Pulsars could be ***strangeon*** stars

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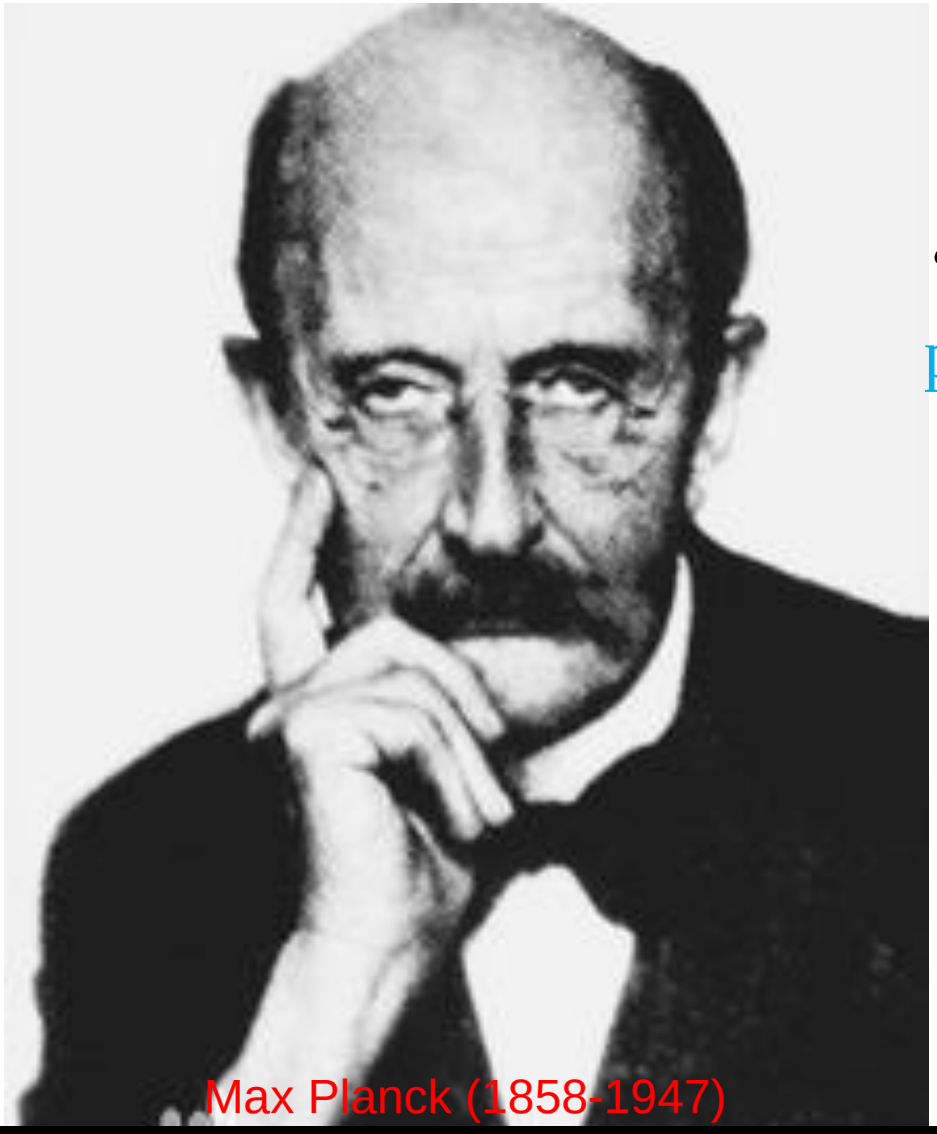
Pulsars could be strangeon stars

Human civilization:

from ***matter*** to ***atom***

Civilized by Understanding ***Matter***

Civilized by Understanding ***Matter***


Max Planck (1858-1947)

"atomism/ realism"

vs.

"energism/ positivism"

Ludwig Boltzmann ***vs.*** Wilhelm Ostwald


(1844-1906)


(1853-1932)

scientific materialism

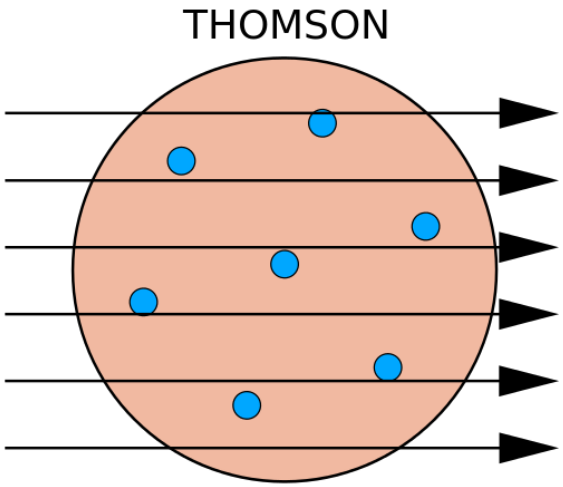
metaphysical interpretation

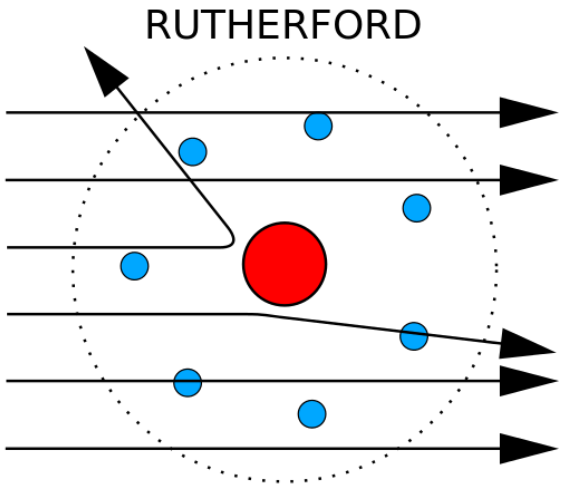
"A scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a ***new generation grows up that is familiar with it***."

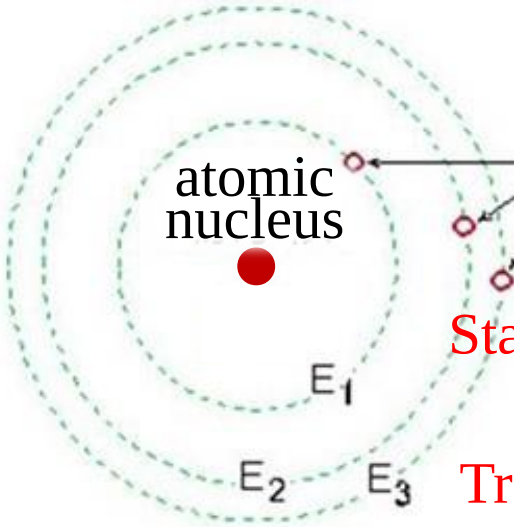
"***Planck's Law***"

Civilized by Understanding ***Matter***

- 1911: Rutherford model, 1913: Bohr model







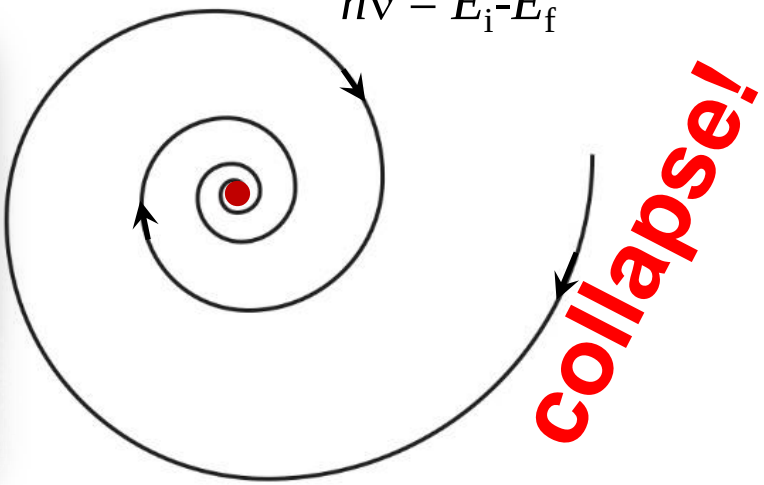
***E*-levels**

Stationary states

($mvr = n\hbar$)

