What is a pulsar?

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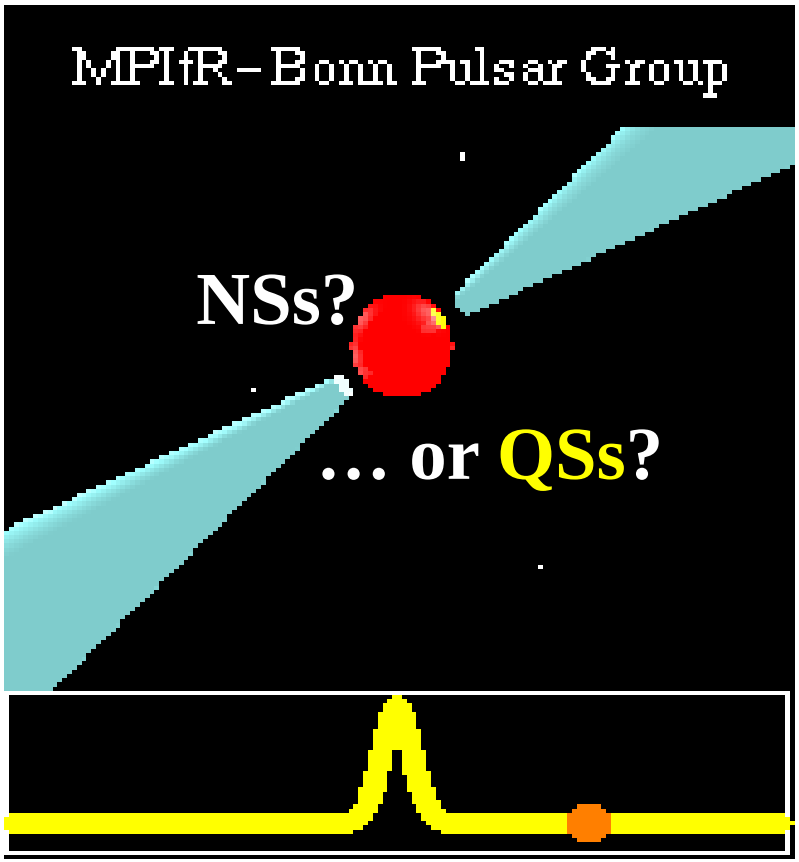
Summary

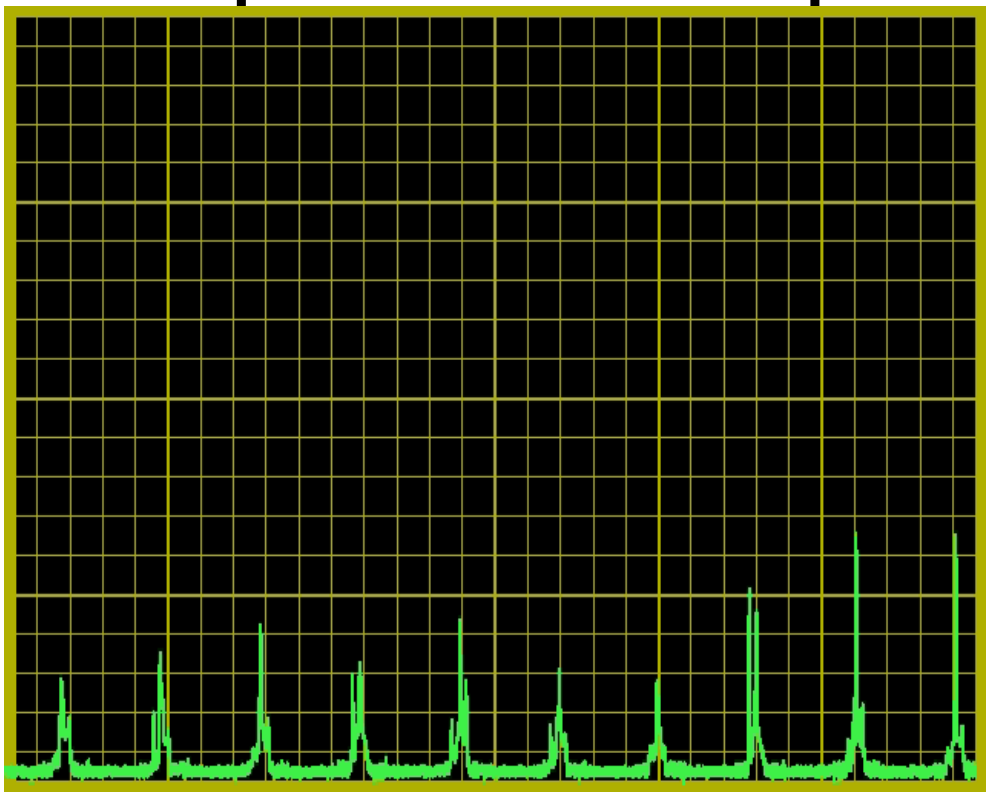
- **Observers: a pulsating star!**
- **Landau: a Gigantic Nuclei**
- **Physicists after 1932: a NS**
- **Physicists after 1960s: a QS?**
- **Conclusions**

