

# What is a pulsar?

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“Pulsar Physics and the Application of Pulsar timing”

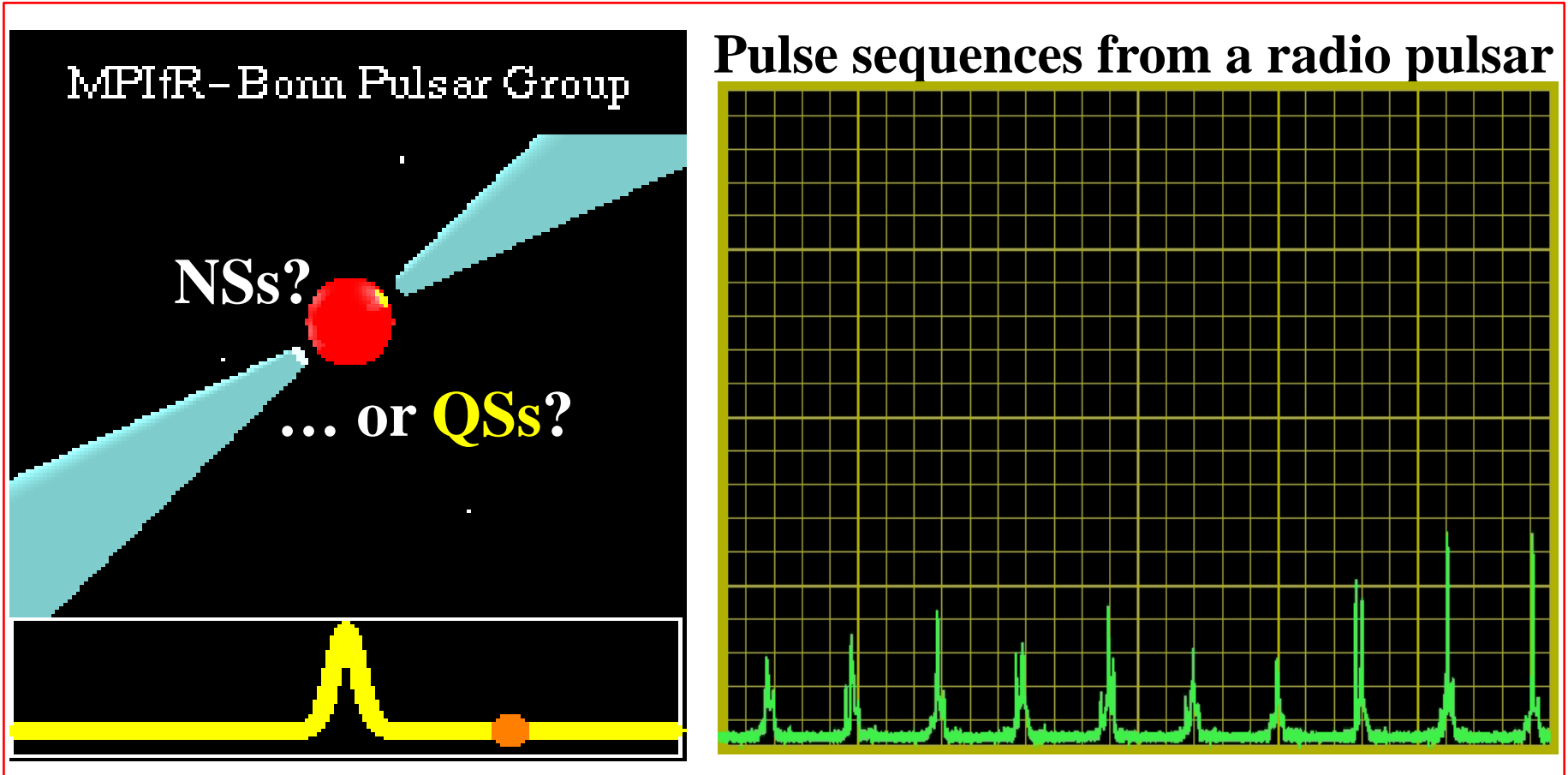
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# Summary