Transition

$h\nu = E_i - E_f$

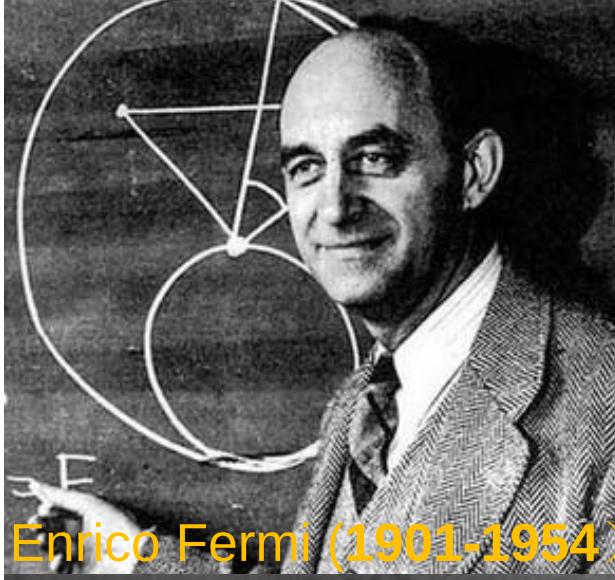


Matrix mechanics (1925) Wave mechanics (1926)

Werner Karl Heisenberg (1901-1976)

Erwin Schrödinger (1887-1961)


Wolfgang E.Pauli (1900-1958)

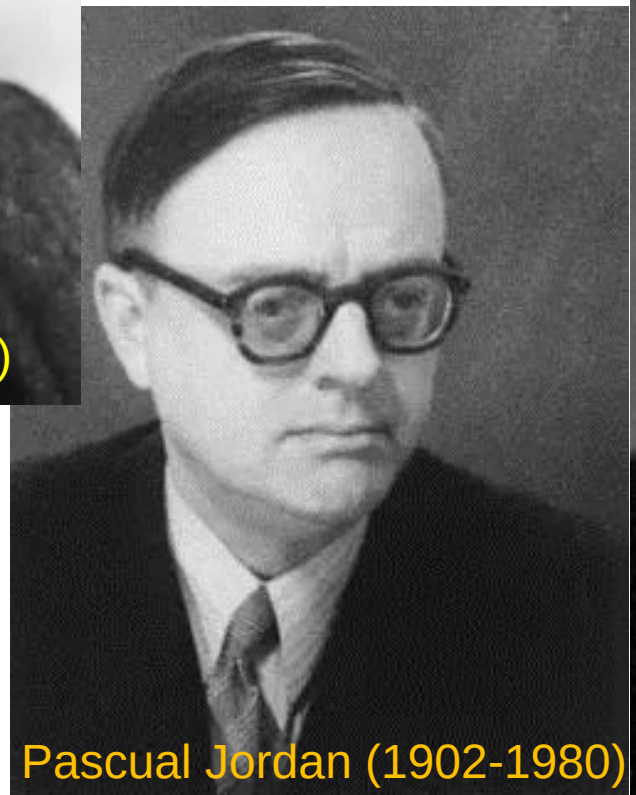

Enrico Fermi (1901-1954)

1925:

Pauli statistics?

1926:

FD statistics!


Pascual Jordan (1902-1980)


Paul Dirac (1902-1984)

The Birth of *New* Statistics

- FD statistics: Fowler, Sommerfeld, Chandrasekhar, Landau…

On Dense Matter. By R. H. Fowler, F.R.S.

Fowler (1926)

§ 1. *Introductory.*—The accepted density of matter in stars such as the companion of Sirius is of the order of 10^5gm./c.c. This large density has already given rise to most interesting theoretical considerations, largely due to Eddington. We recognise now that matter can exist in such a dense state if it has sufficient *energy*, so that the electrons are not bound in their ordinary atom… are in the main free—with sufficie… they may be near. The density … only limited *a priori* by the "siz… The "volumes" of these are perh… sponding atoms, so that densities … materials may not be impossible. … are of an altogether lower order o… by the "sizes" of the nuclei and e… of stellar densities, and the struc… be treated as massive charged poi…

Eddington has recently * poin… such matter. Assuming it to beh…

1928 autumn: Sommerfeld lectured at Presidency College, meeting Chandra.

(1910-1995)

Zur Elektronentheorie der Metalle auf Grund der Fermischen Statistik.

Sommerfeld (1928)

I. Teil: Allgemeines, Strömungs- und Austrittsvorgänge.

Von **A. Sommerfeld** in München.

Mit 4 Abbildungen. (Eingegangen am 17. Dezember 1927.)

In § 1 werden die Grundlagen der neuen Statistik, der Bose-Einsteinschen sowie der Fermi-Diracschen entwickelt, im … einfachter und erweiterter Form. § 2 … Hilfsmitt… Unterscl… klassisch… s zur Ge… Elektron… erung un…

The Compton Scattering and the New Statistics.

By S. CHANDRASEKHAR, The Presidency College, Madras.

(Communicated by R. H. Fowler, F.R.S.—Received June 20, 1929.)

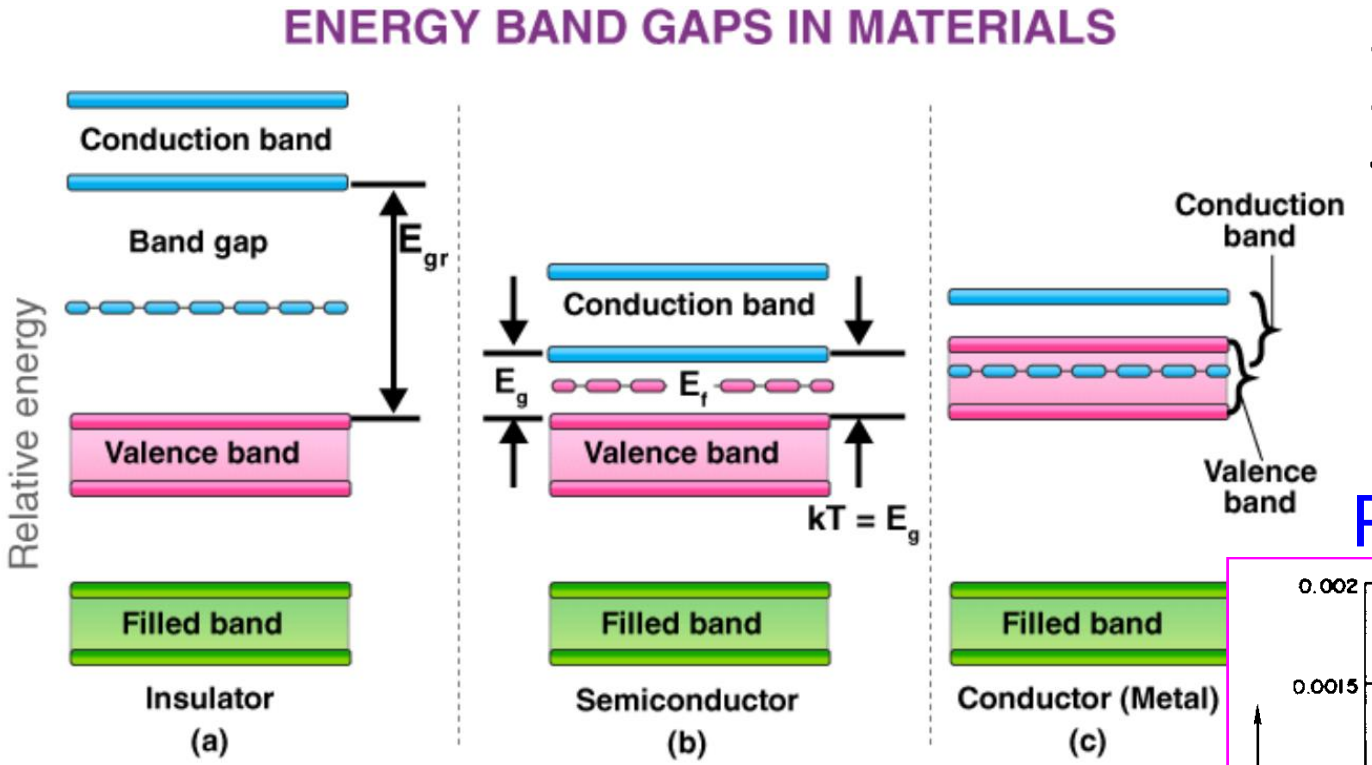
Chandrasekhar (1929)

1. *Introduction.*

Great success has been achieved by Sommerfeld in the electron theory of metals by assuming that there are free electrons in them which obey the Fermi-Dirac statistics. It has been assumed in the case of univalent metals that on the average one electron per atom is free. In general, however, the valency electrons can be considered as free.* These free electrons will take part in the Compton scattering. The analysis of such a Compton effect

The Birth of *New* Statistics

- Band; insulator, semi/conductor, superconductor

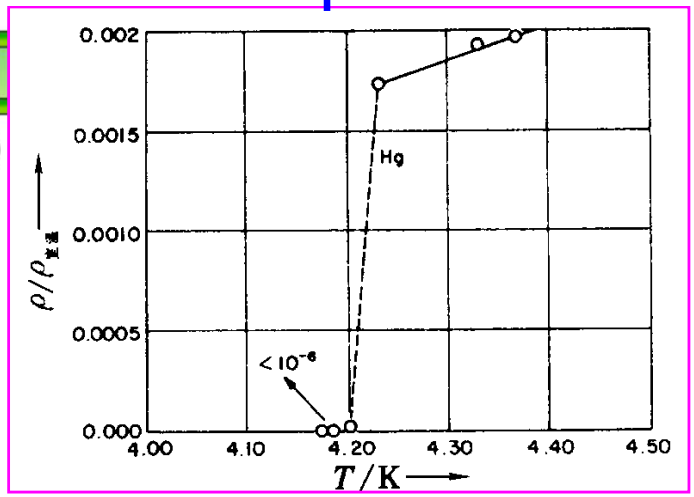


material world

Zero resistance

Meissner effect

Flux quantization



1911: Kamerlingh Onnes (1853-1926)

BCS!

