Fundamental Constants

and their

Time Variation

Harald Fritzsch

LMU Munich

fundamental constants

the problem of modern science

Fritzsch

fundamental constants =>

particle physics
nuclear ...
atomic ...
laser ...
solid state ...
astro ...
cosmology

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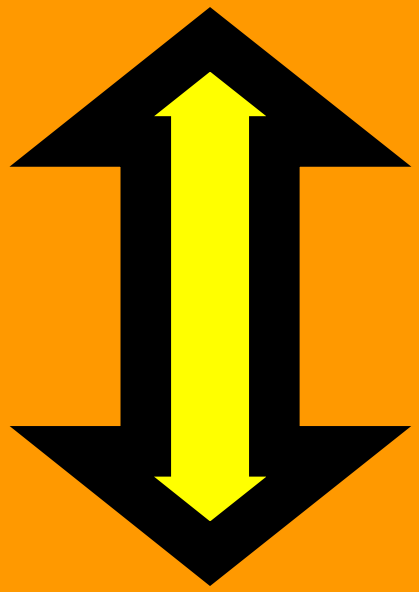
==> chemistry, biology, ...

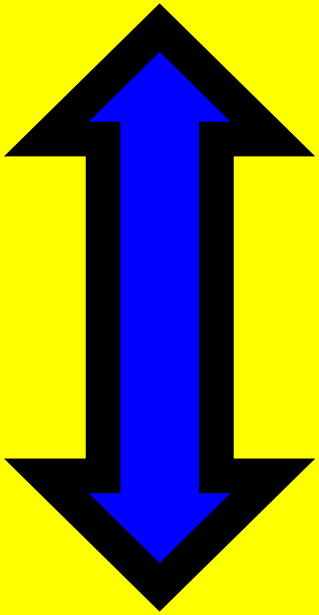
Fundamental constants



Standard Model

Fritzsch

Standard Model



gauge theories

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first gauge theory

Heisenberg

Pauli

Feynman

Schwinger

QED

Fritzsch

QED
2 fundamental constants

$$\alpha$$

$$m_e$$

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1964 ==>

electroweak gauge theory

U(1) x SU(2)

Fritzsch

gauge theory of the

Strong Interactions

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M. Gell-Mann

G. Zweig

1964

quarks

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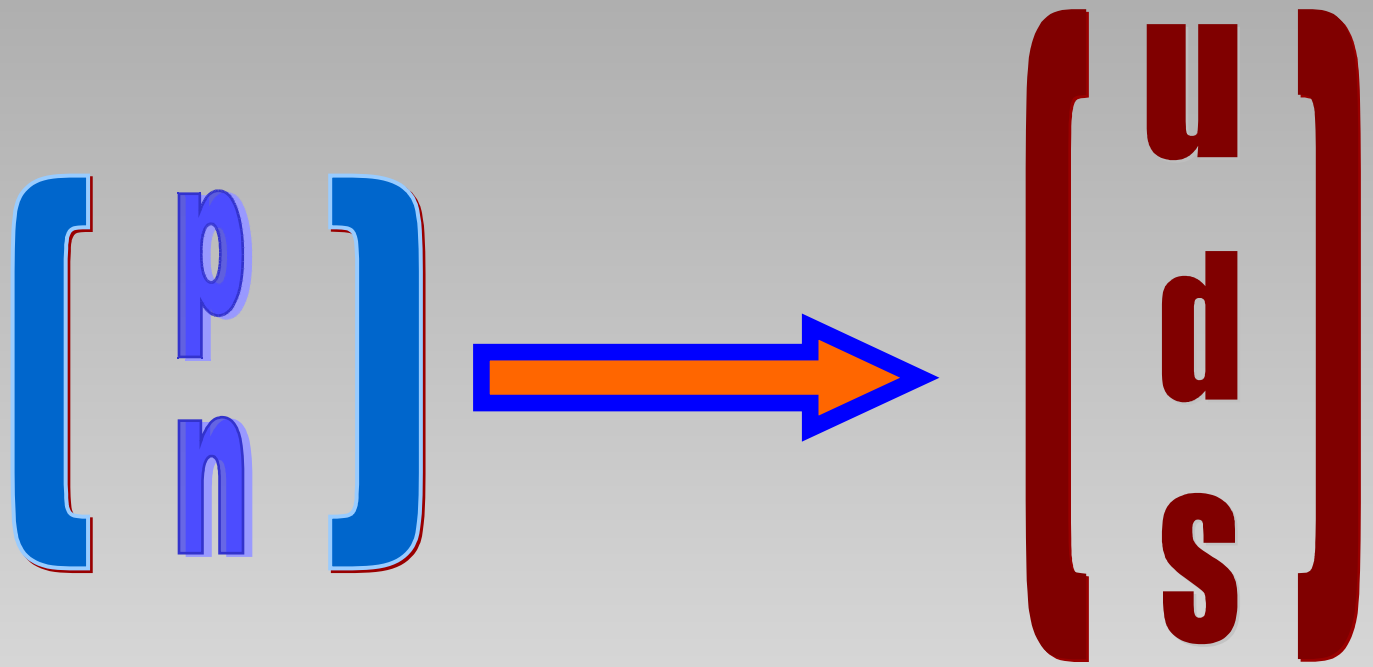


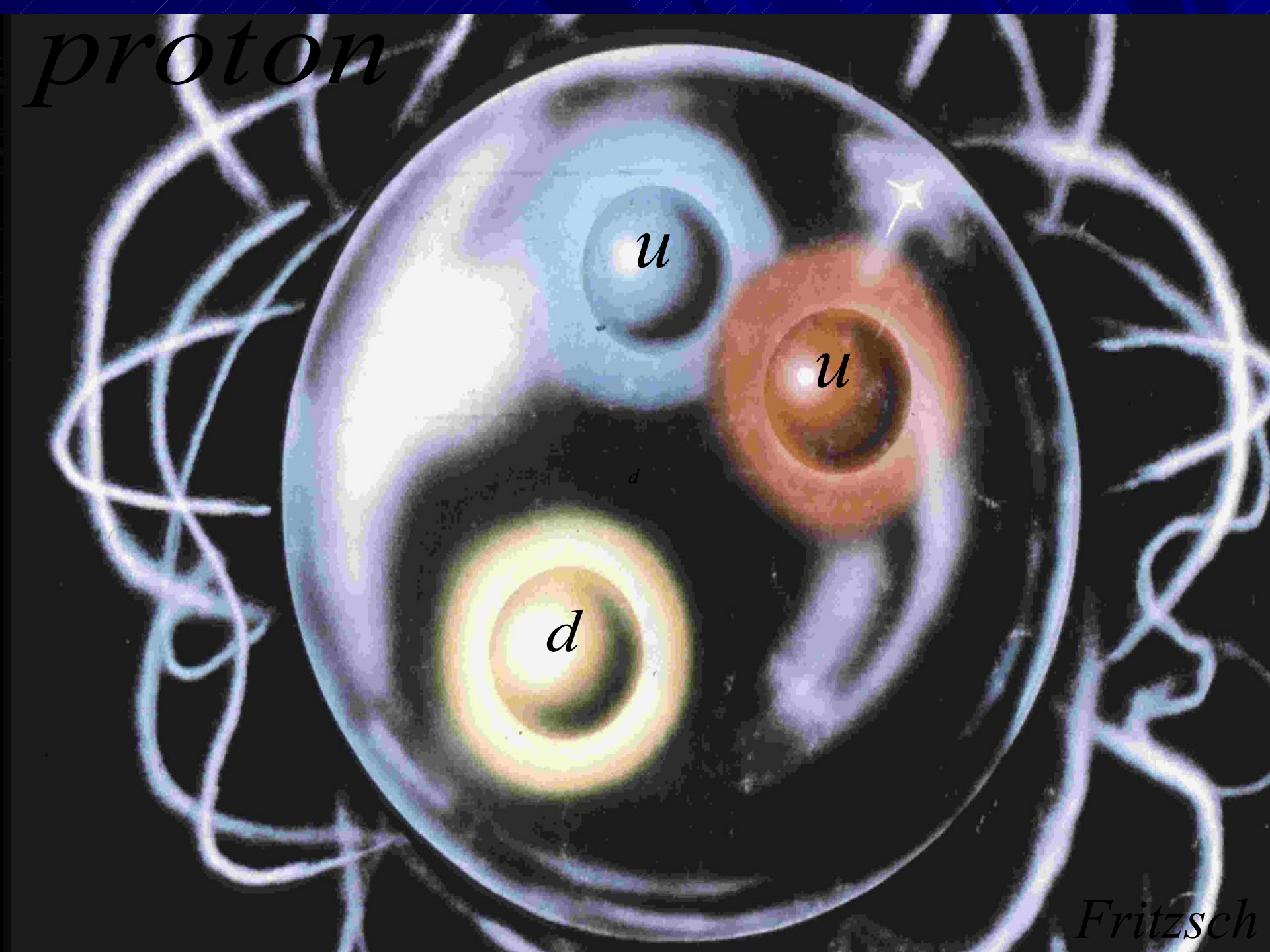
electric charge:

$u: \quad {}^{2}\!/_{3}\, e$

$d: \quad -{}^{1}\!/_{3}\, e$

$s: \quad -{}^{1}\!/_{3}\, e$

Fritzsch


proton
u
u
d
d
Fritzsch

1971 color

q ⟹

q q q

SU(3,c)