- **Observers: a pulsating star!**
- **Landau: a Gigantic Nuclei**
- **Physicists after 1932: a NS**
- **Physicists after 1960s: a QS?**
- **Conclusions**

# Observation: a pulsating star!

## Pulsars: cosmological lighthouse ...

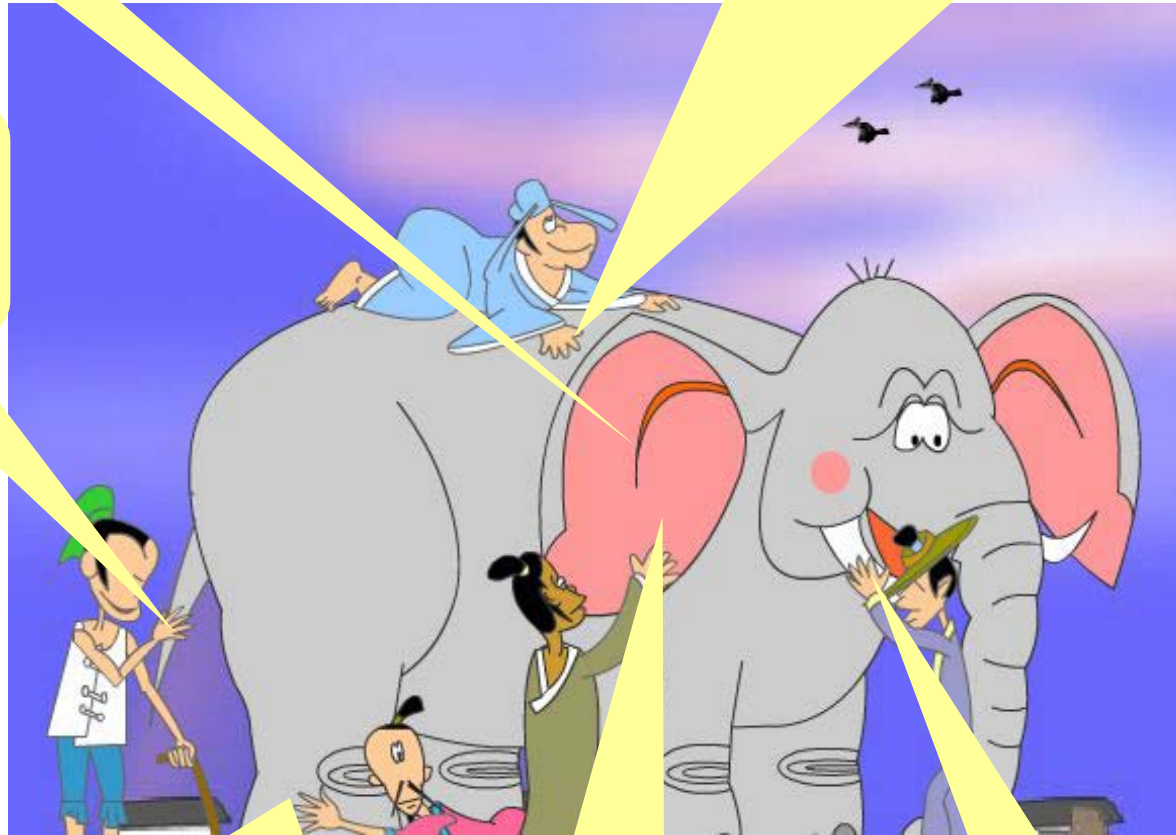


# Different manifestations of pulsar-like stars

RRATs

Accretion-powered X-ray pulsars  
/X-ray bursts

Central  
Compact  
Objects



What's  
a *real*  
'PSR'?

Dim thermal "Neutron" Stars

Radio  
Pulsars

AXPs/SGRs

"What's a PSR?"

<http://vega.bac.pku.edu.cn/rxxu>

R. X. Xu

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# Landau: a Gigantic Nuclei

## Landau's original idea of "gigantic nucleus"

- Rutherford (1920): expected "doublet" in a nucleus.



**Doublet** = *proton* + *electron*

(not hydrogen!!!)

