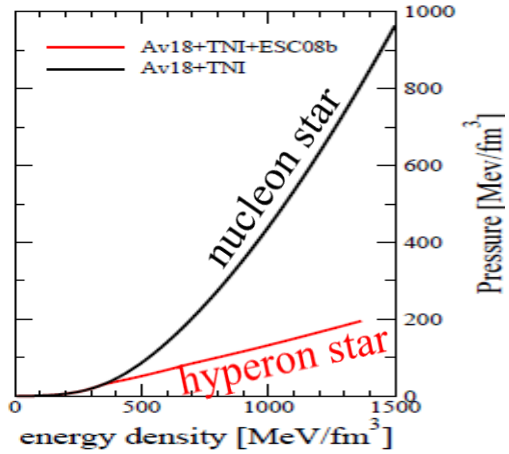
Strangeness manifested: Hyperon?

- Stiff **nucleon matter** ⇒ high M_{max} of **nucleon star**, but **hyperon** seems unavoidable and to **soften** the EoS!



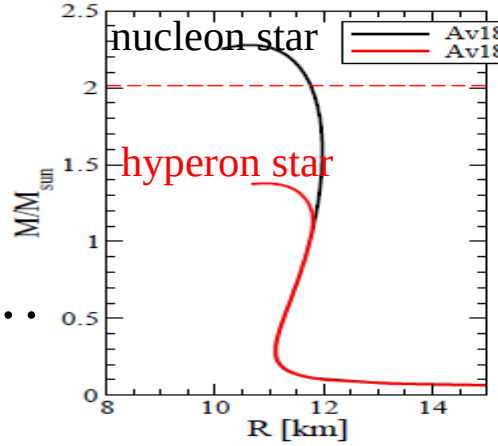
I. Bombaci (arXiv160105339)

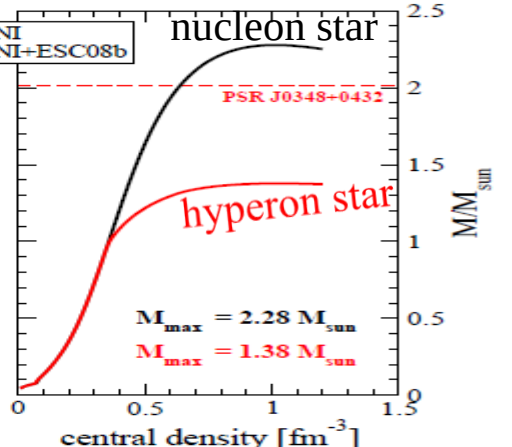




many-body interaction, but…

any tests independent?





Summary

- Why strangeness in compact stars?
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  - **Strange quark matter**
  - Strangeon
- Conclusions

Strangeness manifested: SQM?

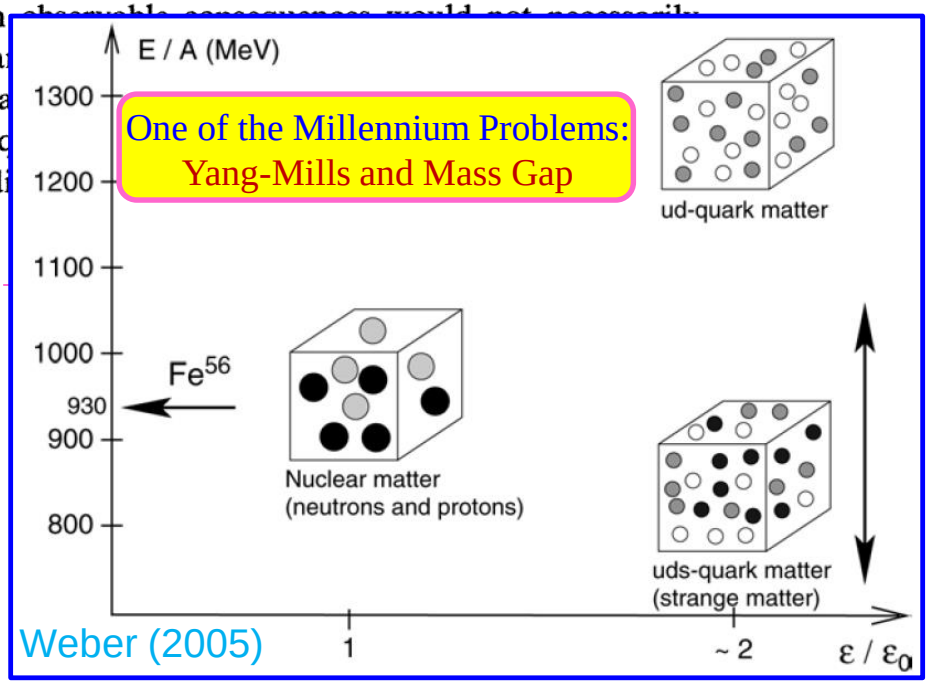
- Witten's impact on dense matter/*strangeness* phys.