Strong correlation between electrons?

The Birth of *New* Statistics

- the **Material world**: ***strong*** besides ***electric***?

electric matter

interaction inbetween ***electric***magnetic

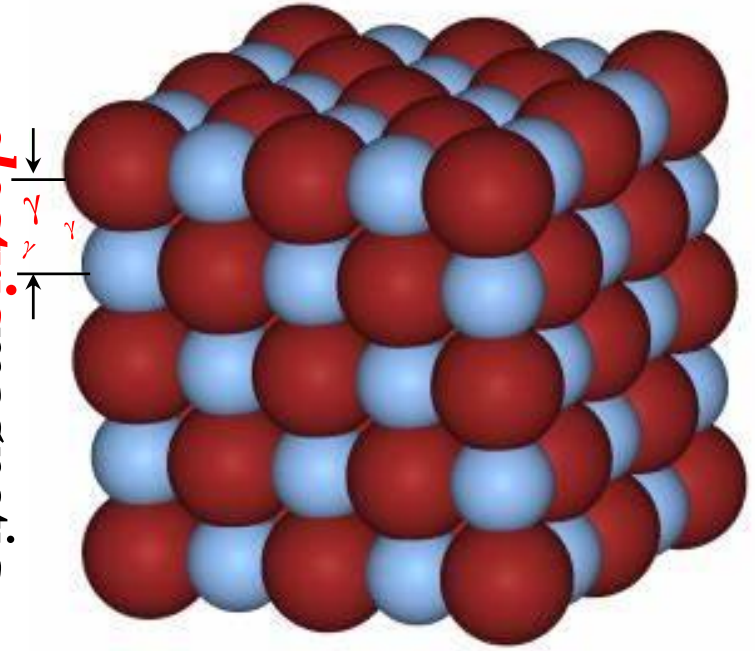
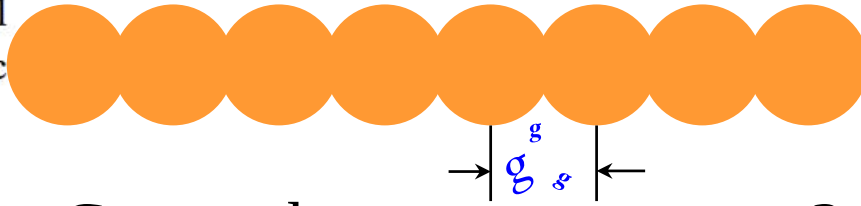


FIGURE 1 A rock containing copper (Malachite). Normal atom matter at pressure free is condensed by the electromagnetic (or simply electric) force, while the strangeon matter, to be explained in §6, is by the fundamental strong interaction. Multiscale forms can exist for both kinds of condensed matter, the electric and the strong ones

Xu (2023)



Can we have ***strong*** matter?

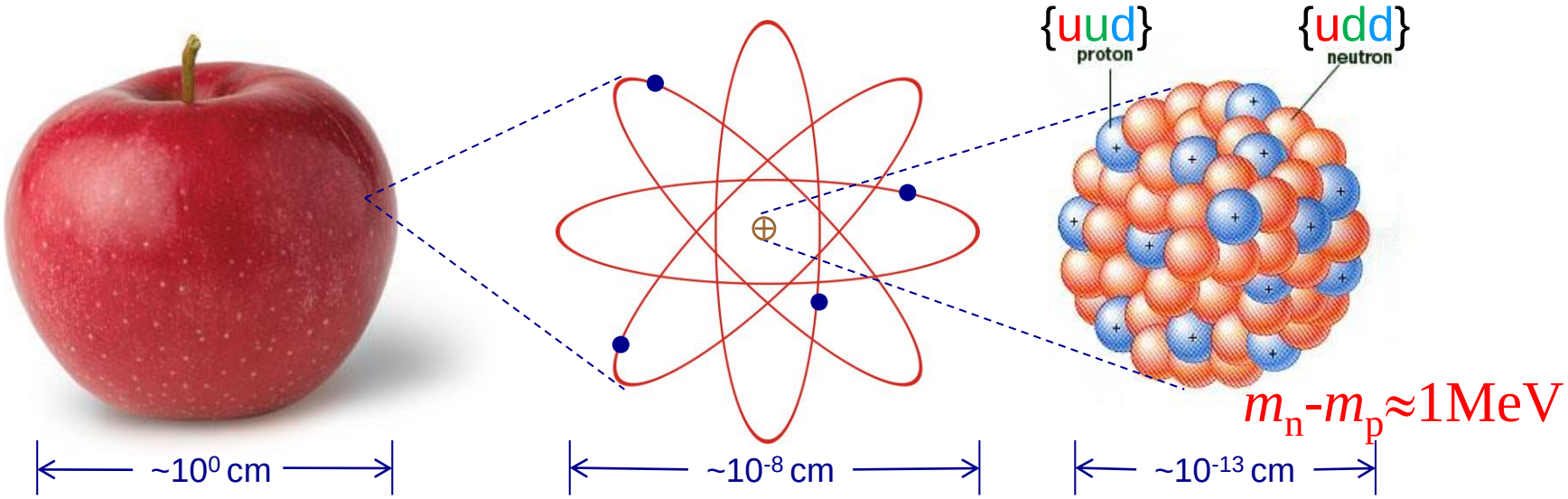
Pulsars could be strangeon stars

Matter condensed by

the ***strong*** force?

Strong matter is *not surprising*!

- Let's do an exercise…to squeeze an apple!



Total baryon number A_{apple}~100g/u~10^{26}.

Electrons no-relativistic before squeezing, but what after?

A giant "nucleus": ~0.5μm, ~ρ_{nucl}, E_e~300MeV if *e* keeps

Gravity-squeezed core: $A >> A_{apple}$ and *not gravity-free*!

Strong matter formation in strong *gravity*

- FD statistics: Fowler, Sommerfeld, Chandrasekhar, Landau…

Subramanyan Chandrasekhar (1910-1995)

"for his theoretical studies of the physical processes of importance to the structure and evolution of the stars"

Nobel Prize in Physics (1983)

THE MAXIMUM MASS OF IDEAL WHITE DWARFS

By S. CHANDRASEKHAR

Chandrasekhar (1931)

ABSTRACT

The theory of the *polytropic gas spheres* in conjunction with the equation of state of a *relativistically degenerate electron-gas* leads to a *unique value for the mass of a star* built on this model. This mass ($=0.91\odot$) is interpreted as representing the upper limit to the mass of an ideal white dwarf.

Edmund Clifton Stoner (1899-1968) noted a limiting mass of white dwarfs ($\sim M_\odot$) in the uniform density approximation (Stoner 1930).

rough treatment. Thus we get an equilibrium state only for masses greater than a critical mass

$$M_0 = \frac{3.1}{m^2}\left[\frac{hc}{G}\right]^{3/2} = 2.8 \times 10^{33} \text{ gr.}$$

Landau (1932)

Landau, Bohr & Rosenfeld

or about $1.5\odot$ (for $m=2$ protonic masses). For $M > M_0$ there exists in the whole

Strong matter formation in strong *gravity*

- A real history: Landau in 1931/1932!

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 s chosen only for the sake of mathe- matic . By this is characterised, for instance, Mr. M of the impossibility of a star consisting throu ical ideal gas; this proof rests on the asser rbitrary L and M, the fundamental equa- tions sisting of classical ideal gas admit, in gener solution. Mr. Milne seems to have over- looke at this assertion results only from the assum ty being constant throughout the star, which is made only for mathematical purposes and h do with reality. Only in the case of this radius R disappears from the relation betwe necessary for regularity of the solution. Any rea ssumptions about the opacity would lead to a relation between L, M and R, which relation would be Eddington's mass-luminosity-relation.

It seems necessary 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)

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

288 L. Landau

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.

How *gigantic* is gigantic?

these general lines we can try to develop a theory of ar 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 ... regions would ... 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.