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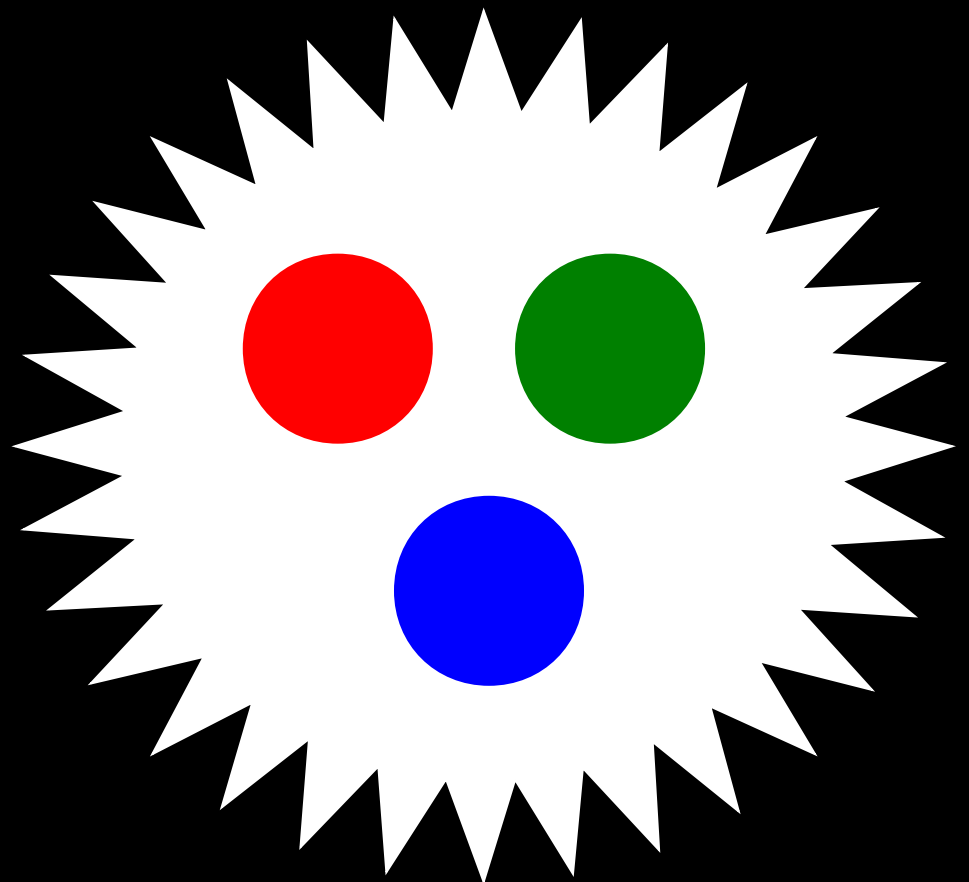
- Hadrons -

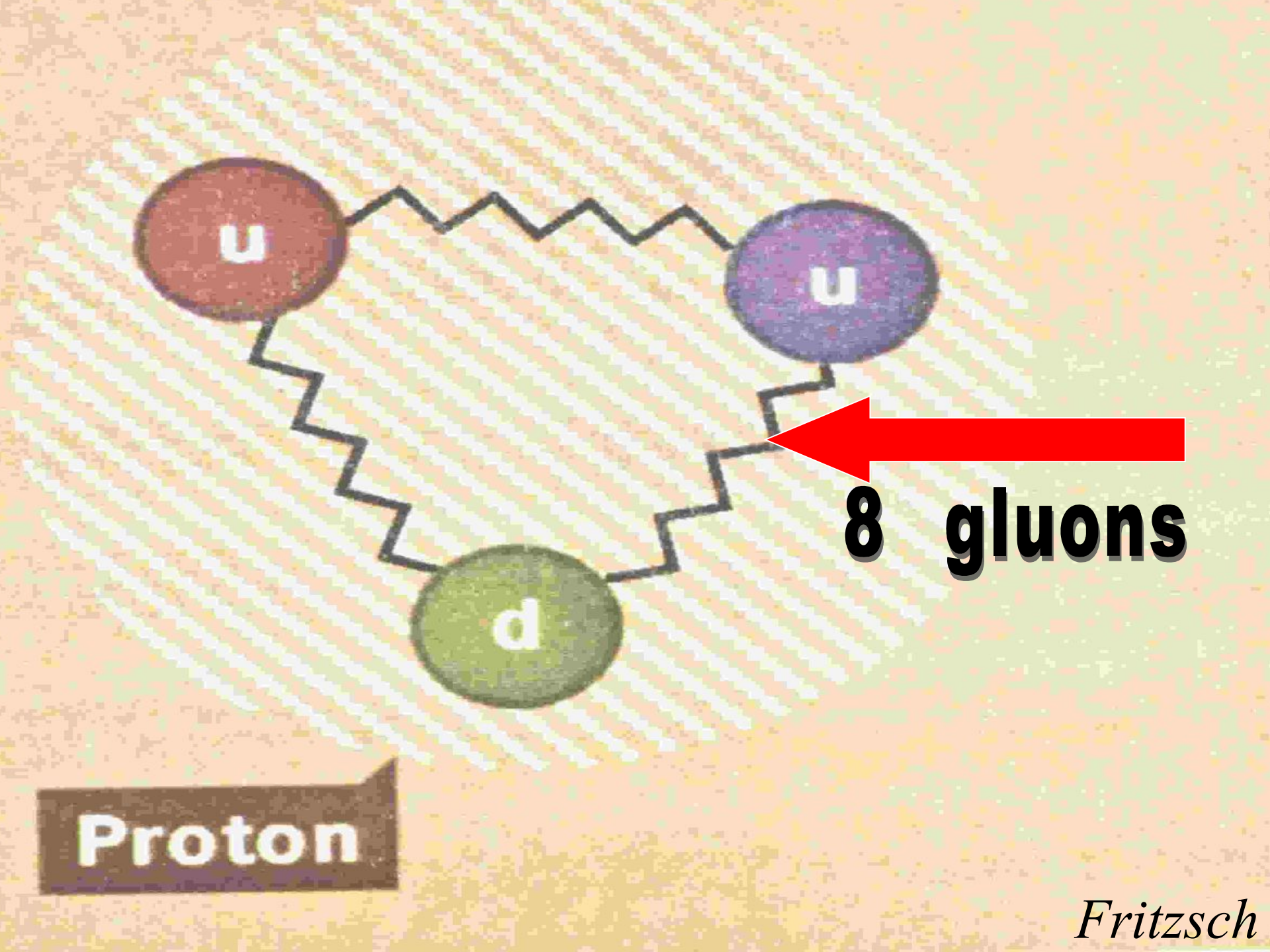
white states



1971 - 1972

QCD

Fritzsch & Gell-Mann



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1973:

Standard Model

SU(3) x SU(2) x U(1)