$^{12}\text{C} = 6 \text{ protons} + 6 \text{ doublets}$

Harkins changed "**Doublet**" to "**Neutron**" in 1921.

- **What's** the energy sources of stars?

**What** if a WD mass  $> M_{\text{chandra}}$ ?

Landau (1931, Switzerland): published '32

A star has a **core** of gigantic nucleus:

**Gigantic nucleus** = *protons* + *doublets*

where QM doesn't work!



Lev Davidovich Landau (1908~1968)

"for his pioneering studies of the theory of the condensed state of matter and particularly of liquid helium." --- Nobel prize '62

# Landau: a Gigantic Nuclei

Landau { as a physicist in condense matter physics  
as an astrophysicist: *he did care this role!*

In 1937, in order to balance out his strong political pressure, Landau submitted and then published a paper to *Nature* (but, unfortunately, he was still sent to jail the next year!)

“Internal temperature of stars” 132, 567 (1933) (G Gamov)

“Scattering of light by light” 138, 206 (1936) (A I Akhieser and I Ya Pomeranchuk)

“Origin of stellar energy” 141, 333 (1938) ← (Sov. Phys., 1, 285, 1932) ←

“Production of showers by heavy particles” 140, 682 (1937) (G Rumer)

“The theory of phase transitions” 138, 840 (1936)

Brief message of “ZETF 7(1937) 19,627; Phys. Z. Sowj. 11(1937) 26, 545”

“The intermediate state of supraconductors” 141, 688 (1938)

Brief message of “Zh.Eksp. Teor. Fiz. 13 (1943) 377; J. Phys. USSR 7 (1943) 99”

6 *Nature* papers published, but 3 by him *independently!*

# Landau: a Gigantic Nuclei



James Chadwick

“for the discovery of  
the neutron”  
--- Nobel prize '35

- Chadwick's discovery of neutron in '32  
Certainly, a matter composed by  $p$  and  $n$  should have to be *neutron-rich* because of  $e$  inside!



Gigantic Nuclei = Neutron (rich) Star

- Baade & Zwicky in '34: NS after SN!



*Walter Baade*  
*Fritz Zwicky*





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- **Physicists after 1960s: a QS?**
- **Conclusions**

# Physicists after 1932: a NS?

- **Detail NS is then modeled by physicists ...**  
assuming hadrons (e.g.,  $p$  and  $n$ ) are point-like *structureless* particles!