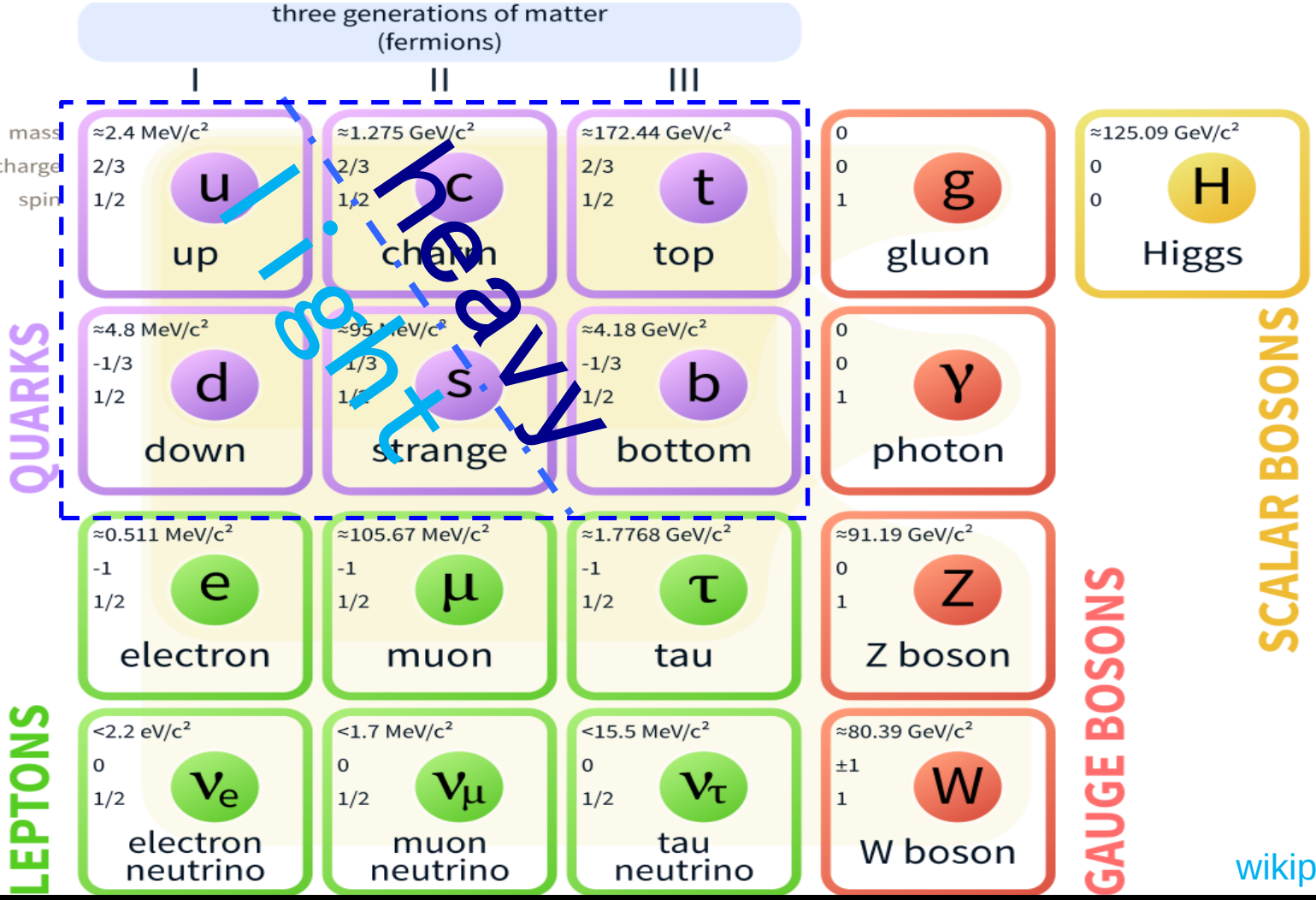
The theory of stellar structure founded on the above considerations is yet to be constructed, and only such a theory can show how far they are true.

February 1931, Zurich.

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

Now is era of the *standard* model!

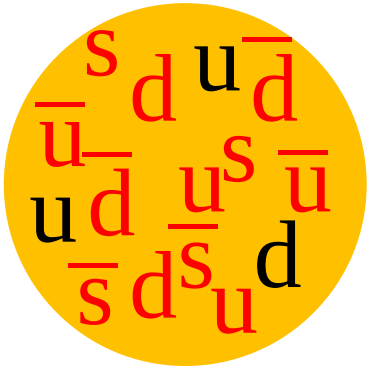
- Quark flavors in the standard model of particle physics



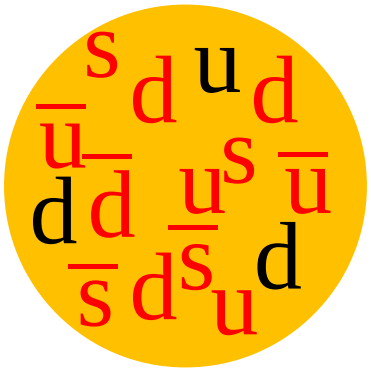
wikipedia.org

Now is era of the *standard* model!

- What's a **p**roton? What's a **n**eutron?



p={u^{2}d^{1}s^{0}}



n={u^{1}d^{2}s^{0}}

A perturbative calculation of quantum chromodynamics (QCD) may predict a nucleon sea with ***light-flavor symmetry***, but the observed flavor asymmetry in the light-quark sea would be the result of the non-perturbative nature.

Strangeness and Hadron Structure

John Ellis[a]

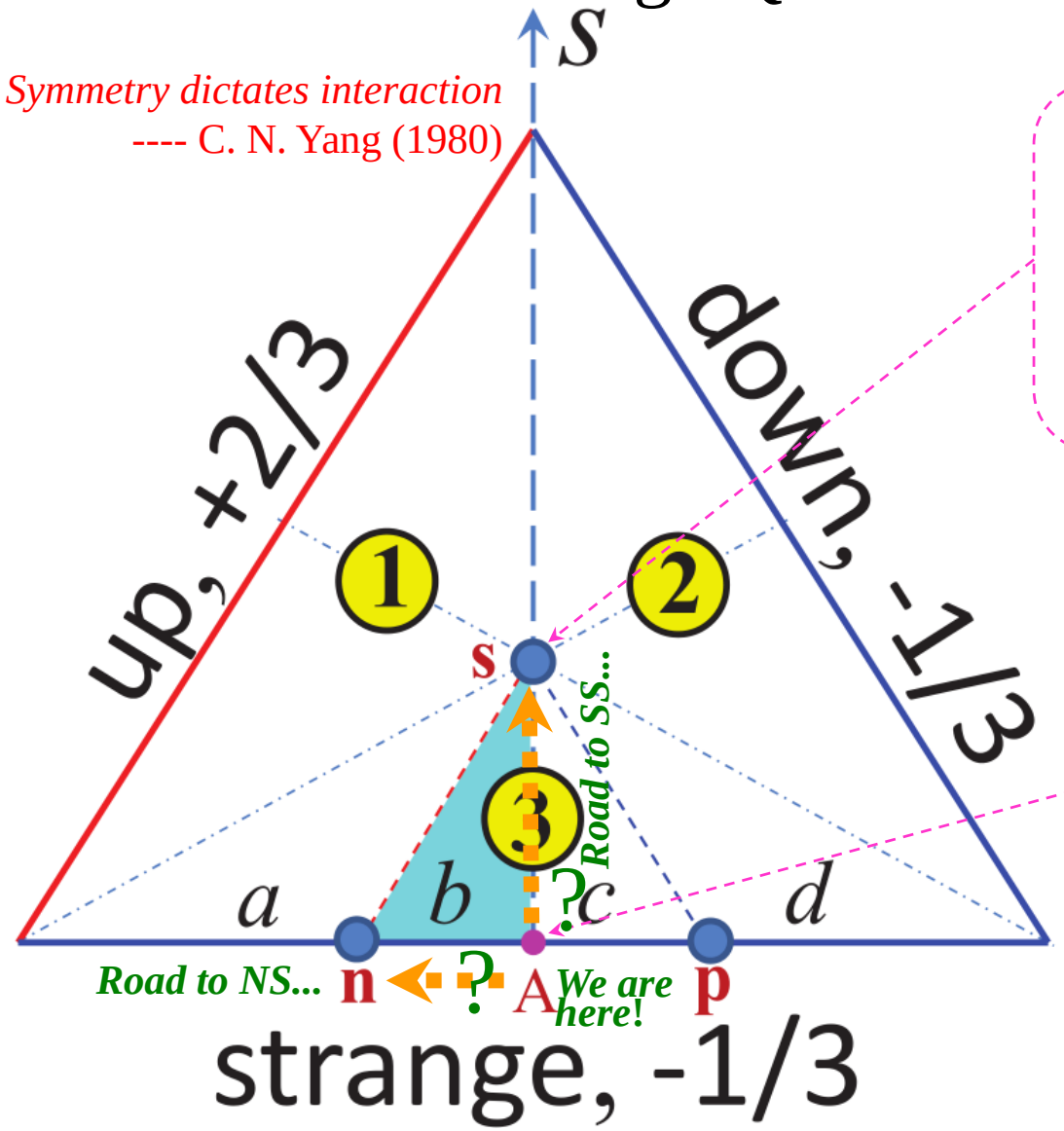
[a]Theoretical Physics Division, CERN
CH - 1211 Geneva 23

The nucleon wave function may contain a significant component of $\bar{s}s$ pairs, according to several measurements including the π-nucleon σ term, charm production and polarization effects in deep-inelastic scattering. In addition, there are excesses of ϕ production in LEAR and other experiments, above predictions based the naive Okubo-Zweig-Iizuka rule, that may be explained if the nucleon wave function contains a polarized $\bar{s}s$ component. This model also reproduces qualitatively data on Λ polarization in deep-inelastic neutrino scattering. The strange component of the proton is potentially important for other physics, such as the search for astrophysical dark matter.