2 ==> 28

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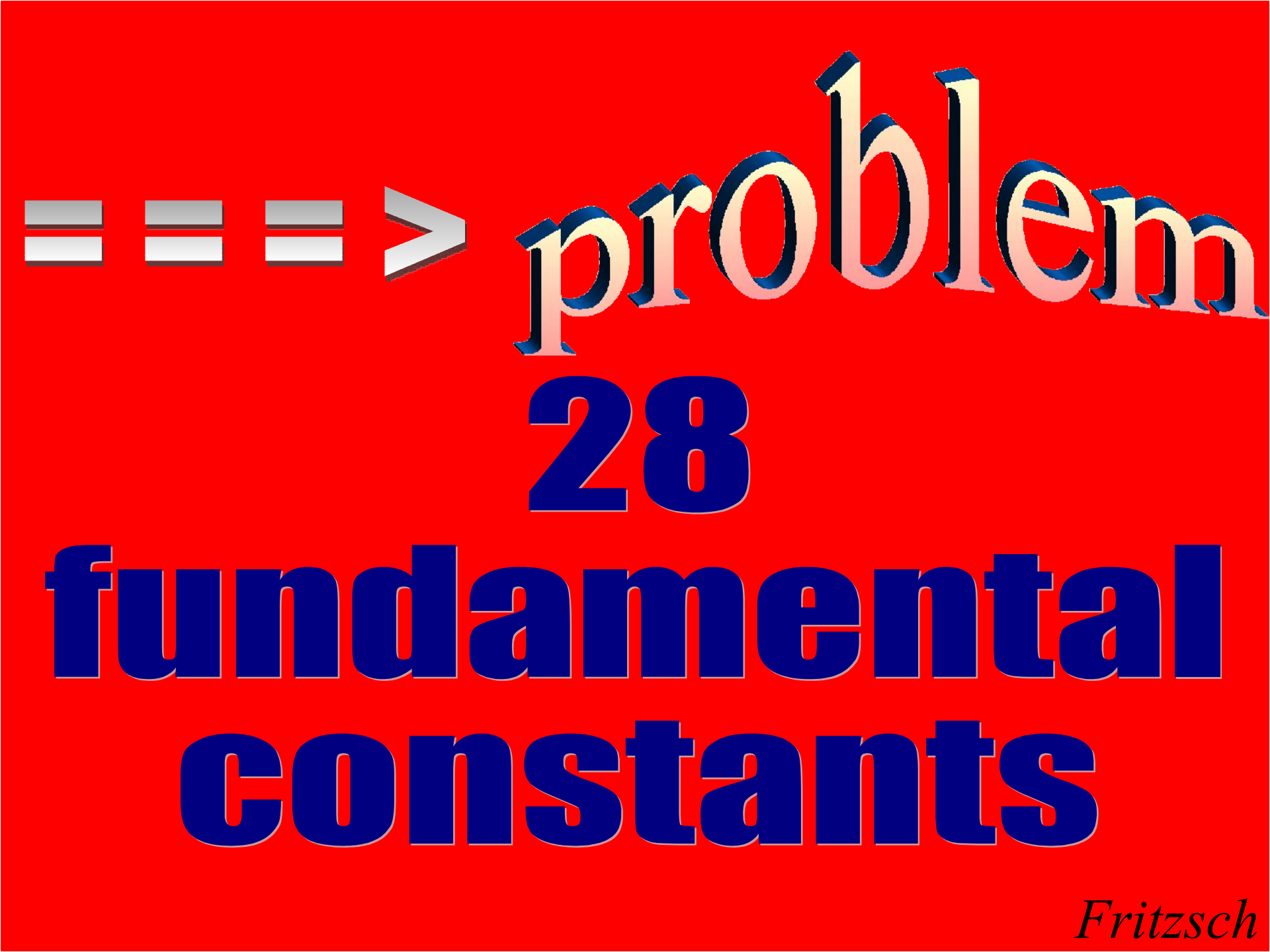
= = = > problem
28
fundamental
constants
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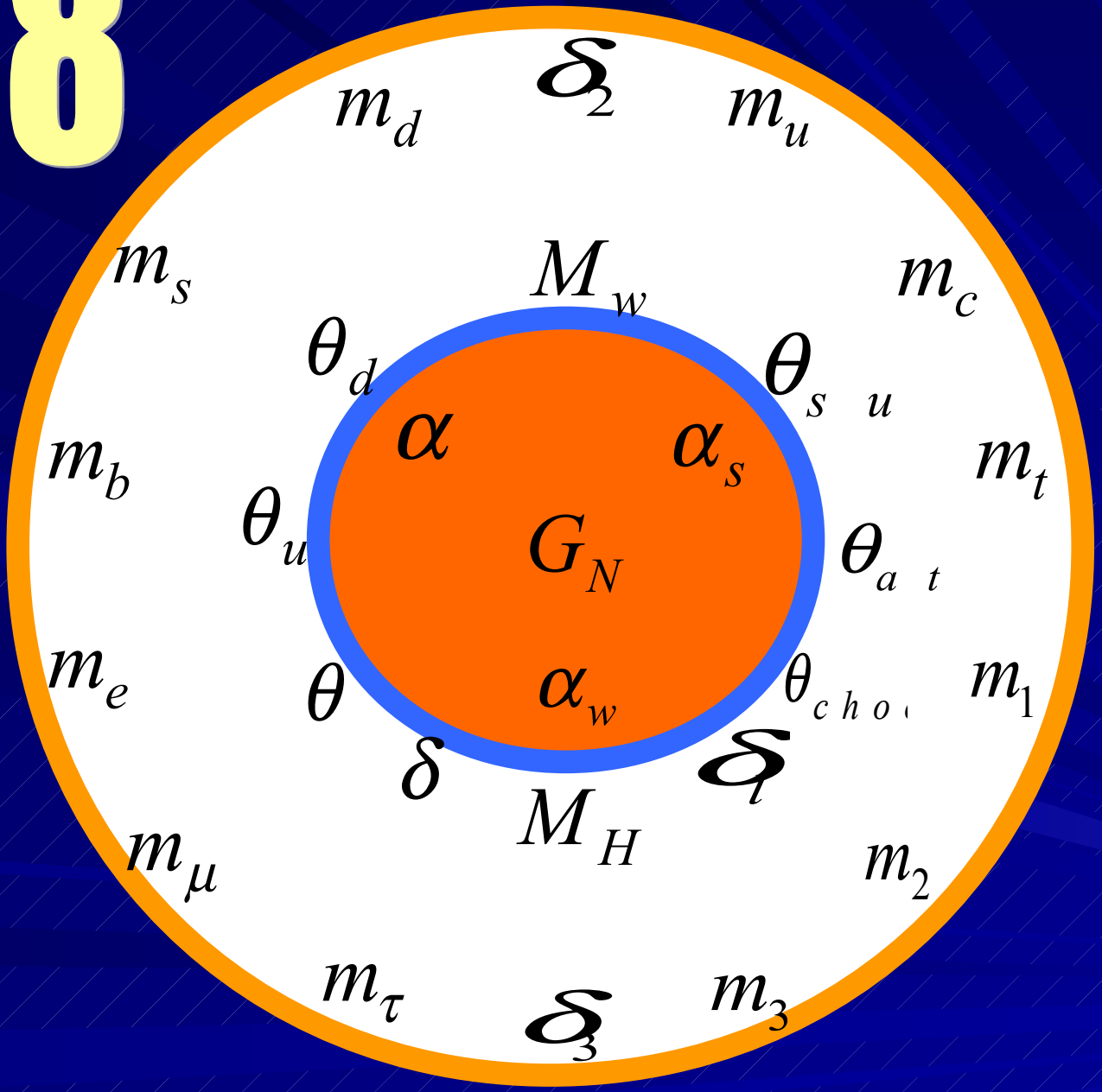
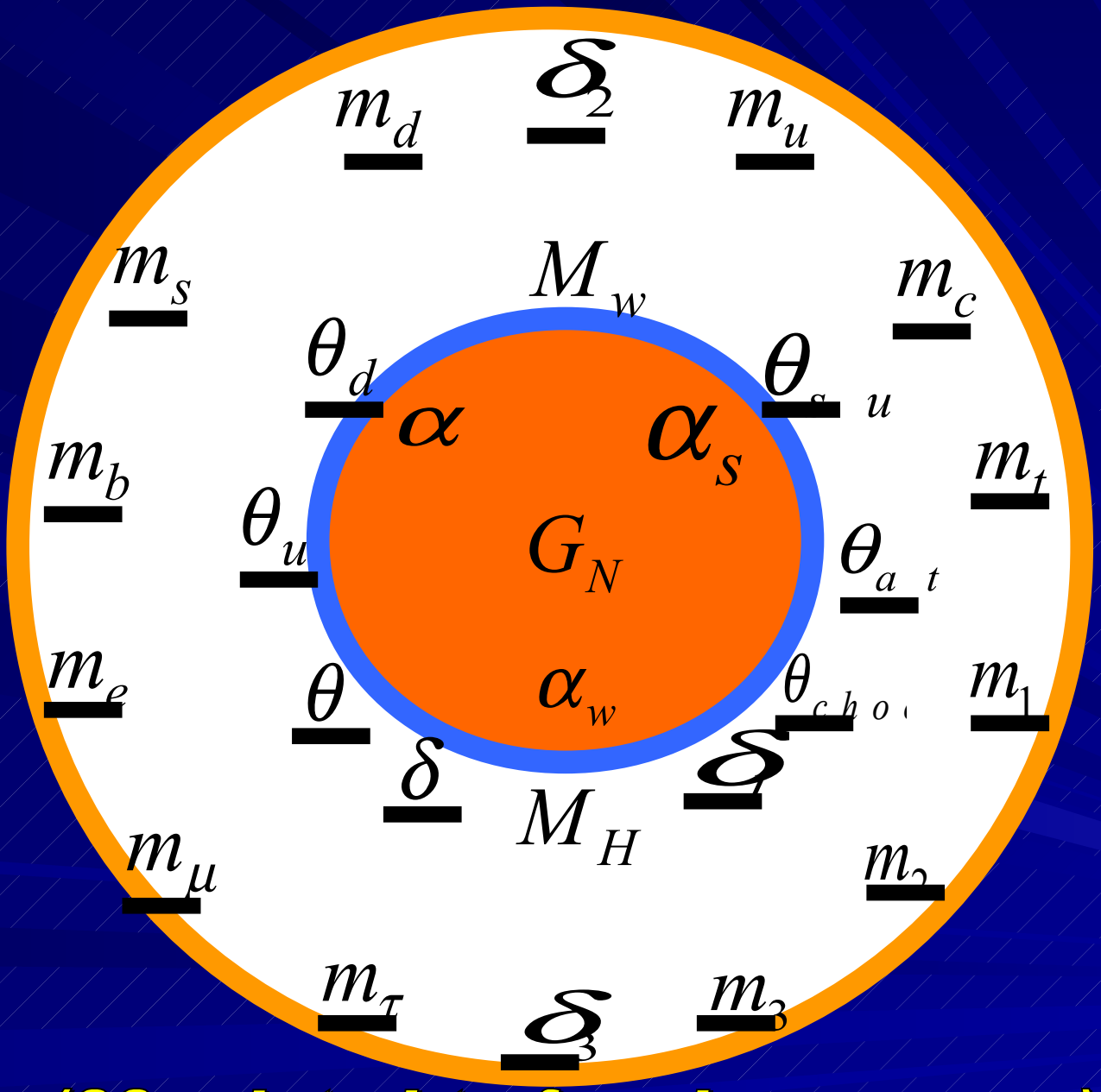
Newtons constant G	1
fine structure constant	1
coupling constant of strong interaction	1
coupling constant of weak interaction	1
mass of W boson	1
mass of Higgs boson	1
masses of 6 quarks and 6 leptons	12
flavor mixing of quarks	4
flavor mixing of leptons	6