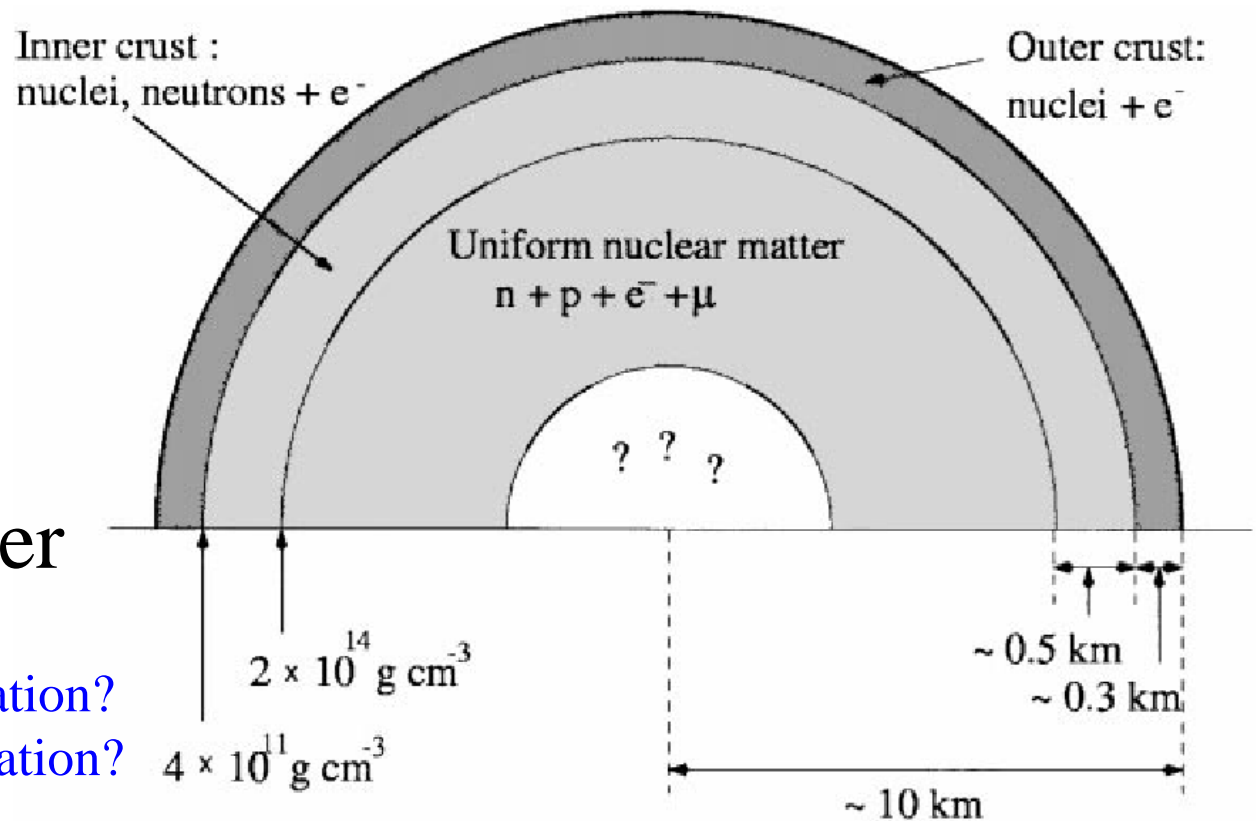
➤ Atmosphere

➤ Outer crust

➤ Inner crust

➤ Neutron matter

➤ Core? hyperons?  
 $\pi$ -condensation?  
K-condensation?



Heiselberg 2002

# Physicists after 1932: a NS?

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... and ... most of astronomers are trying to understand observations by borrowing this conventional model.

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# Physicists after 1960s: a QS?

... but, hadrons are NOT point-like!



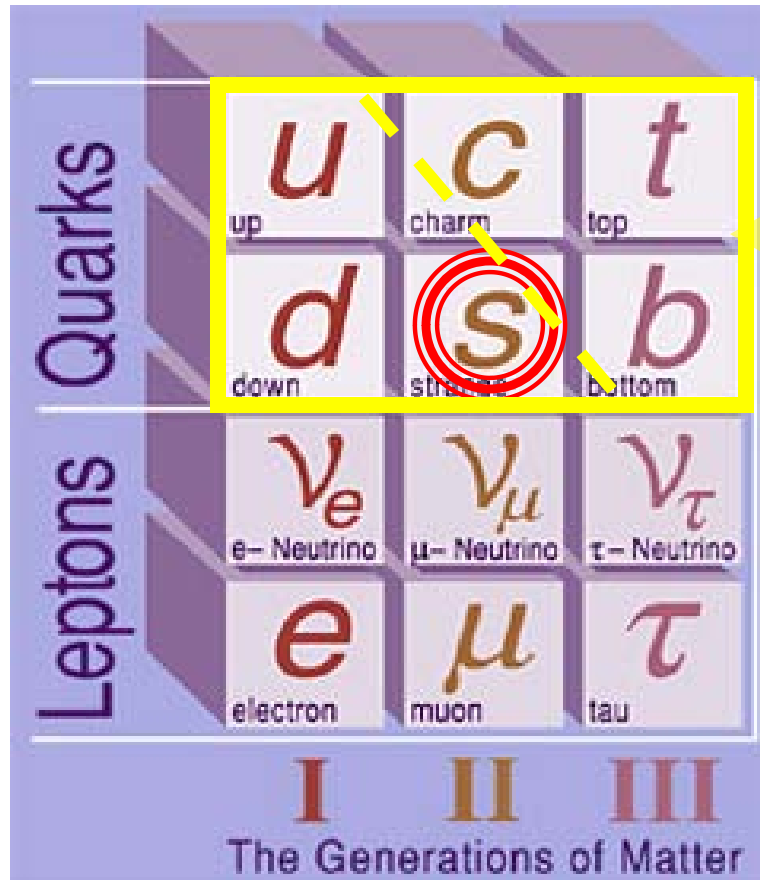
Quarks?