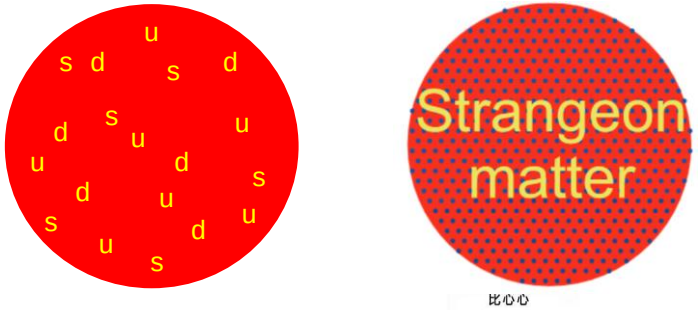
CERN-TH/2000-112 hep-ph/0005322

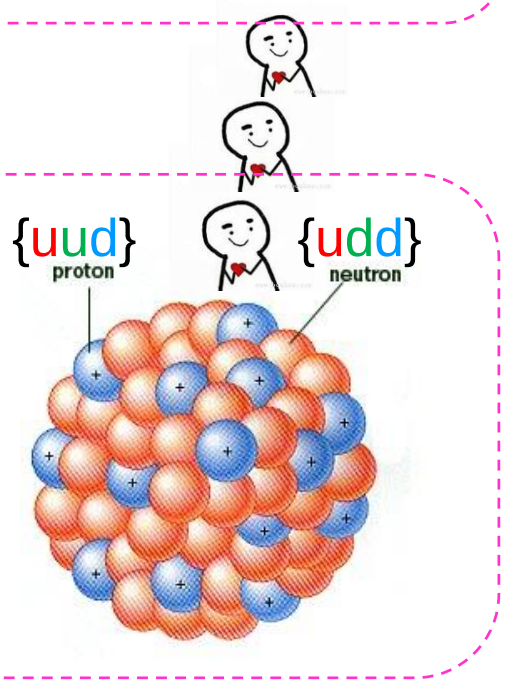
Other ***two*** along with Landau (1932)

- Neutron star? Strange Quark star? Strangeon Star?



pQCD? **NQCD**?





Detailed ways to neutralize…

- NS *vs.* SS…

neutronization

$\overline{u} + e^- \rightarrow \overline{d} + \nu_e$

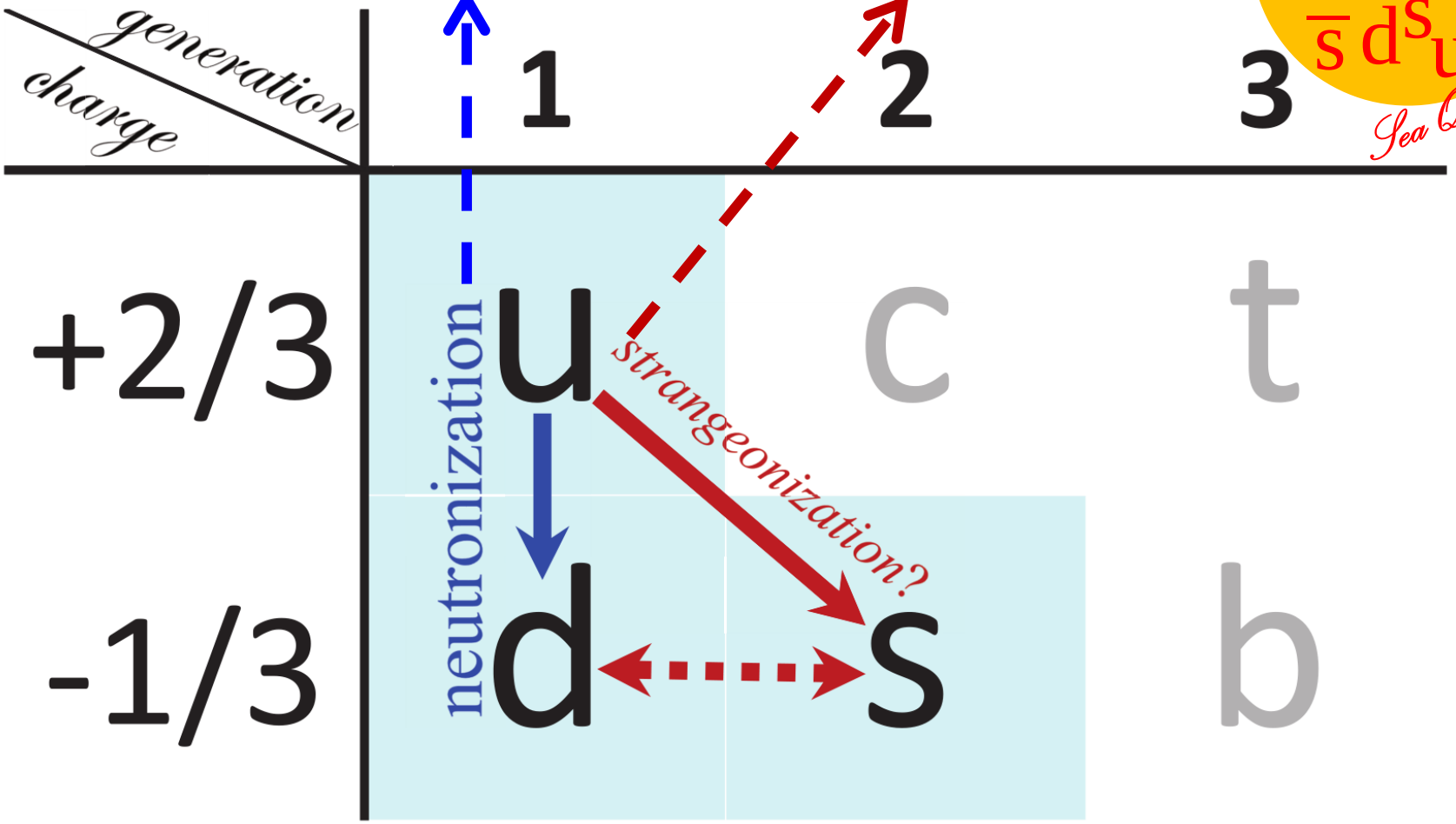
$\overline{u} + e^+ \rightarrow d + \overline{\nu}_e$

strangeonization?

$\overline{u} + e^- \rightarrow \overline{s} + \nu_e$

$\overline{u} + e^+ \rightarrow \overline{s} + \nu_e$

p=$\{u^2 d^1 s^0\}$



Pulsars could be strangeon stars

What if pulsars could be *strangeon* stars?

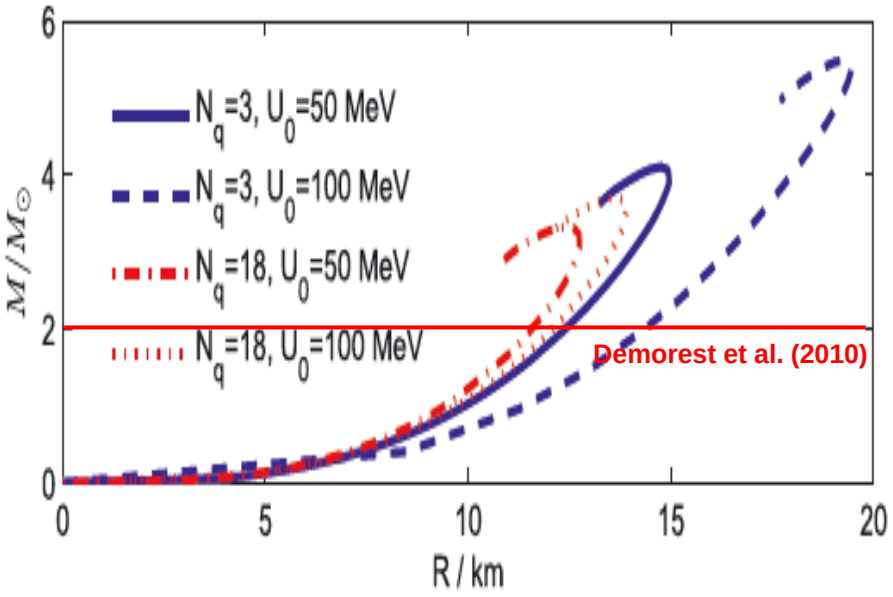
A very *stiff* equation of state!