PHYSICAL REVIEW D VOLUME 30, NUMBER 2 15 JULY 1984

Cosmic separation of phases

Edward Witten*
Institute for Advanced Study, Princeton, New Jersey 08540
(Received 9 April 1984)

A first-order QCD phase transition that occurred reversibly in the early universe would lead to a surprisingly rich cosmological scenario. Although
survive, it is at least conceivable that the phase tra
cess in dense, invisible quark nuggets, providing a
QCD effects only. This possibility is viable only if
MeV. Two related issues are considered in appendi
quark-matter component of cosmic rays, and the
have produced a detectable gravitational signal.



Strange quark matter in bulk may constitute the true ground state of the strong-interaction matter rather than ^{56}Fe.

Strangeness manifested: SQM?

- An intuitional explain of ***Witten's conjecture***

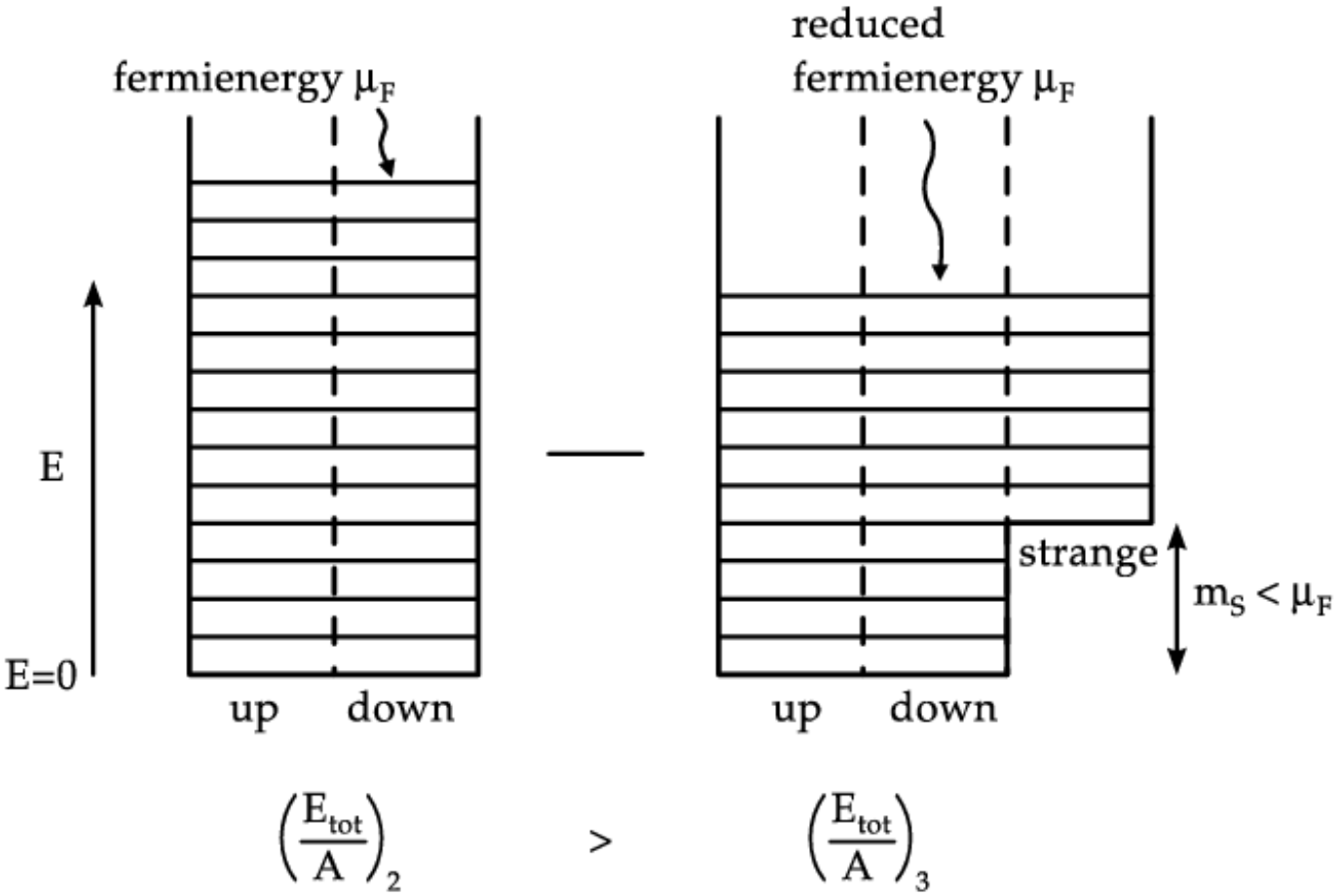
m_u = 2~8 MeV

m_d = 5~15 MeV

m_s ~ 100 MeV

$\rho = 2\rho_N$

μ_F ~ 500 MeV



Greiner et al. (1998)

Strangeness manifested: SQM?

- but…**free** quarks (SQM) seem also to **soften** the EoS…

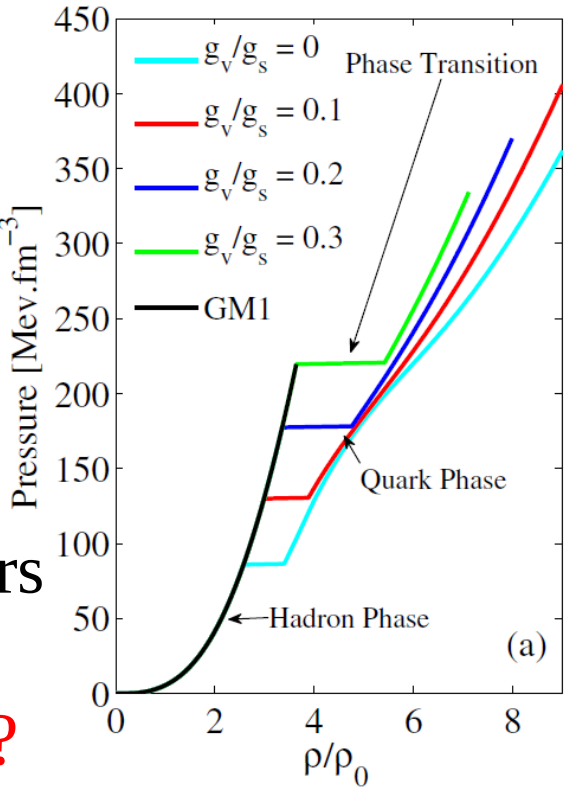
MIT-bag-based EoS tends to be too soft, but stiff EoS could be possible if introducing ***repulsive forces*** between quarks, forming hybrid stars.

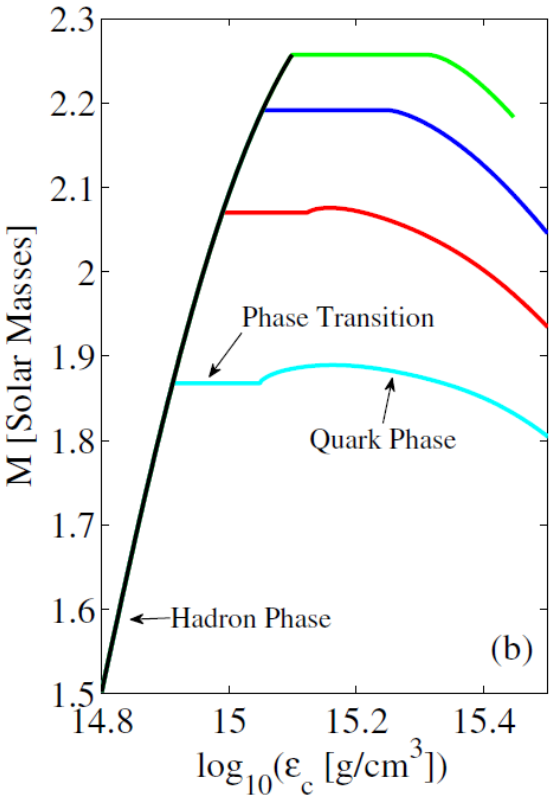
The vector coupling constant g_v is treated as a ***free parameter***.