- 1950s~1960s: A success in the *classification of hadrons* discovered in cosmic rays and in accelerators
- ***M. Gell-Mann*** (1964): Quarks? - --- in *mathematical description*, rather than in reality.
- ***Zweig, Chinese group*** (1960s): *in reality?*
- 1973: SU(3) non-Abelian gauge theory  $\Rightarrow$  *asymptotic freedom*
- *Experimental evidence* for the last flavor of quark (***t***) in 1990s

*Murray Gell-Mann*  
M. Gell-Mann

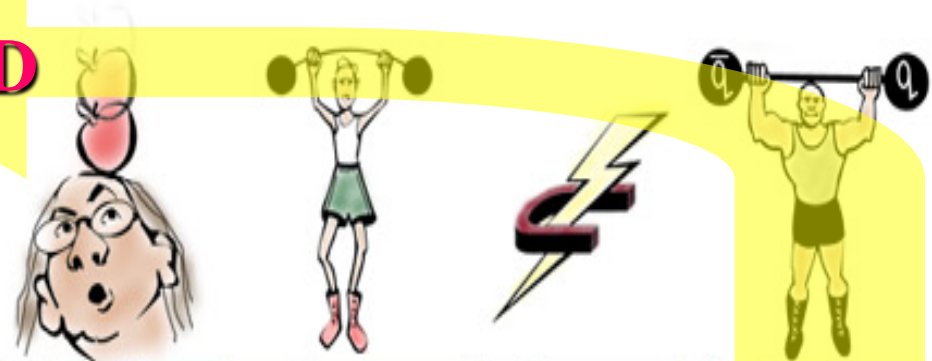
# Physicists after 1960s: a QS?

- The standard model of particle physics



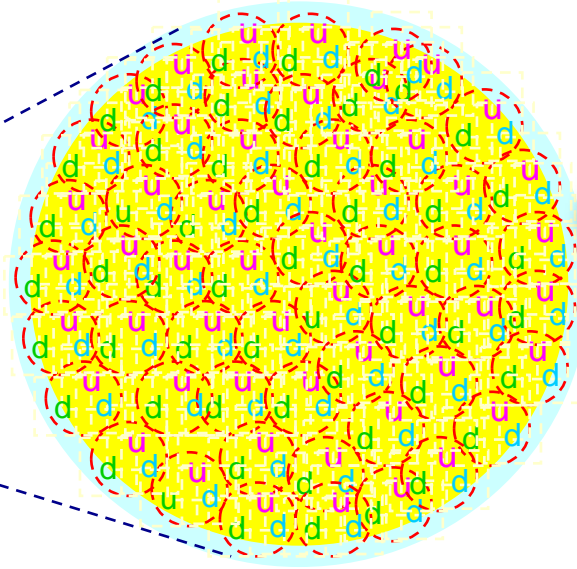
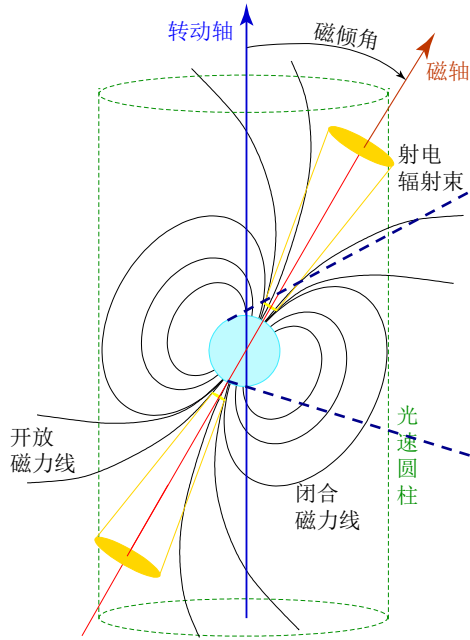
## Interaction via gauge bosons

QCD



	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	$W^+$ $W^-$ $Z^0$	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and $W^+$ $W^-$	Quarks and Gluons

# Physicists after 1960s: a QS?



Landau's  $n$ -rich gigantic nucleus

- Liquid? *Solid*?
- Still only *three* quarks grouped?
- *Quark*-degree still negligible?
- More flavors? (*strange* flavor)

*'Thomson atom'!*

What's the *difference* between daily life nuclei and the "gigantic" ones?