Lennard-Jones quark matter and massive quark stars

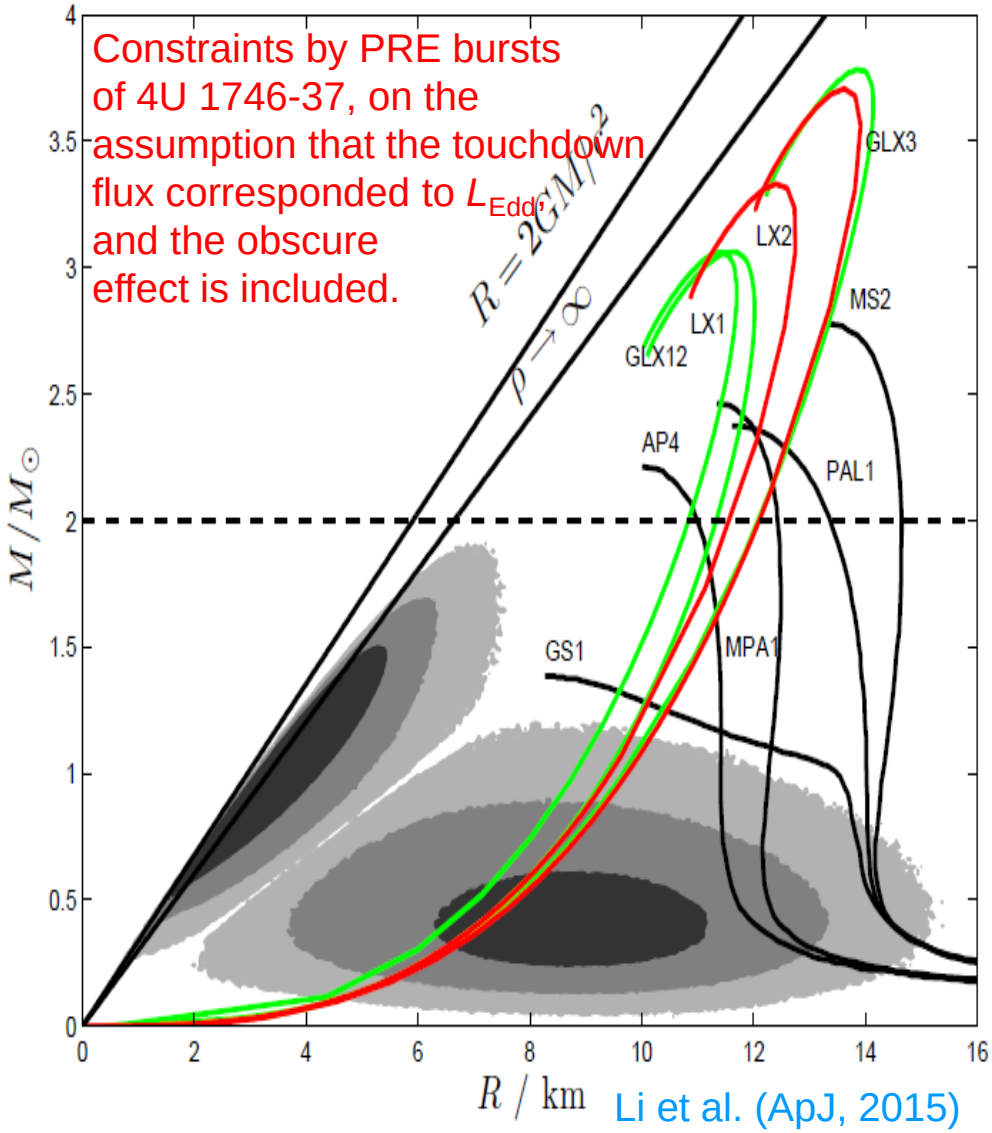
X. Y. Lai★ and R. X. Xu

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.

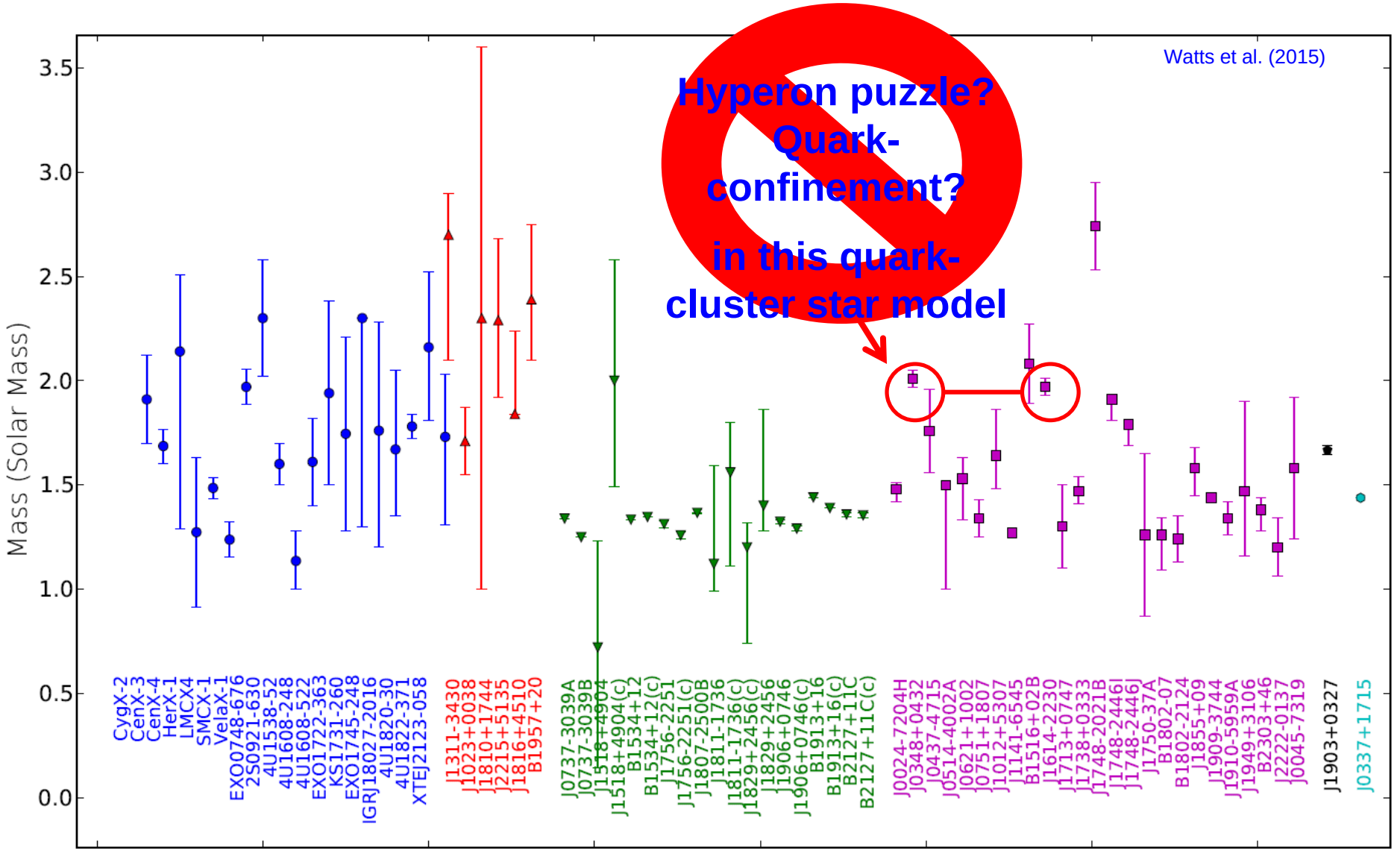


(Lai & Xu 2009 MNRAS, 398, L31)



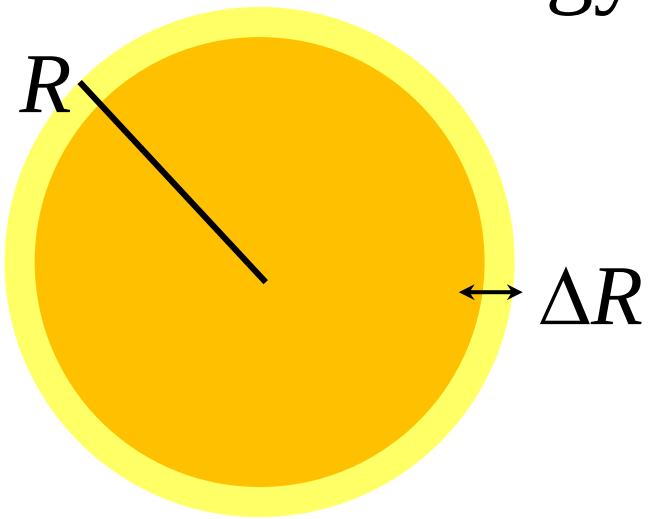
Li et al. (ApJ, 2015)

A very *stiff* equation of state!