Lenzi & Lugones (2012)

Yes, massive hybrid stars could be stable, but…

any tests independent?





Summary

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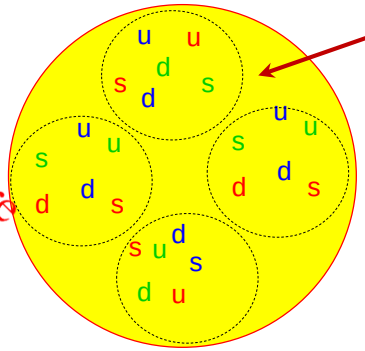
Strangeness manifested: Strangeon!

- A *generalized* Witten's conjecture ($E_{scale} < 1GeV!$)

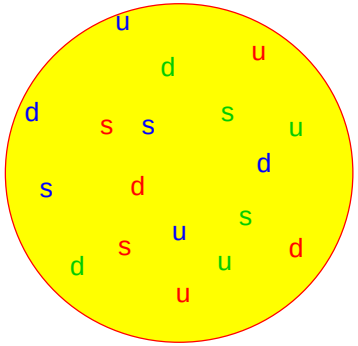
Strangeon matter in bulk constitutes the true ground state of the strong-interaction matter rather than ^{56}Fe.

Strange quark matter in bulk constitutes the true ground state of the strong-interaction matter rather than ^{56}Fe.

General Witten's conjecture



Strangeon
(strange nucleon)



Witten's conjecture

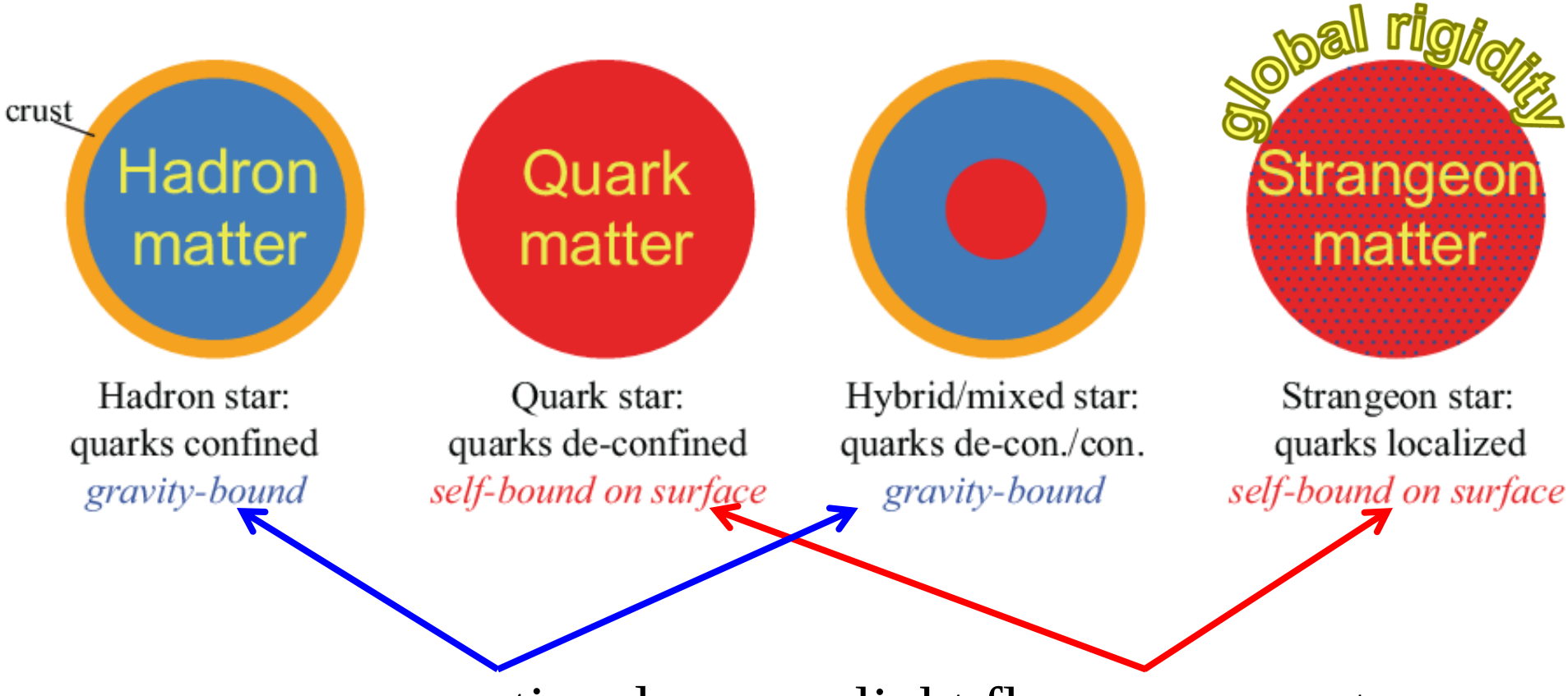
Strangeon Matter
(strangeon number ~ 10^{57} for star)