- *Electrons* are included in gigantic nuclei but not in normal nuclei due to **large scale**
- NSs at *supra-nuclear density* (a few nuclear saturation densities) due to **gravity**

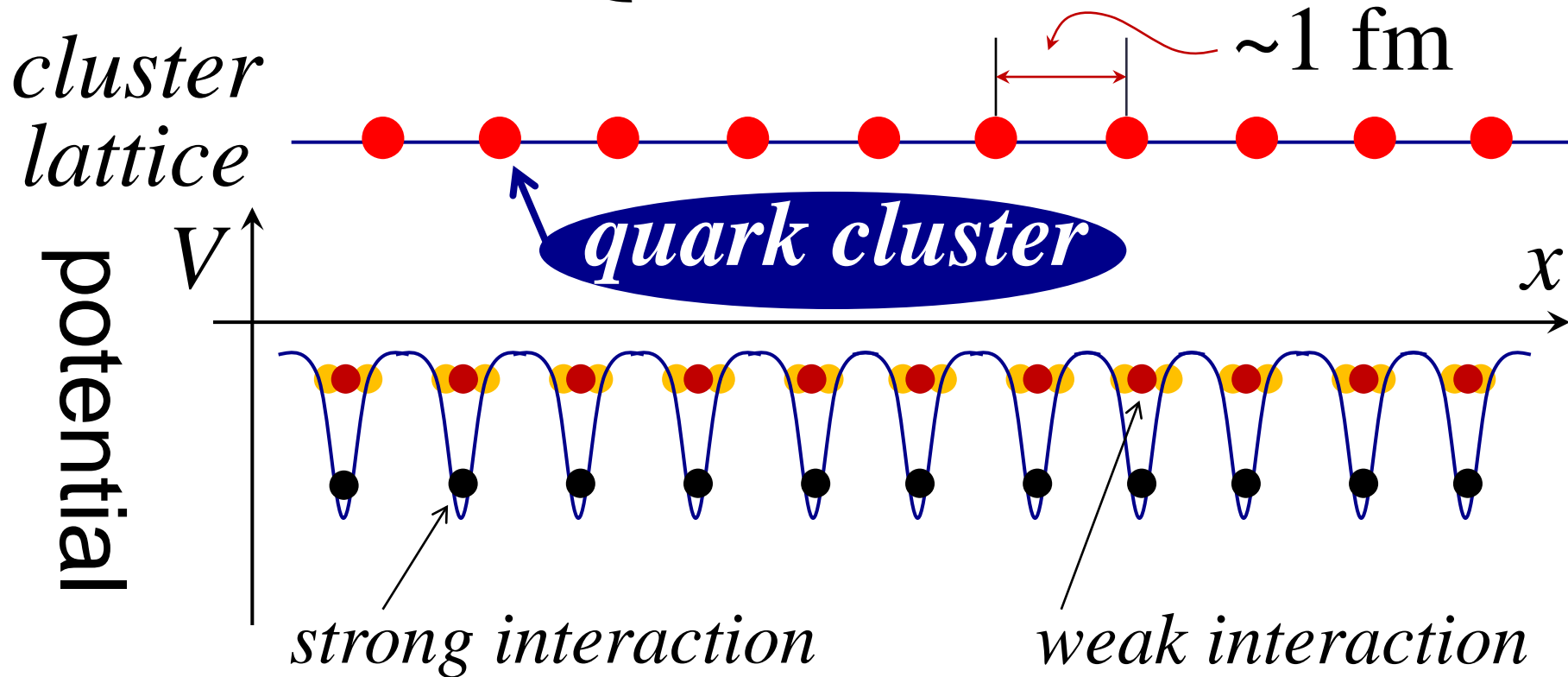
Questions relevant to the gigantic nuclei:

- Still only two *flavors* participated? → strangeness?
- Still only three *quarks grouped*? →  $n$ -quark clusters?
- Still in Gamow's *liquid drop* state? → solid?