Huge *free energy* to power events

- We face major challenge to understand extr.ev
  - The free energy: B-field vs. quake? (Xu et al. 2006)



$$E_{\rm stored} \approx \frac{GM^2}{R} \sim 10^{53}\,\frac{\Delta R}{R}\ \ {\rm ergs}$$

for $M \sim M_\odot$

AXP/SGRs (flares, even superflares), GRBs, FRBs…

magnetars vs. *strangeon stars*?

How to determine quantitatively the free energy?

Huge *free energy* to power events

- Anisotropic stars in general relativity (spherically)

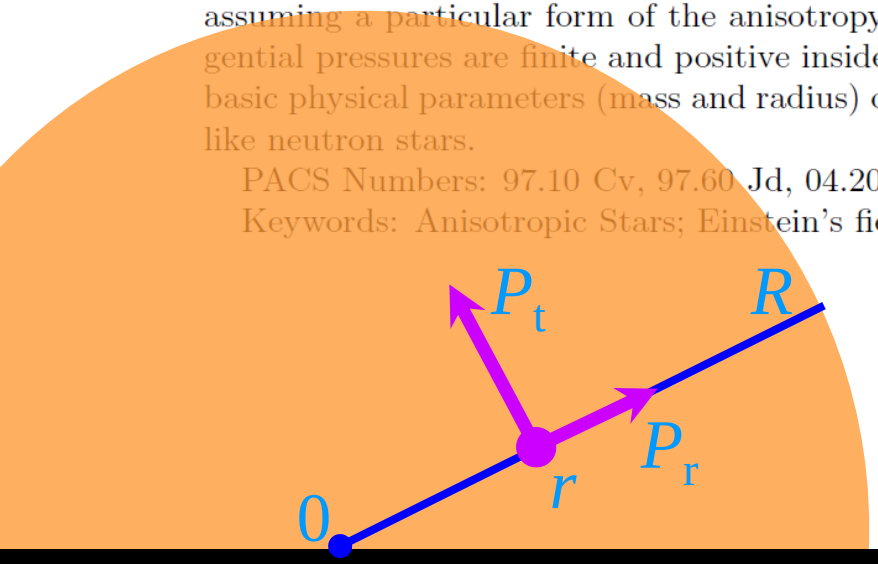
Anisotropic Relativistic Stellar Models

T. Harko*
Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong, P. R. China.

M. K. Mak†
Department of Physics, The Hong Kong University of Science and Technology,Clear Water Bay, Hong Kong, P. R. China.

We present a class of exact solutions of Einstein's gravitational field equations describing spherically symmetric and static anisotropic stellar type configurations. The solutions are obtained by assuming a particular form of the anisotropy factor. The energy density and both radial and tangential pressures are finite and positive inside the anisotropic star. Numerical results show that the basic physical parameters (mass and radius) of the model can describe realistic astrophysical objects like neutron stars.

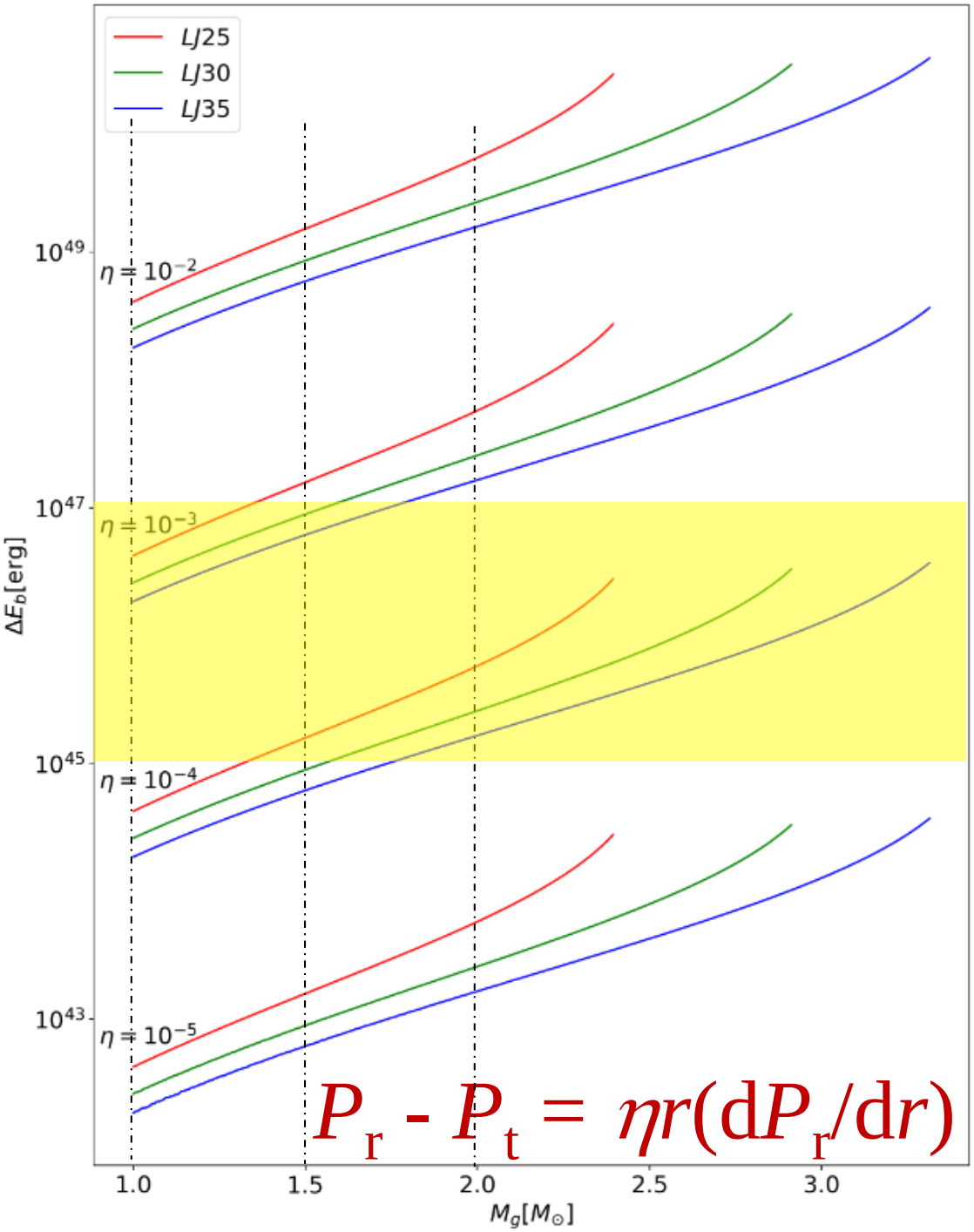
PACS Numbers: 97.10 Cv, 97.60 Jd, 04.20.Jb
Keywords: Anisotropic Stars; Einstein's field equations; Static interior solutions. An. Phys. 2002

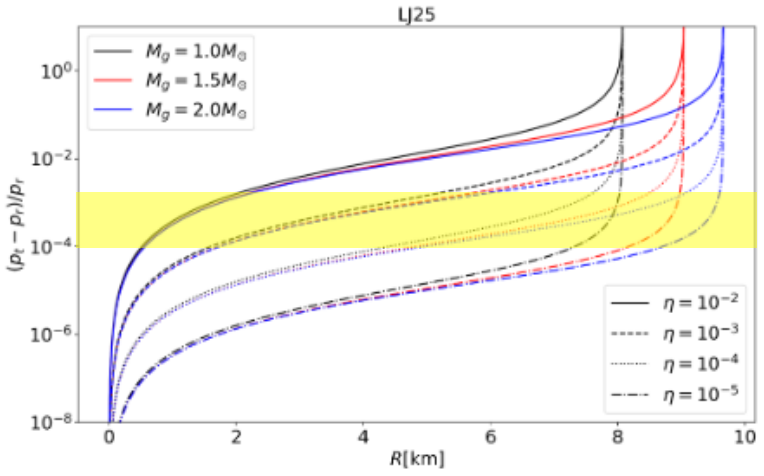


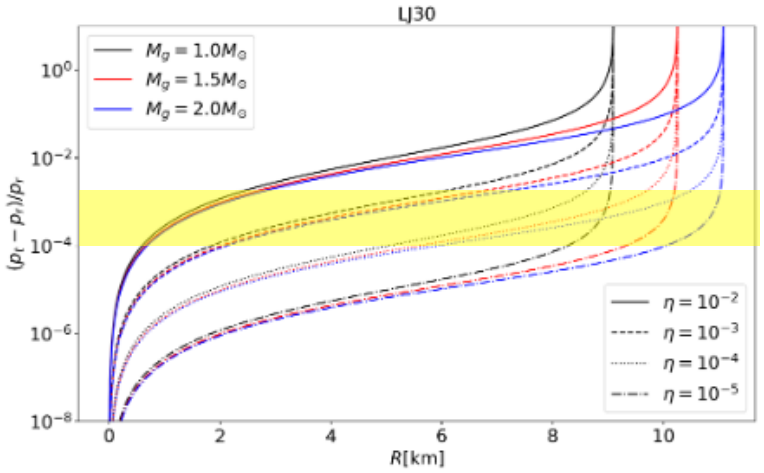
$P_t > P_r \Rightarrow$ higher M_{max}!