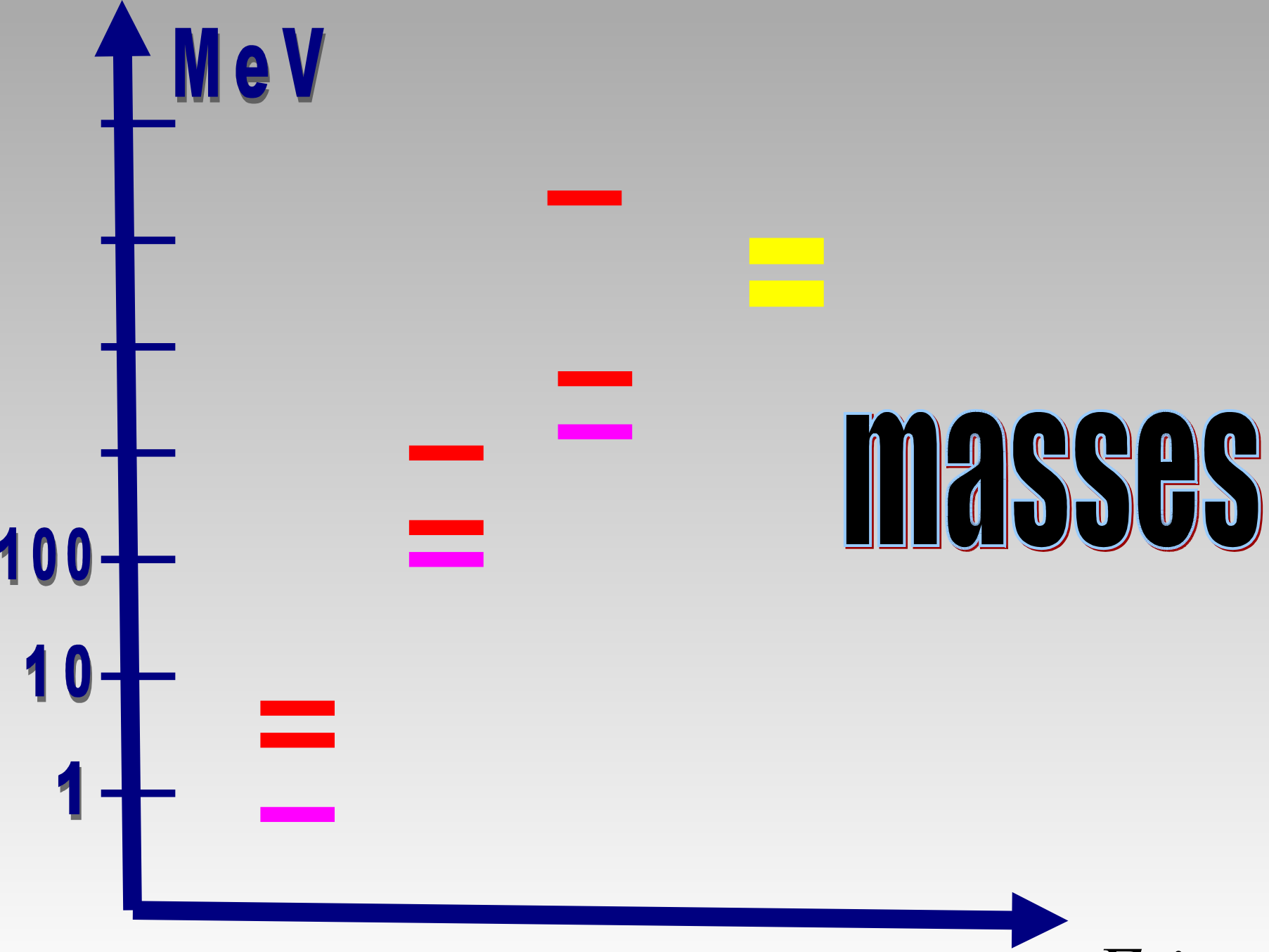
28


m_d
δ_2
m_u
m_s
M_w
m_c
θ_d
$\theta_{s\ u}$
α
α_s
m_b
m_t
θ_u
G_N
$\theta_{a\ t}$
m_e
θ
α_w
$\theta_{c\ h\ o}$
m_1
δ
δ_1
M_H
m_μ
m_2
m_τ
δ_3
m_3

Fritzsch



(22 related to fermion masses) *Fritzsch*



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Arnold *Sommerfeld, 1916*

fine-structure constant

$$\alpha = e^2 2\pi / hc$$

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$$\alpha = \frac{e^2}{\hbar c} \approx \frac{1}{137}$$

electrodynamics + relativity + quantum theory

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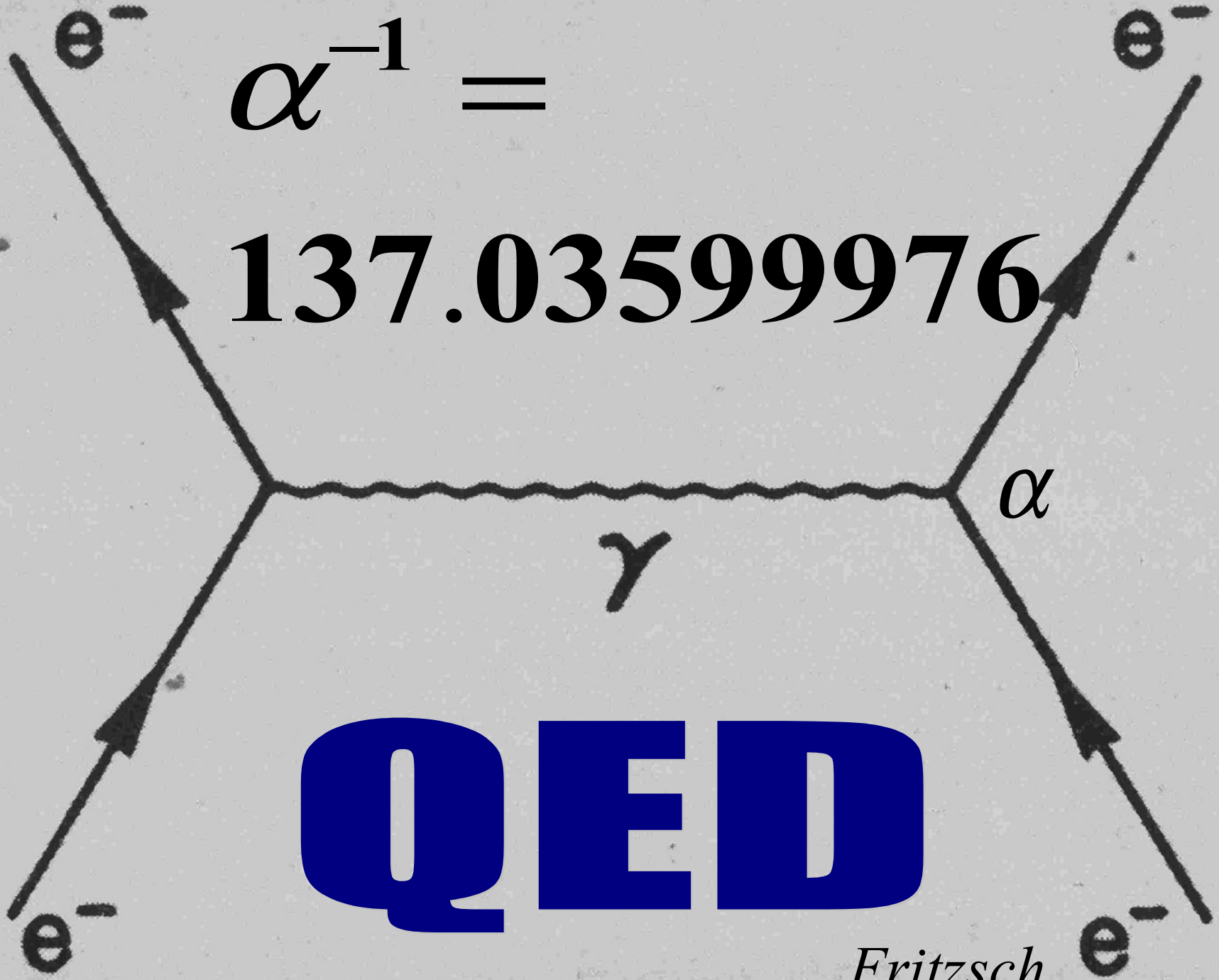
$$\alpha^{-1} =$$