Observation: a pulsating star!

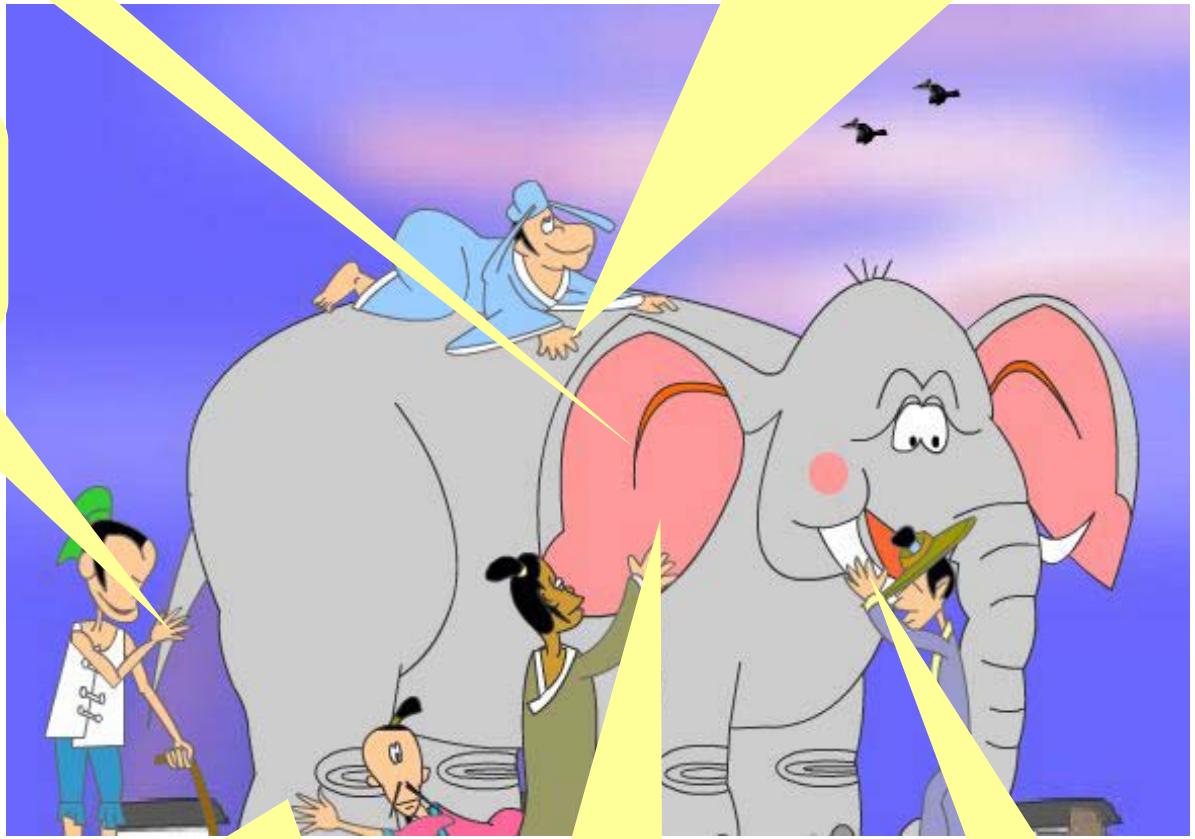
Pulsars: cosmological lighthouse ...



Pulse sequences from a radio pulsar



Different manifestations of pulsar-like stars



RRATs

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

Central Compact Objects

Dim thermal "Neutron" Stars

Radio Pulsars

AXPs/SGRs

What's a *real* 'PSR'?