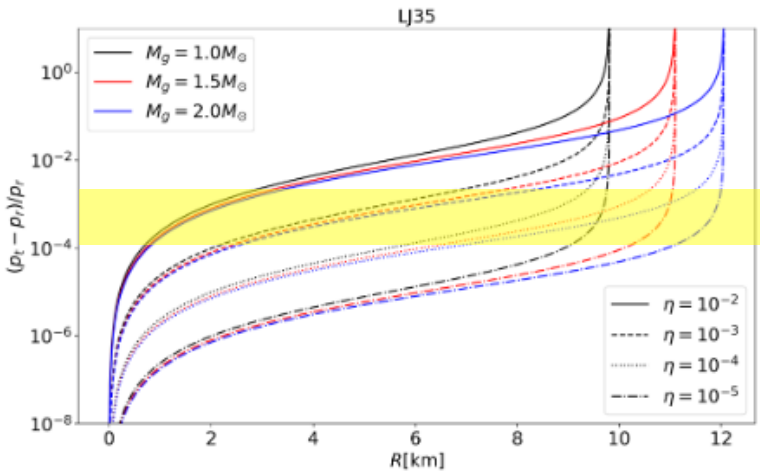
Free-energy *releasing*...

$P_t \sim P_r$


LJ25
LJ30
LJ35
10^{49}
10^{47}
10^{45}
10^{43}
$\eta = 10^{-2}$
$\eta = 10^{-3}$
$\eta = 10^{-4}$
$\eta = 10^{-5}$
ΔE_b[erg]
1.0
1.5
2.0
2.5
3.0
$M_g[M_\odot]$
$P_r - P_t = \eta r(dP_r/dr)$


LJ25
$M_g = 1.0M_\odot$
$M_g = 1.5M_\odot$
$M_g = 2.0M_\odot$
$\eta = 10^{-2}$
$\eta = 10^{-3}$
$\eta = 10^{-4}$
$\eta = 10^{-5}$
$(p_t - p_r)/p_r$
R[km]

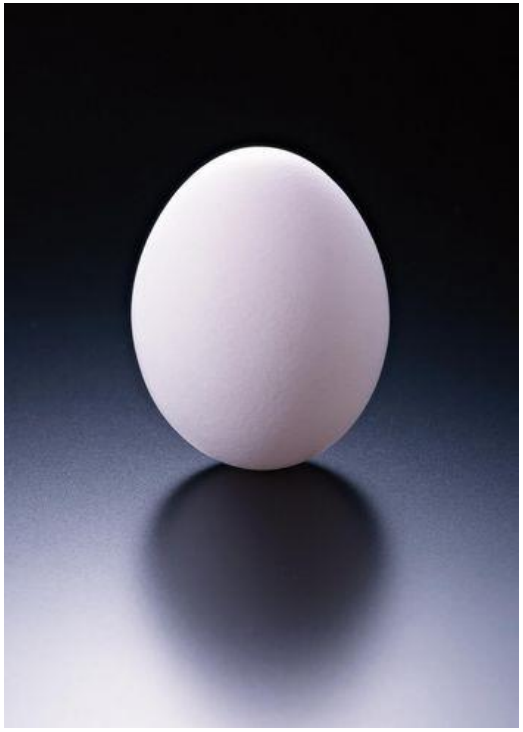

LJ30
$M_g = 1.0M_\odot$
$M_g = 1.5M_\odot$
$M_g = 2.0M_\odot$
$\eta = 10^{-2}$
$\eta = 10^{-3}$
$\eta = 10^{-4}$
$\eta = 10^{-5}$
$(p_t - p_r)/p_r$
R[km]


LJ35
$M_g = 1.0M_\odot$
$M_g = 1.5M_\odot$
$M_g = 2.0M_\odot$
$\eta = 10^{-2}$
$\eta = 10^{-3}$
$\eta = 10^{-4}$
$\eta = 10^{-5}$
$(p_t - p_r)/p_r$
R[km]

May others…

- To distinguish: an easy ***example*** …

Eggs: ***Raw*** or ***Cooked*** ?



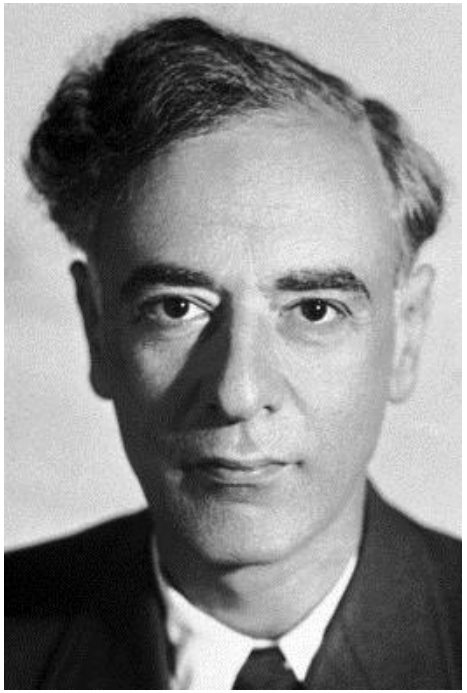
Pulsars B1821-11: *precession* or even *free precession*?

(Stairs, Lyne & Shemar, 2000, Nature, 406, 484)

Pulsars could be strangeon stars

Summary

Three Arguments to Strangeon Star

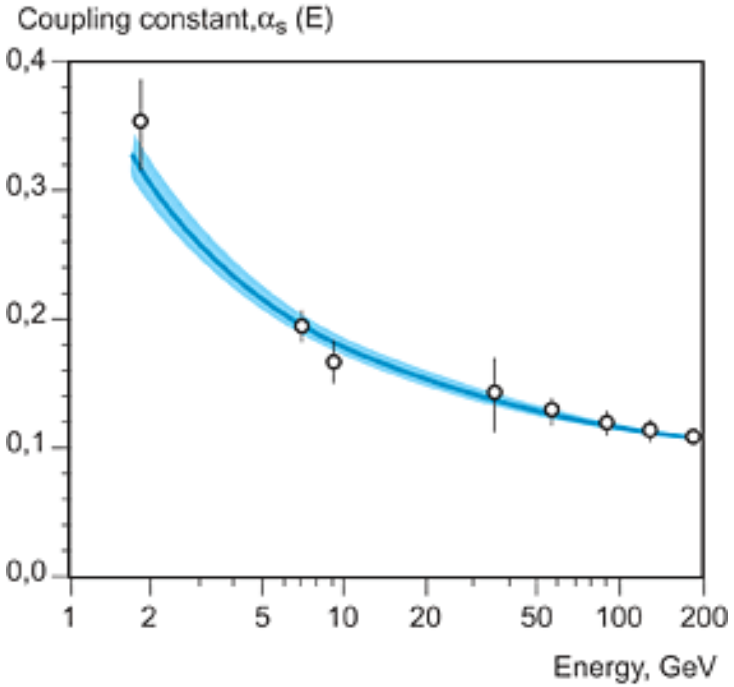


Lev Davidovich Landau
(1908-1968)

Neutrality

Edward Witten
(1951-)

New-degree



Strong-coupling QCD
(1973-)

No-perturbativity

strangeon star

Summary

- It has been ***90 years*** since Landau re-considered Fowler/Chandersekhar's statistics of white dwarfs, but the **basic unit** inside the resultant gigantic nucleus is still uncertain.

- In the triangle, the units could be **3**-flavour ***symmetric strangeons*** rather than **2**-flavour ***asymmetric nucleons*** if the Nature really loves symmetry when building the world.

- To test the models in the further…

THANKS!