137.03599976



QED

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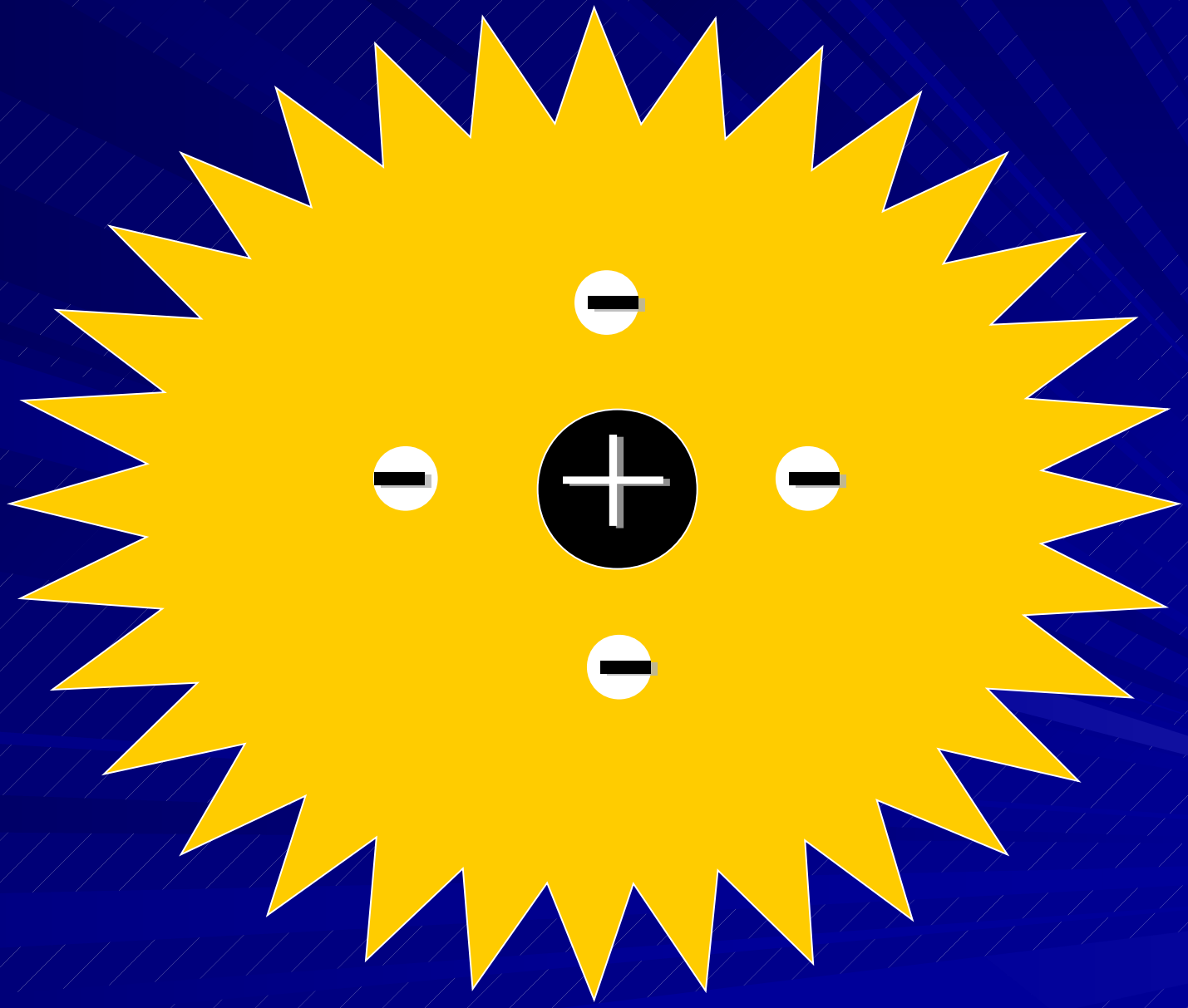
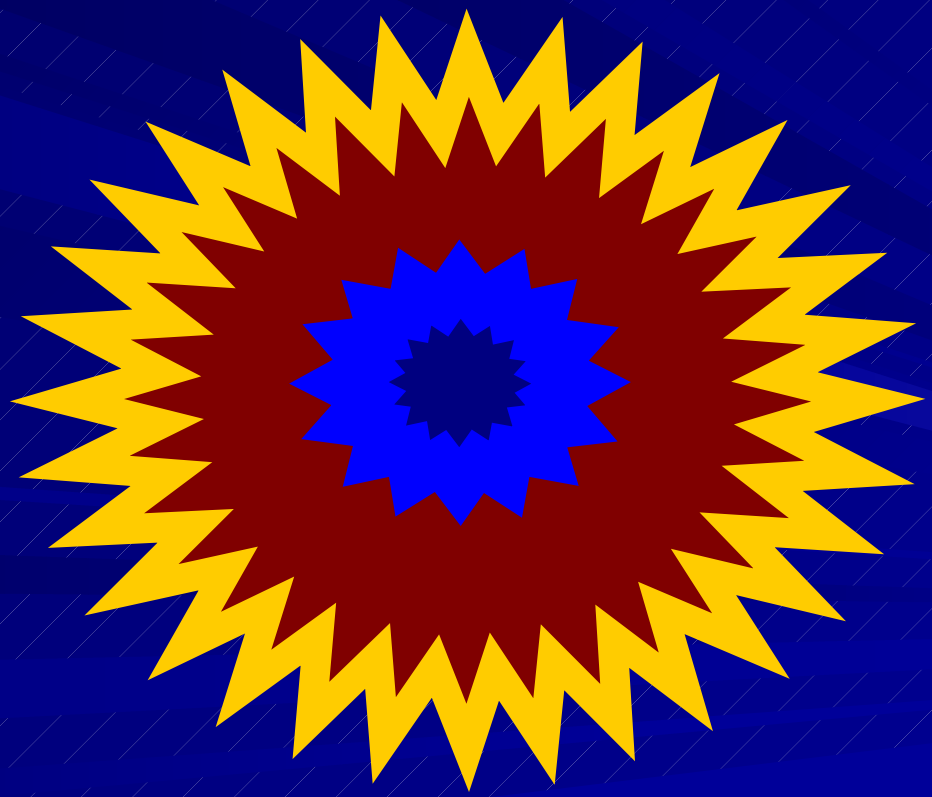
partial screening



fine-structure constant ==>

function of energy



$$\alpha(\quad ^{2}G\cdot e\cdot$$

LEP: ~1/127

$$\alpha(M)_{Z}1 \neq 1\ 2\ 7$$

nucleon mass

fundamental constant?

==> QCD

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quark masses ==> 0

$$M_p = E(gluons, quarks) / c^2$$

mass <=> field energy

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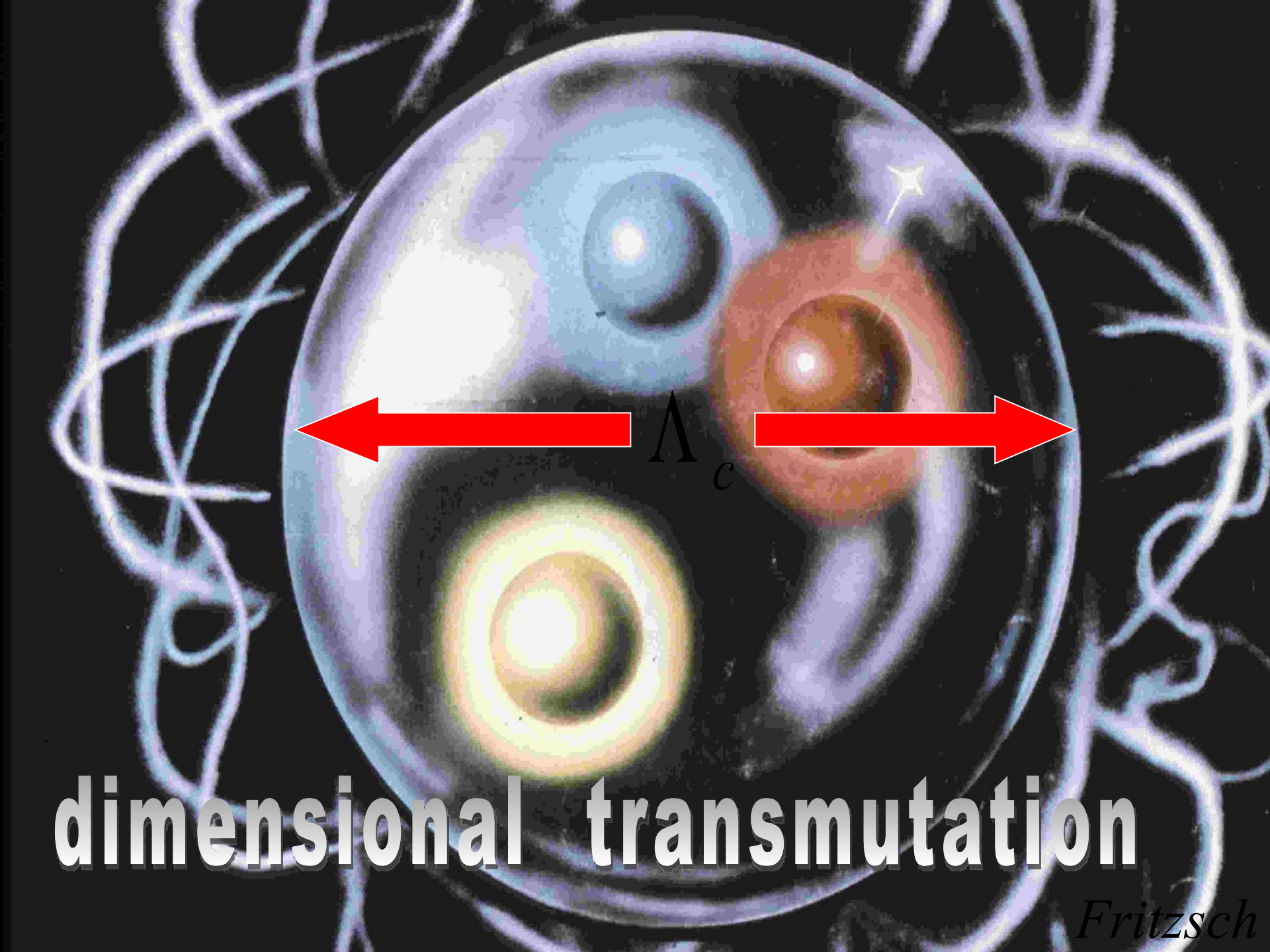
Λ_c
dimensional transmutation
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nucleon mass
(quark masses => 0 =

$$M = const. \bullet \Lambda_c$$

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Experiments:

$\Lambda_c \sim 250$ MeV

mass <==> confined field energy

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real world:

$$M_n = c_u \Lambda + c_u m_u + c_d m_d + c_s m_s + c_e m_e + \Lambda_{QCD}$$

QCD u d s QED

M (proton) = 860 + 21 + 19 + 36 + 2

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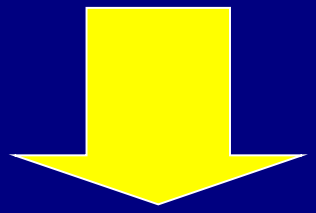
Standard Model:

fundamental constants in our universe



universal

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Are the fundamental constants functions of time and space?

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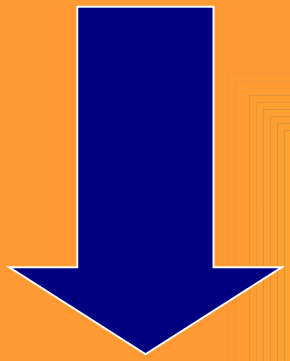
α :



function of energy

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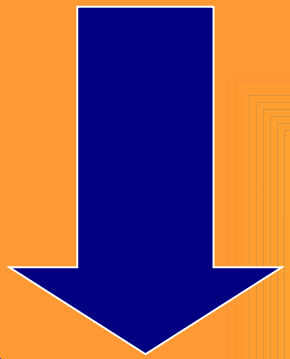
α :



? function of time?

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Oklo Phenomen

About 1.8 billion years ago, in Gabon, Westafrika.

Natural Reactor, which operated about 100 million years.