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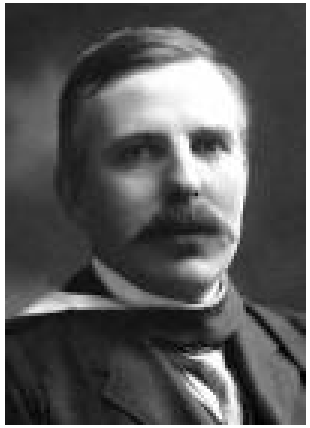
Landau: a Gigantic Nuclei

Landau's original idea of "gigantic nucleus"

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



Doublet* = *proton* + *electron

(not hydrogen!!!)

^{12}C = 6 protons + 6 doublets

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

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

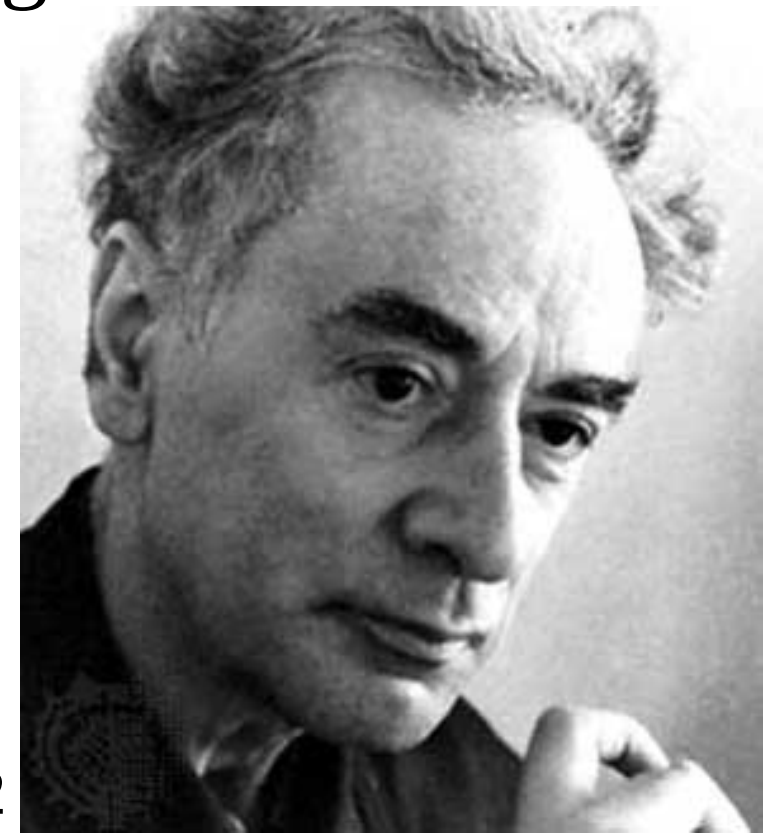
  What if a WD mass > $M_{chandra}$?

  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

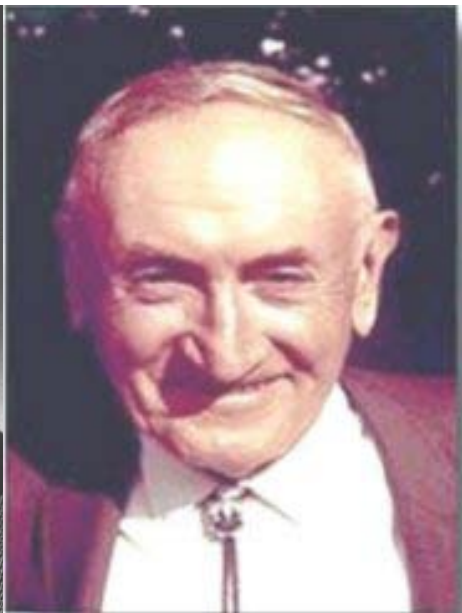
- Chadwick's discovery of neutron in '32

  Certainly, a matter composed by ***p*** and ***n*** should have to be ***neutron-rich*** because of ***e*** inside!