***My gigantic nuclei:***  
solid quark (clustering) stars!

# Physicists after 1960s: a QS?

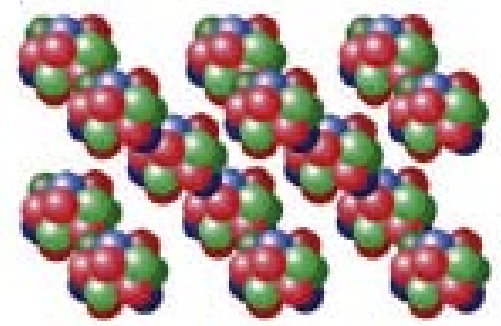
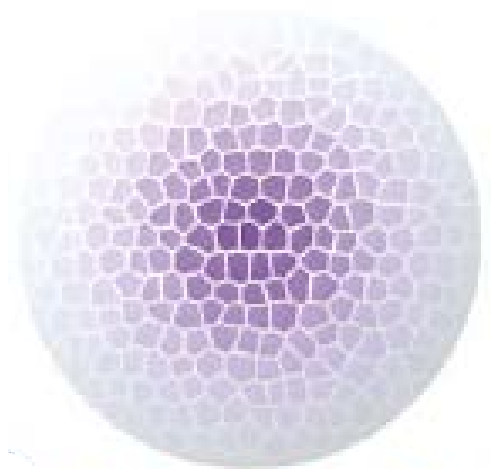
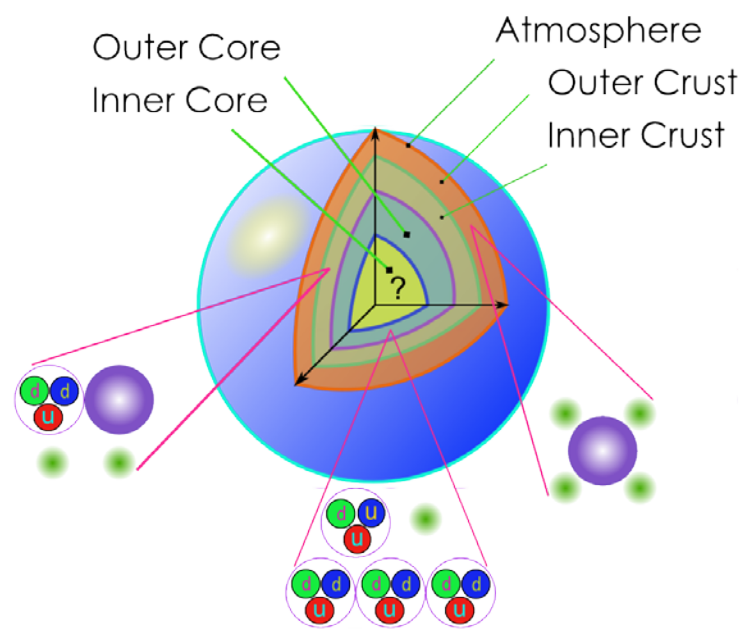
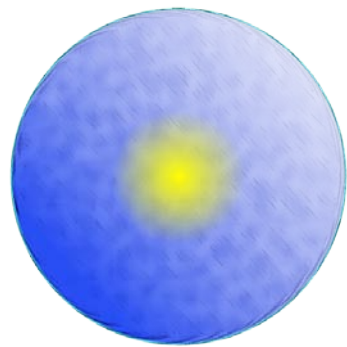
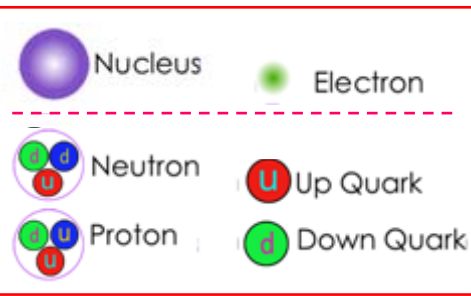
- The *state* of QM: *solid*?