High concentration of uranium
3.7% U 235 at that time (today 0.72 %)

Moderator: water from river Oklo

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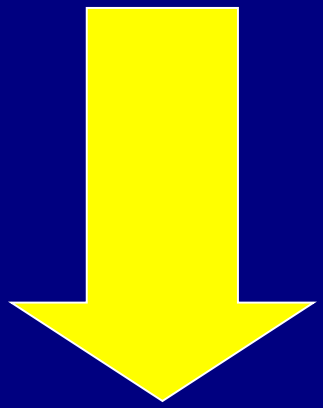
discovery: 1972



Natural reactor

(output: ~ 100 kw)

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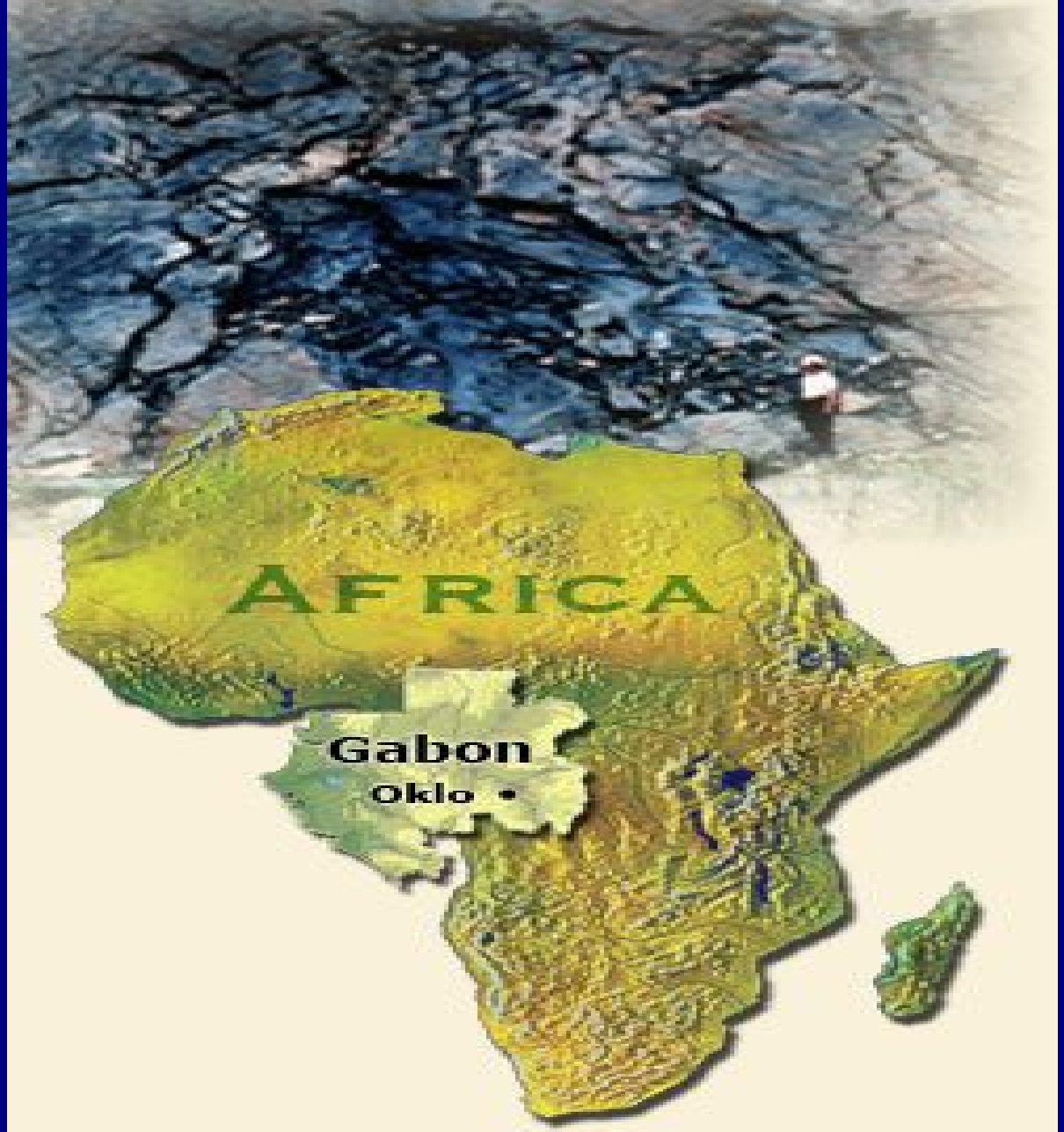

The uranium isotopes found at Oklo strongly resemble those in the spent nuclear fuel generated by today's nuclear power plants.

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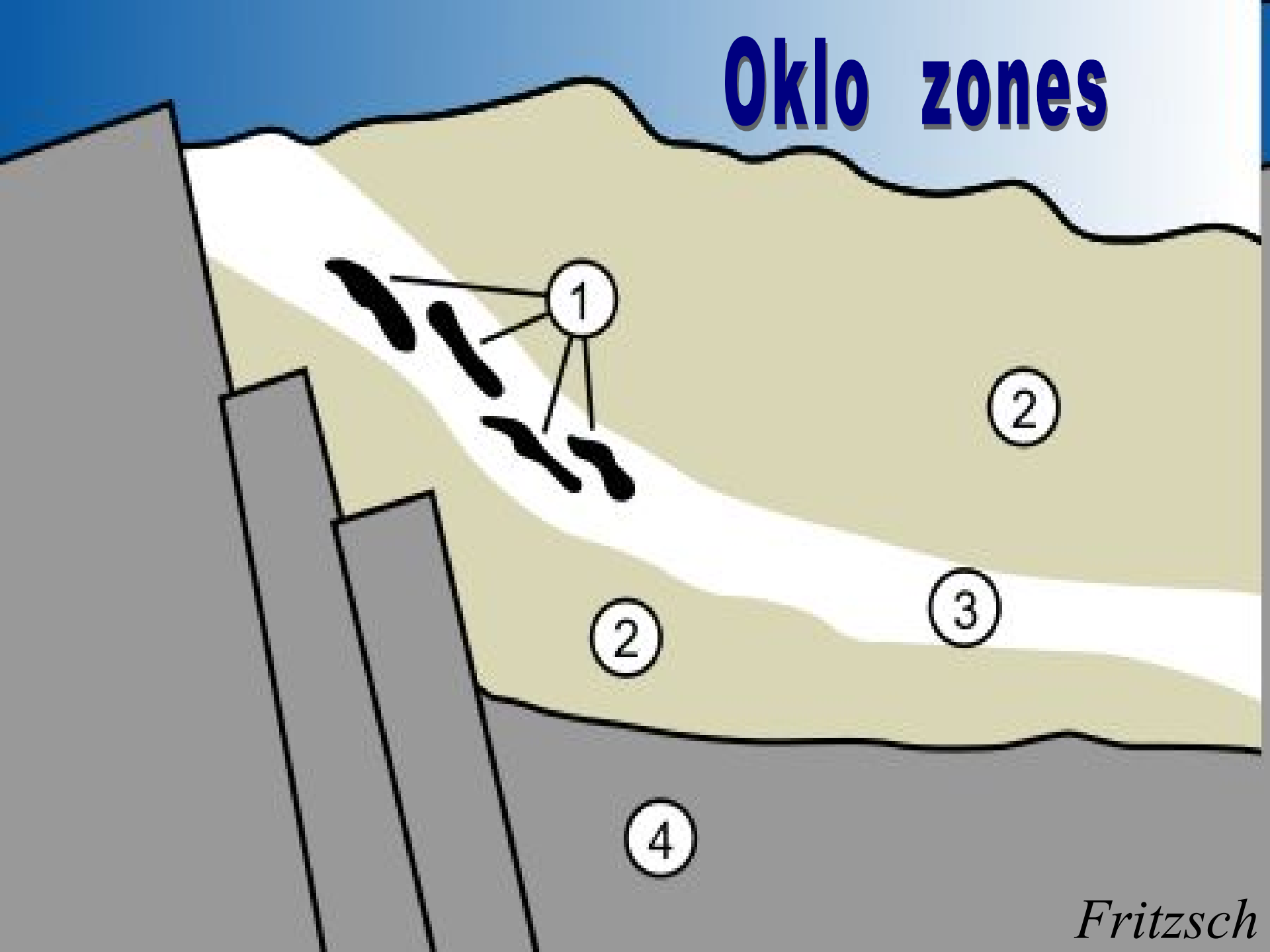
Oklo zones



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samarium:

neutron capture

$$Sm(149) + n \Rightarrow Sm(150) + photon$$

cross section about 80 kb

nuclear resonance: E = 0.0973 eV

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change of resonance position less than 0.1 e\ in 2 billion years

constraint for fine-structure constant:

$$\left(\frac{\alpha(Oklo) - \alpha(now)}{\alpha} \right) \leq 10^{-7}$$

(Dyson, Damour)

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Change of alpha per year

must be less than

$$10^{-16}$$

per year

(if no other parameters change)

==>constraint questionable

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limits on time variation of constantes, related to stable matter:

fine-structure constant
mass of electron
QCD scale
quark masses

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time variation of QCD scale:

$$\dot{\Lambda} / \Lambda \leq 10^{-15} \; / \; year$$

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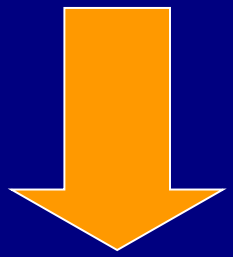
u / d - quarks

~ 20 MeV of proton mass



$$\dot{m}_{u,d} / m_{u,d} \leq 10^{-15} / year$$

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unstable particles

mass of muon, tauon,
c-quark, b-quark and t-quark

flavor mixing angles
mass of weak boson

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b-quarks

$$change(m_b) \leq 10^{-6} \ / \ year$$

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t-quark:

m = 171.3 +/- 2.3 MeV

$$change(m_t) \leq 0.002 / year$$

Fritzsch

1686

Newtons constant of gravity

1686

PHILOSOPHIÆ NATURALIS PRINCIPIA MATHEMATICA.