$$p + e \rightarrow n + \nu_e$$

Gigantic Nuclei = Neutron (rich) Star

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



Walter Baade
Fritz Zwicky

Summary

- **Observers: a pulsating star!**
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- ✓ ***Physicists after 1932: a neutron star***
- **Physicists after 1960s: a QS?**
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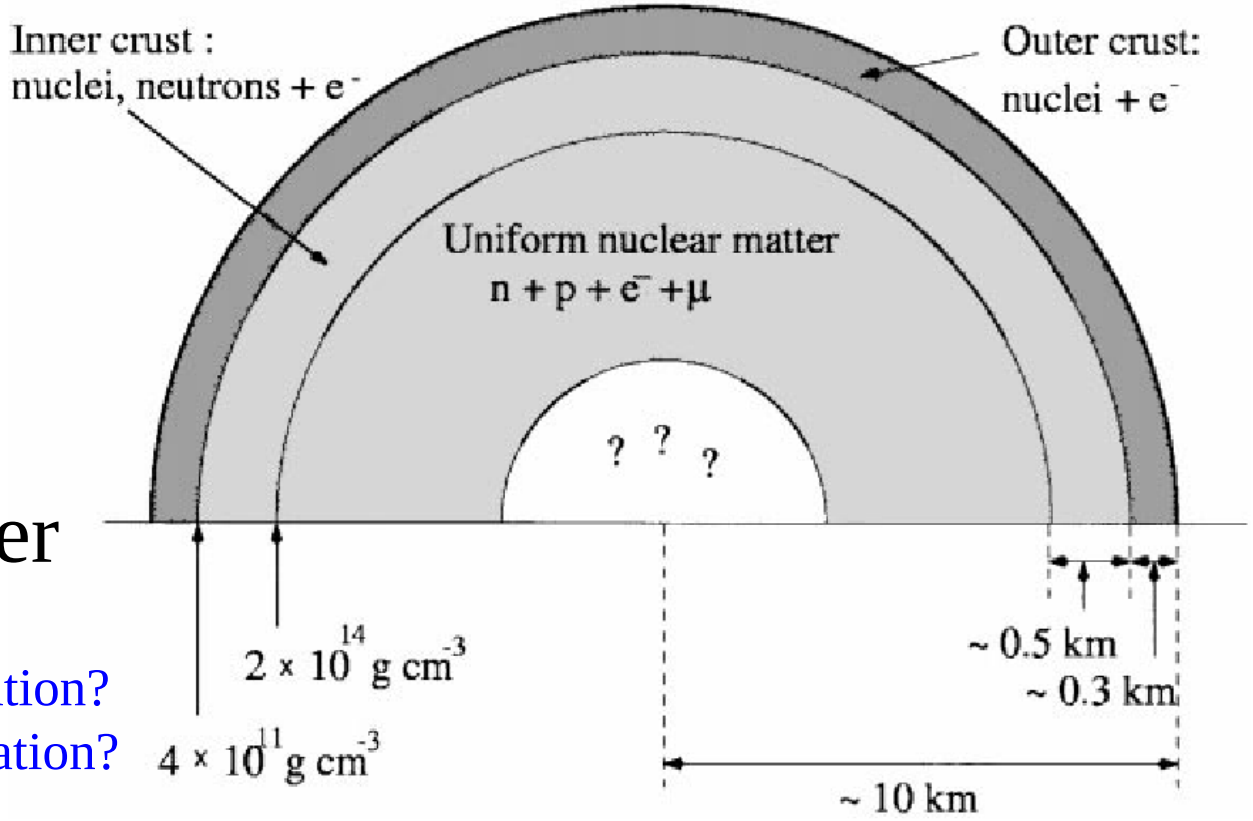
Physicists after 1932: a NS?

- **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? π-condensation? K-condensation?



Heiselberg 2002

Physicists after 1932: a NS?

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

Summary

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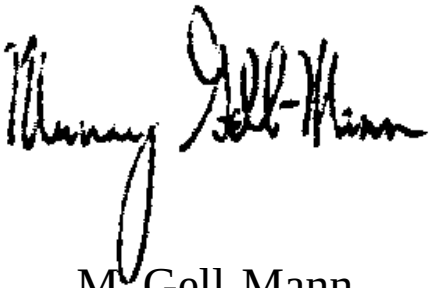
Physicists after 1960s: a QS?

… but, hadrons are NOT point-like!

Quarks?