Strange ***Quark*** Matter
(quark number ~ 10^{57} for star)

strangeon['streɪdʒɪɒn]= **strange** + nucle**on** with strangeness $S = -B$

Strangeness manifested: Strangeon!

- Different models of pulsar's nature in the market



conventional
Neutron Star

light flavour symmetry:
Strange Star

Strangeness manifested: Strangeon!

Mon. Not. R. Astron. Soc. **398,** L31–L35 (2009) doi:10.1111/j.1745-3933.2009.00701.x

Lennard-Jones quark matter and massive quark stars

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Accepted 2009 June 16. Received 2009 June 8; in original form 2009 May 17

ABSTRACT

Quark clustering could occur in cold quark matter because of the strong coupling between quarks at realistic baryon densities of compact stars. Although one may still not be able to calculate this conjectured matter from the first principles, the intercluster interaction might be analogized to the interaction between inert molecules. Cold quark matter would then crystallize in a solid state if the intercluster potential is deep enough to trap the clusters in the wells. We apply the Lennard-Jones potential to describe the intercluster potential and derive the equations of state, which are stiffer than those derived in conventional models (e.g. MIT bag model). If quark stars are composed of the Lennard-Jones matter, they could have high maximum masses ($>2\,M_\odot$) as well as very low masses ($<10^{-3}\,M_\odot$). These features could be tested by observations.

NR & hard core

→ **Stiff** EoS

Surface self-bound

→ **Low** mass

Strangeness manifested: Strangeon!

Any tests independent?

Strangeness manifested: Strangeon!

- To understand observations with strangeon star

	Peculiarity	Manifestation	Mechanism	Ref.
surface	binding energy.	drifting subpulse, μstructure	gap sparking in RS75	Xu et al. (1999), Yu & Xu (2011)
		clean fireball for SNE/SGR	photon-driven explosion	Chen et al. (2007), Dai et al. (2011)
	self-bound	mass as low as ~$10^{-2}M_\odot$	bound not by gravity	Xu & Wu (2003), Xu'05, Li et al.'15
	none-atomic X	Plankian radiation of X-ray	no-atmosphere if bare	Xu (2002)
		absorption in thermal spec.	hydrodynamics of e-sea	Xu et al. (2012)
	strangeness bar.	low-z emission, type-I XRB	$2f$ matter separated from $3f$	Xu (2014)
		optical/UV exce. of XDINS	bremsstrahlung radiation	Wang et al. (2017)
global	stiff EoS	high $M_{\rm max}$ ($2\sim3M_\odot$)	NR strangeons, hard core	Lai et al. (09ab, 13) Guo et al. (2014)
	anisotropic P	SGR/AXP's burst and flare	quake-induced ener. release	Xu et al.'06, Zhou et al.'14, Lin et al.'16
	rigidity	precession, GW radiation	solid, mountain building	Xu (2003) Xu (2006)

Summary

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Conclusions

- Strangeness would play an important role in the physics of compact star, and thus a key to solve the EoS problem of dense matter.

- Strangeness could have three manifestations in compact stars: hyperon, strange quark matter, and strangeon.