Autore *Ja S. NEWTONO* Equite Aurato, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

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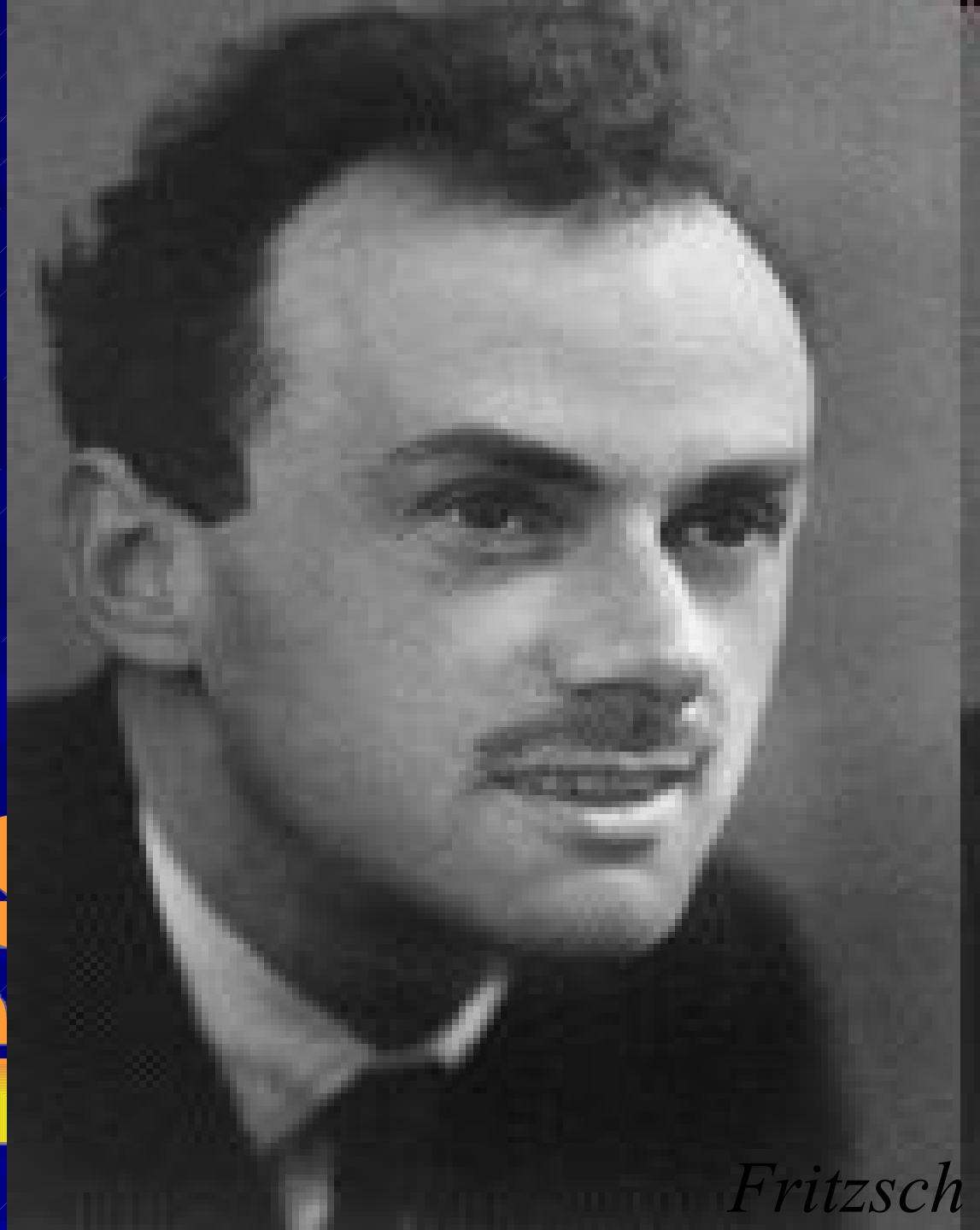
Dirac (~1930)

Time Variation of Newtons constant G



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Dirac:

$$\frac{1}{G}\frac{dG}{dt} = H \approx 6 \cdot 10^{-11}/\text{year}$$

excluded recently by satellite experiments - NASA-

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Time Variation of alpha?

Observation of fine structure of atomic levels

Quasars
5-7 billion years back

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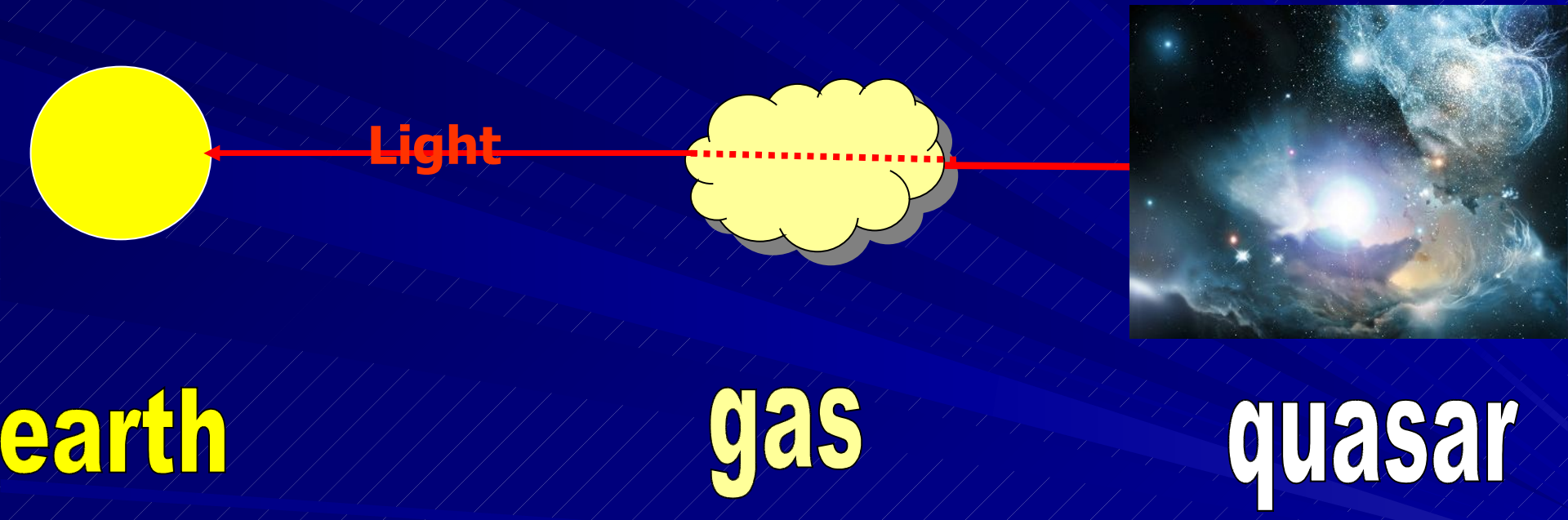
Quasar absorption spectra



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Keck telescope Hawaii

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Experiment at Keck telescope (Australia, England, USA)

(Webb, Wolf, Flambaum...)

Fine structure of Fe, Ni, Mg, Sn, A -

Quasars, back to 11 bn years in time

$\Delta\alpha/\alpha(\theta..-5\ 4\ 0\ .\ 1\ 2\ )\ 1^{5}\ 0$

$L\ i\ n\_e\ .a\ r\ \alpha A\ p\ \varphi\Omega d.\ d\ 2t\ \bar{p}\ ^{5}e0\ r\ \_y\ e\_\ c$

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N. Kanekar et al. (May 2010) arXiv:1004.5383 same result as Webb et al.

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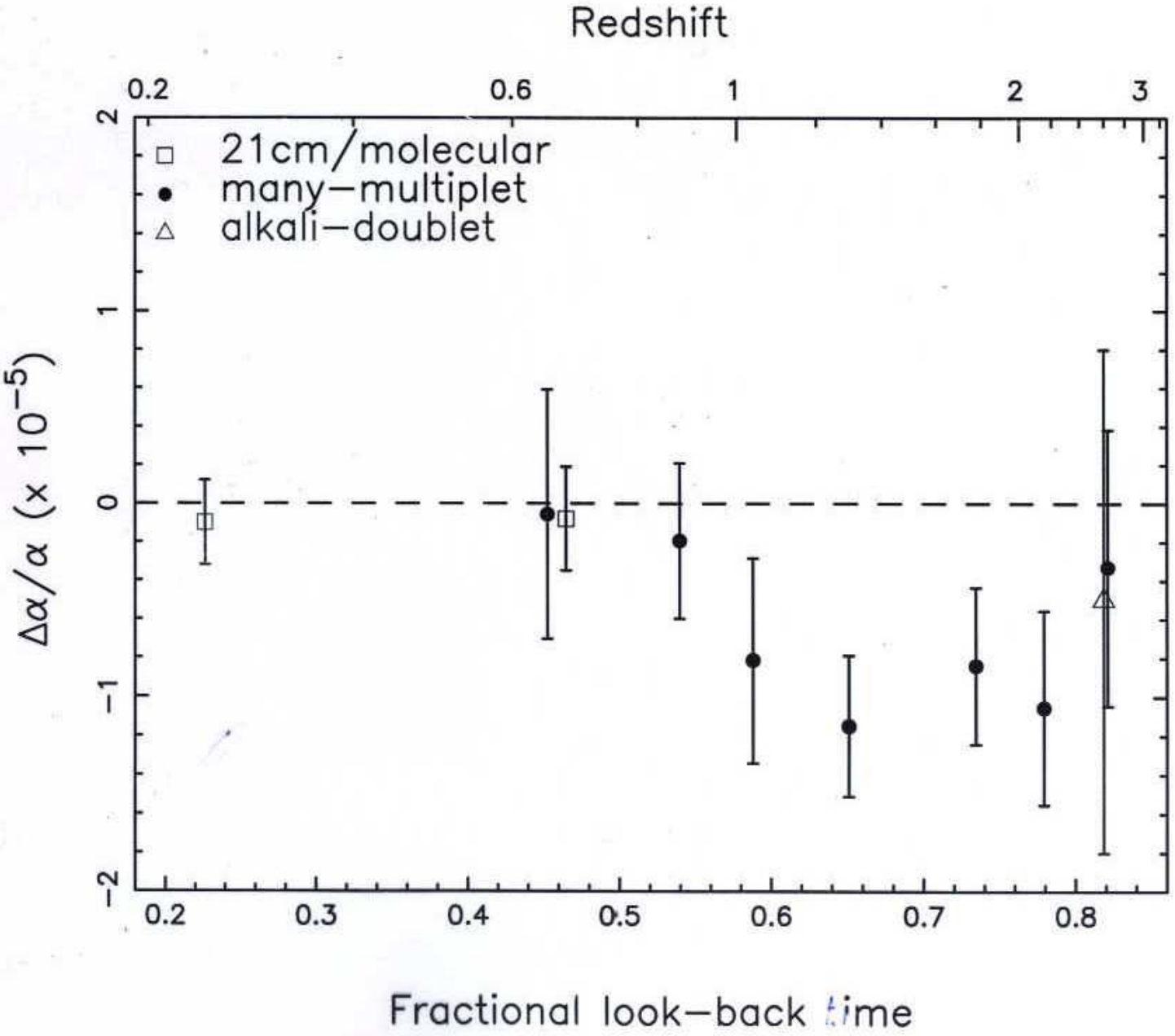
Redshift
0.2
0.6
1
2
3
21cm/molecular
many−multiplet
alkali−doublet
Δα/α (x 10^−5)
2
1
0
−1
−2
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Fractional look−back time