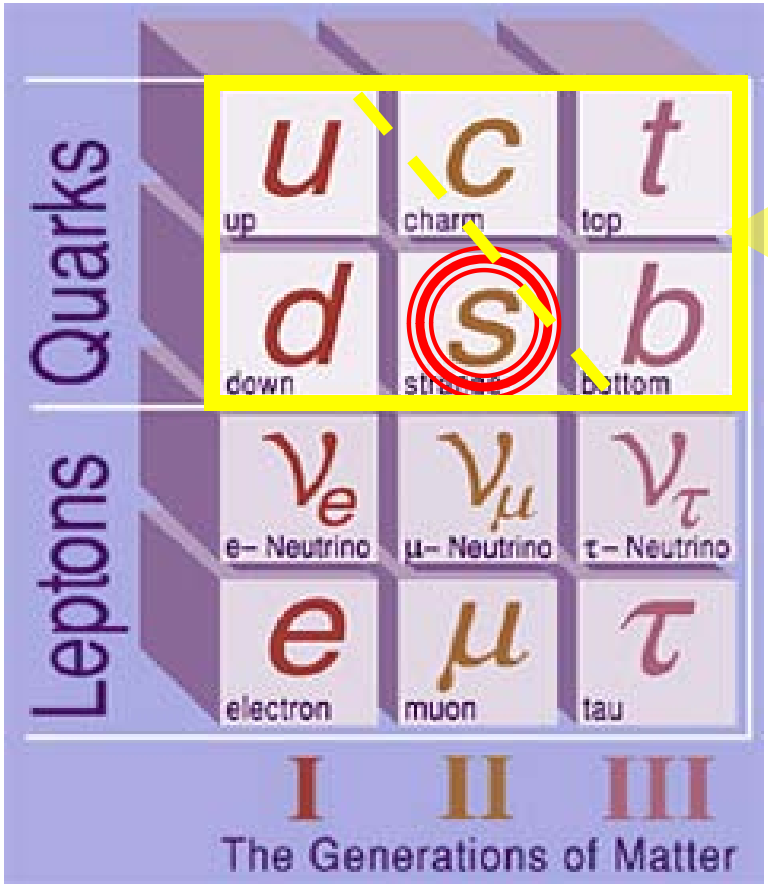


M. Gell-Mann

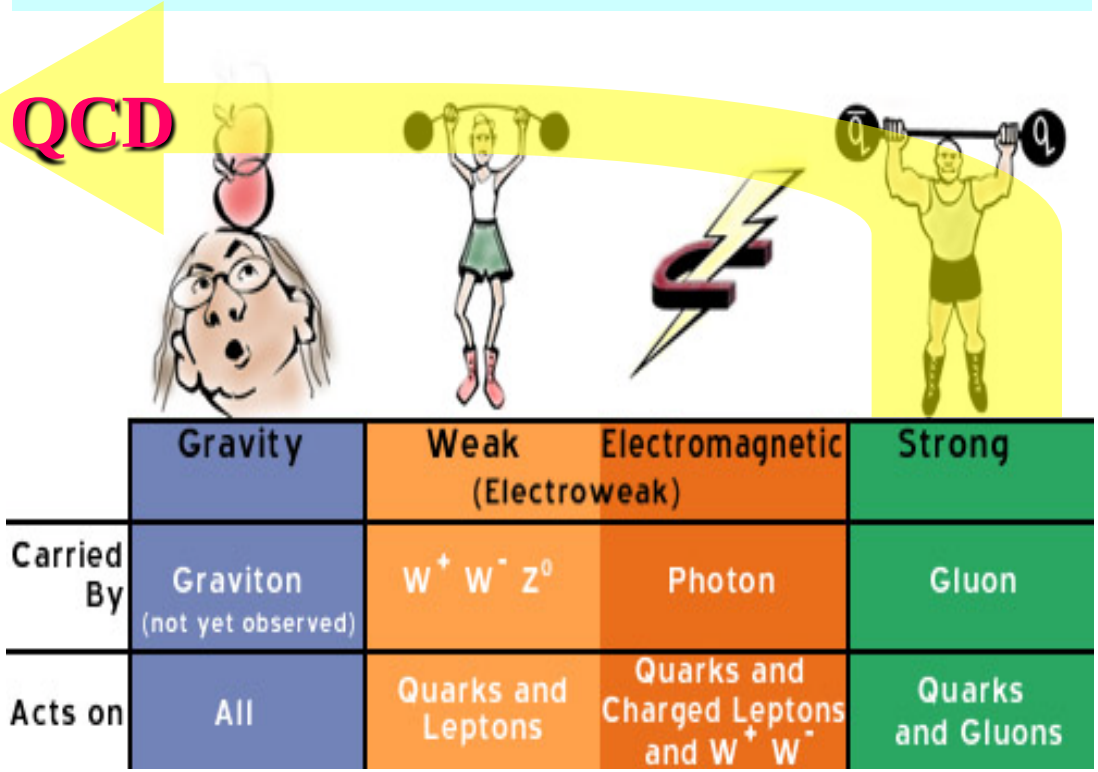
- 1950s~1960s: A success in the *classification of hadrons* discovered in cosmic rays and in accelerators
- ***M. Gell-Mann*** (1964): Quarks? ---- in *mathematical description*, rather than in reality.
- ***Zweig***, ***Chinese group*** (1960s): *in reality?*
- 1973: SU(3) non-Abelian gauge theory ⇒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

Physicists after 1960s: a QS?