- *Classical solid*: barrier penetration *negligible*
- *Quantum solid*: penetration *significant*



# Three “neutron stars”: old and new



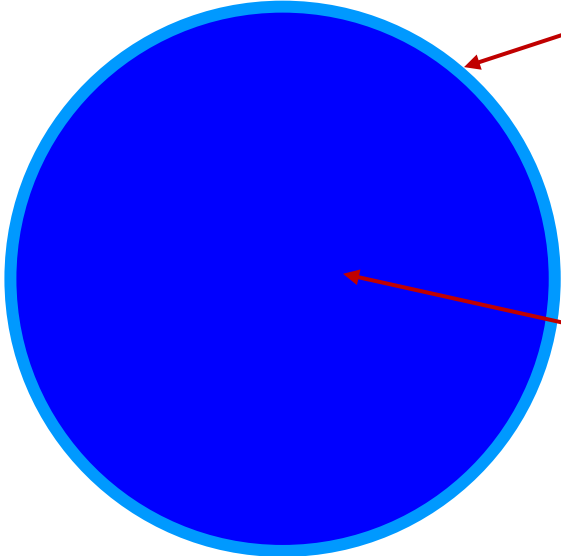
“Gigantic nucleus”  
proposed by  
Landau in 1931

Normal  
neutron star

“Neutron” star:  
*quark*-clustering  
matter (QM)?

# Quark stars in astrophysics

Any essential *differences* between NSs and solid QSs?



- *Surface*: self- or gravity- *confined*?
- *Global*: Eggs: Raw or Cooked ?  
complete or partial *solid*?

**NR** → stiff *EoS*? (**ER**: soft!)  
idea gas:  
 $P = (1/3) \rho^1$

$E = (c^2 p^2 + m^2 c^4)^{1/2} \sim p^2 \rightarrow P \sim \rho^\gamma$   
( $\gamma > 1!$ )

# Physicists after 1960s: a QS?

Any essential *differences* between ...?

- Subpulse drifting: binding energy problem!
- Nonatomic spectra of isolated neutron stars
- Clean fireball for SNE & GRB?

• *Surface*:

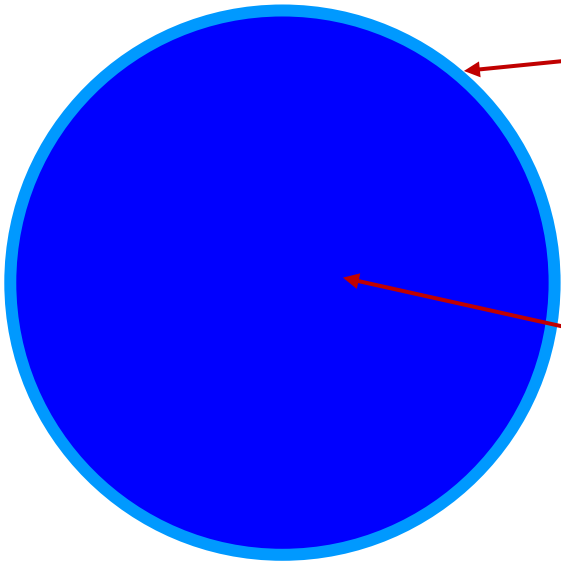
self- or gravity- *confined*?

• *Global*:

complete or partial *solid*?

**NR** → stiff (**ER**: soft!) *EoS*?

- 2- $M_{\text{sun}}$  NS: A stiffer equation of state
- Rigidity-like body: precession Pulsars (B1821-11)?
- Gravitational & elastic free energy: quake-induced fireballs?
- Consequence for Fermi: Non-detection of AXP!
- Consequence for LIGO?



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✓ *Conclusions*

# Conclusions

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**Question:** *What is a pulsar?*

**Answer:** *It is a quark (clustering) star.*

(ie. *a gigantic nuclei* in Landau's words)

*Thank you !*

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