- We proposed fourteen years ago that the nature of SN-produced compact star is strangeon star, which fits observations and …

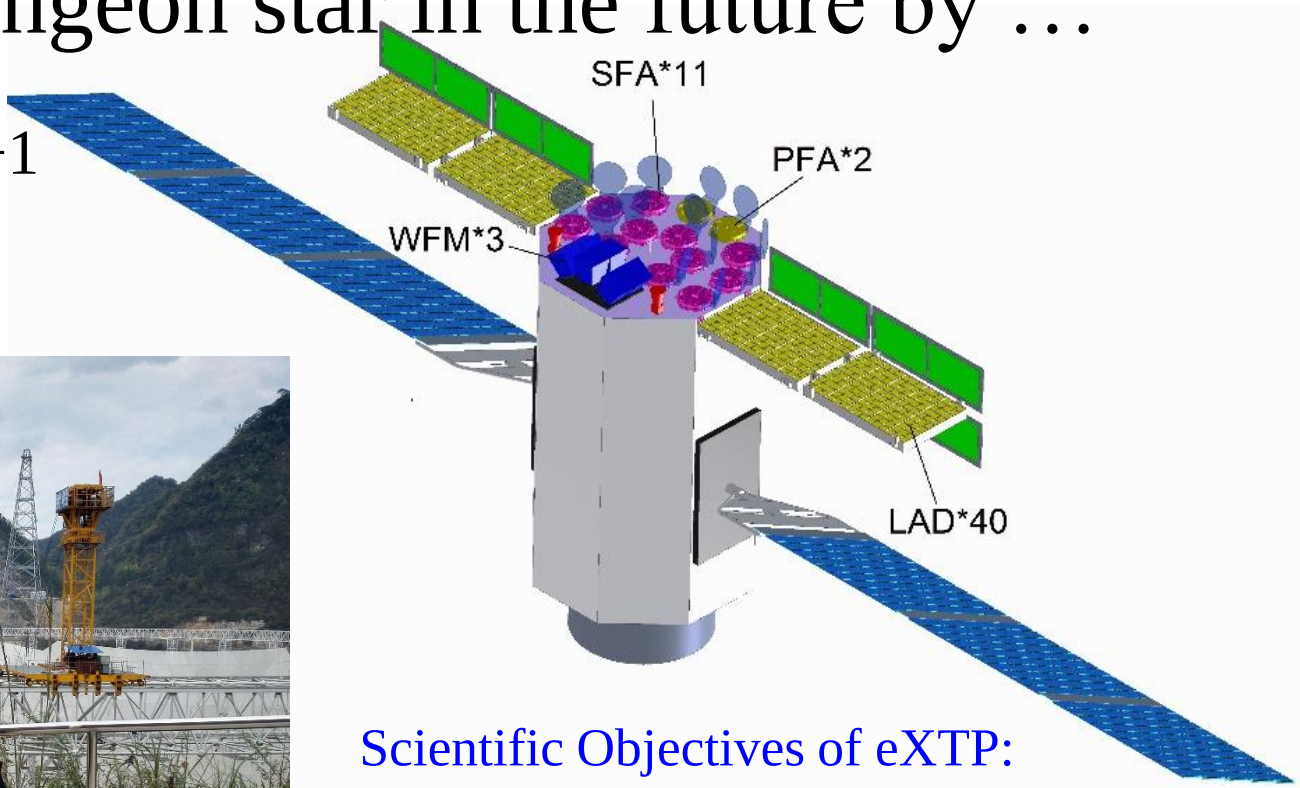
Conclusions

- To identify strangeon star in the future by …

Chinese FAST/SKA 2+1

"2" = HI & PSR

"1" = others



Scientific Objectives of eXTP:

One singularity (BH)

Two stars (NS or SS)

Three extremes (gravity, density, magnetism)

Strangeness哲学：诚邀英才加盟！

- 博士后：签约（2~3）年

  普通(9+?)万元/年（博雅18万）+ ~40m^2

  提前一个月递交材料评审，通过即可进站

- 博士生：直博5年，硕“申请-考核制”4年

  5000元/月

- 欢迎以联合培养、访问学者等参与(资薪)

r.x.xu@pku.edu.cn

THANKS!