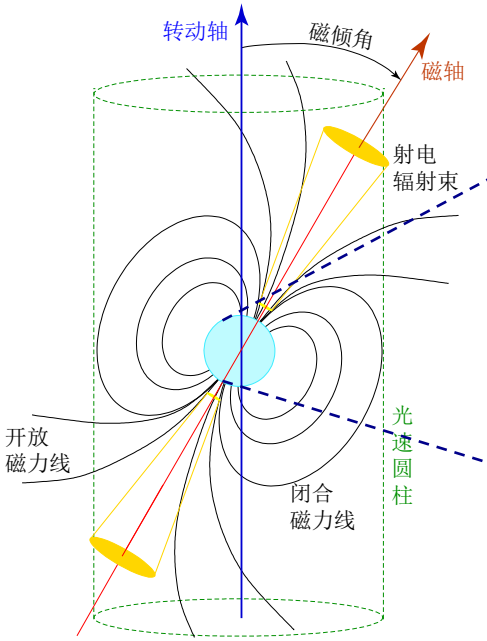
- **The standard model of particle physics**

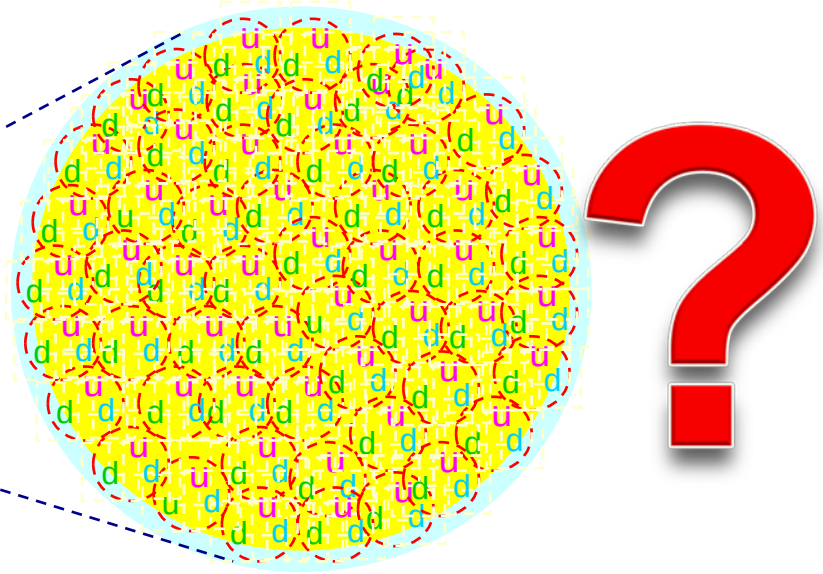


Interaction via gauge bosons



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**

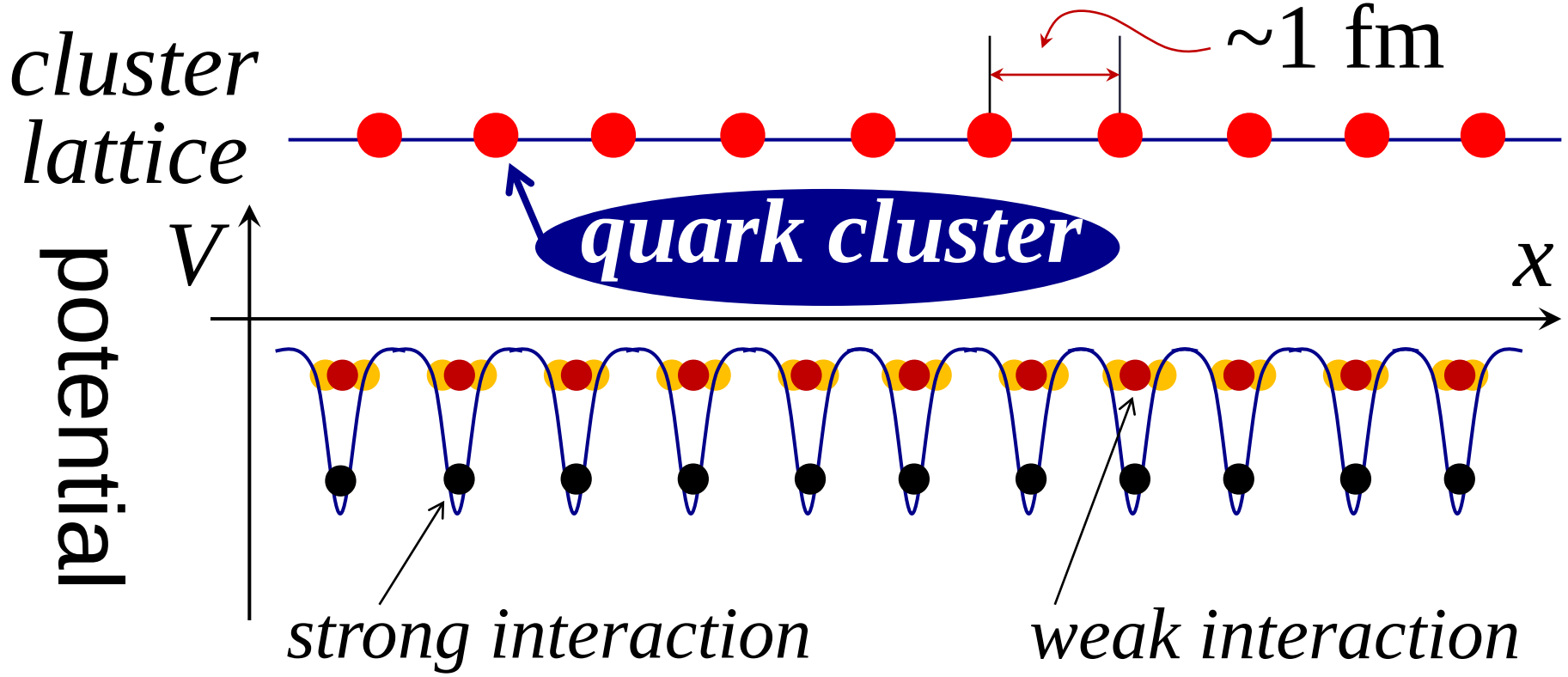
Questions relevant to the gigantic nuclei:

- 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!

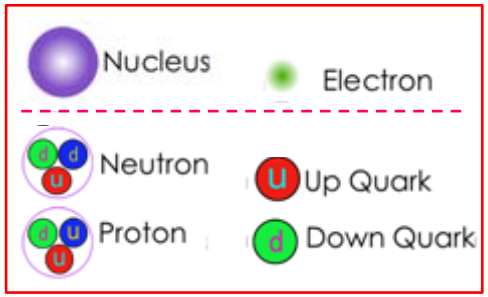
Physicists after 1960s: a QS?

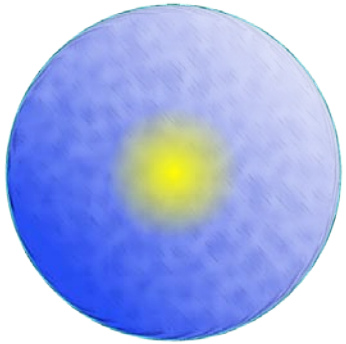
- The ***state*** of QM: ***solid***?

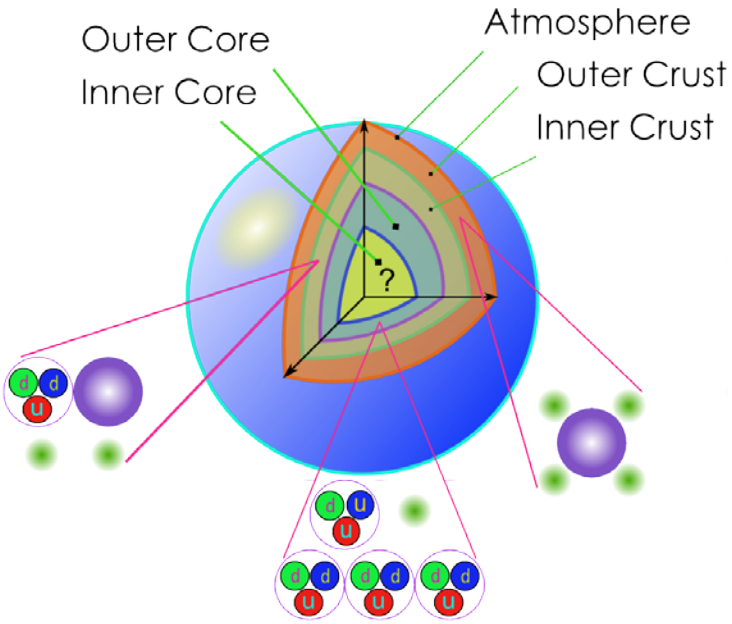


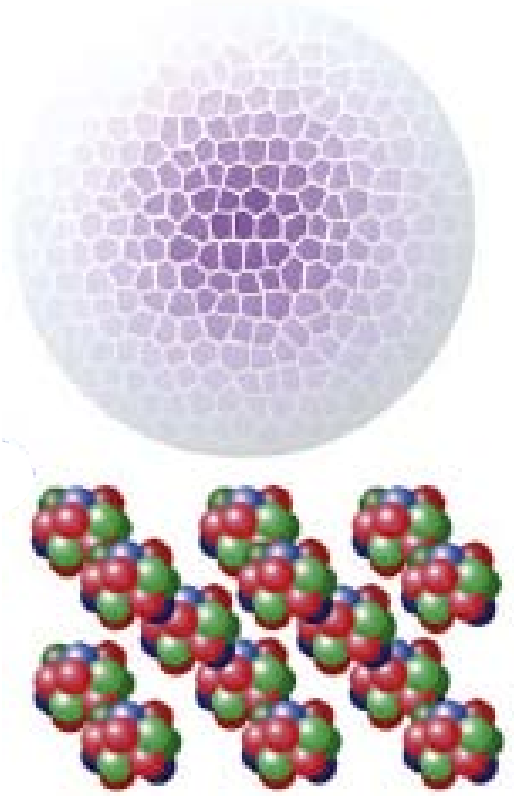
- *Classical solid*: barrier penetration *negligible*
- *Quantum solid*: penetration *significant*

Three “neutron stars”: old and new









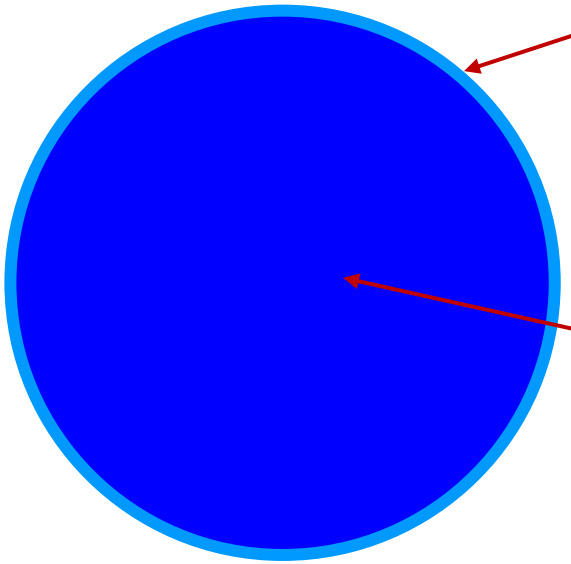
“Gigantic nucleus” proposed by Landau in 1931

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***: complete or partial ***solid***?

Eggs: Raw or Cooked ?

NR $\rightarrow$ stiff ***EoS***? (**ER**: soft!)

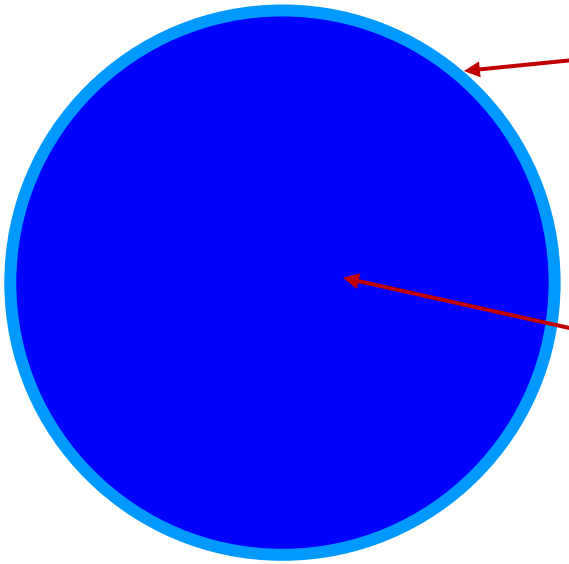
$E = (c^2p^2+m^2c^4)^{1/2} \sim p^2 \rightarrow P \sim \rho^{\gamma}$ ($\gamma > 1$!)

idea gas: $P = (1/3)\,\rho^1$

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 $\rightarrow$ stiff (**ER**: soft!) ***EoS***?

- 2-M_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

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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