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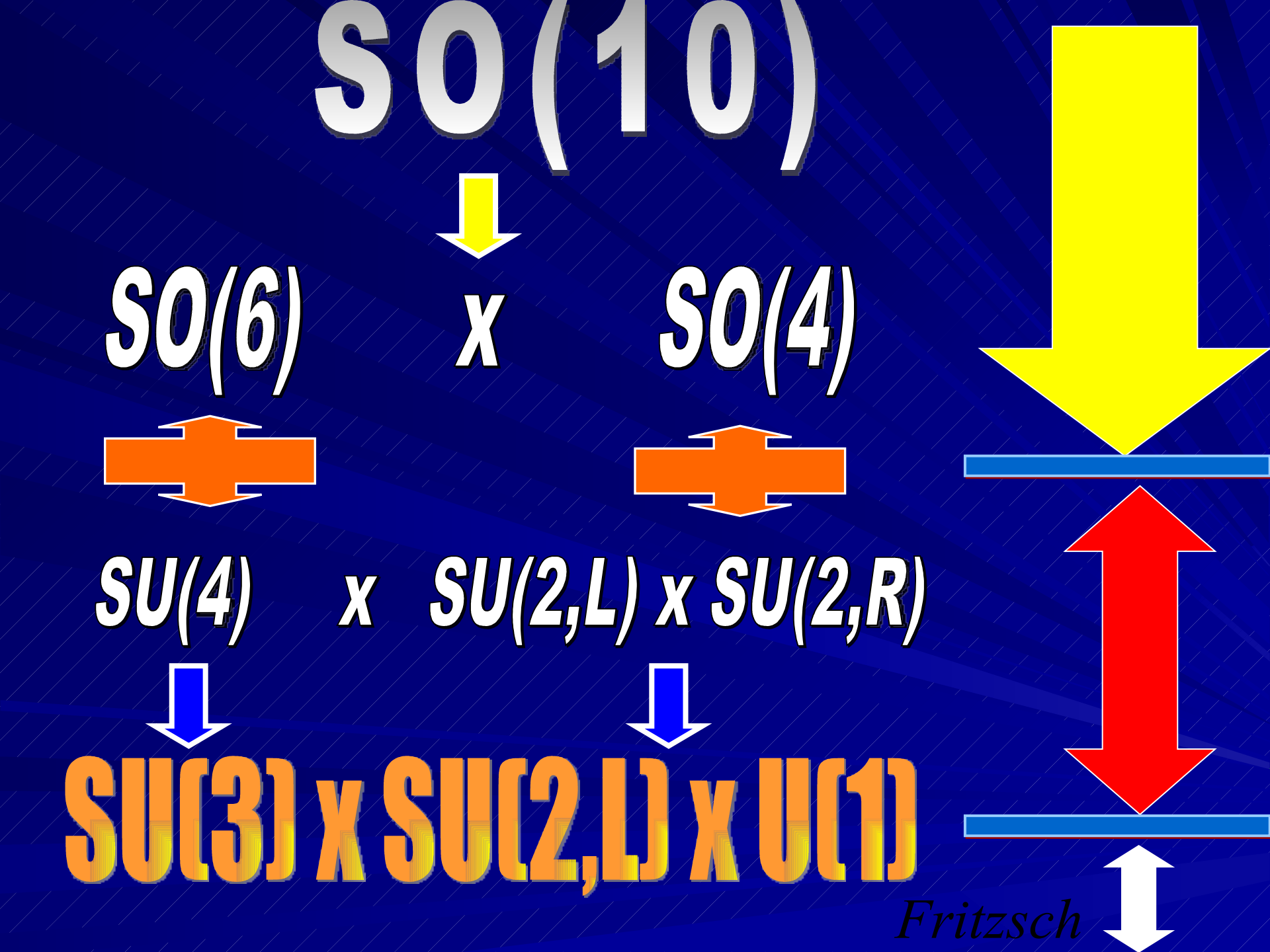
grand unification:

SU(3)xSU(2)xU(1) ==>SO(10)

(Fritzsch - Minkowski; Georgi - 1975)


SO(10)
SO(6) x SO(4)
SU(4) x SU(2,L) x SU(2,R)
SU(3) x SU(2,L) x U(1)
Fritzsch

Grand Unification

3 coupling constants

electromagnetic, weak and strong interactions

reduced to two parameters:

unification scale
and
unified coupling

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SO(10)

Fermions in 16-plet

(incl. righthanded neutrinos)

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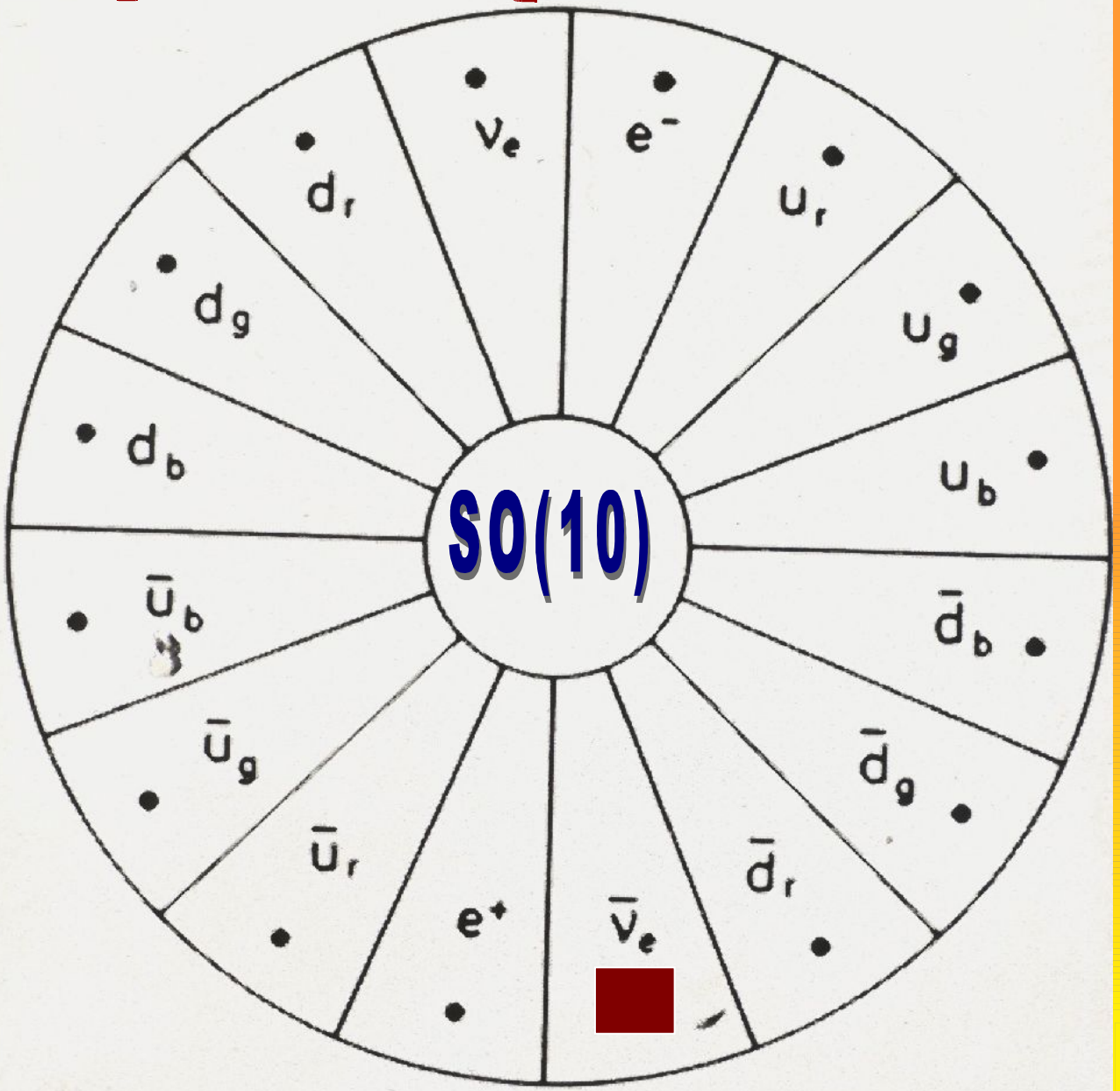
Leptons and Quarks in SO(10)



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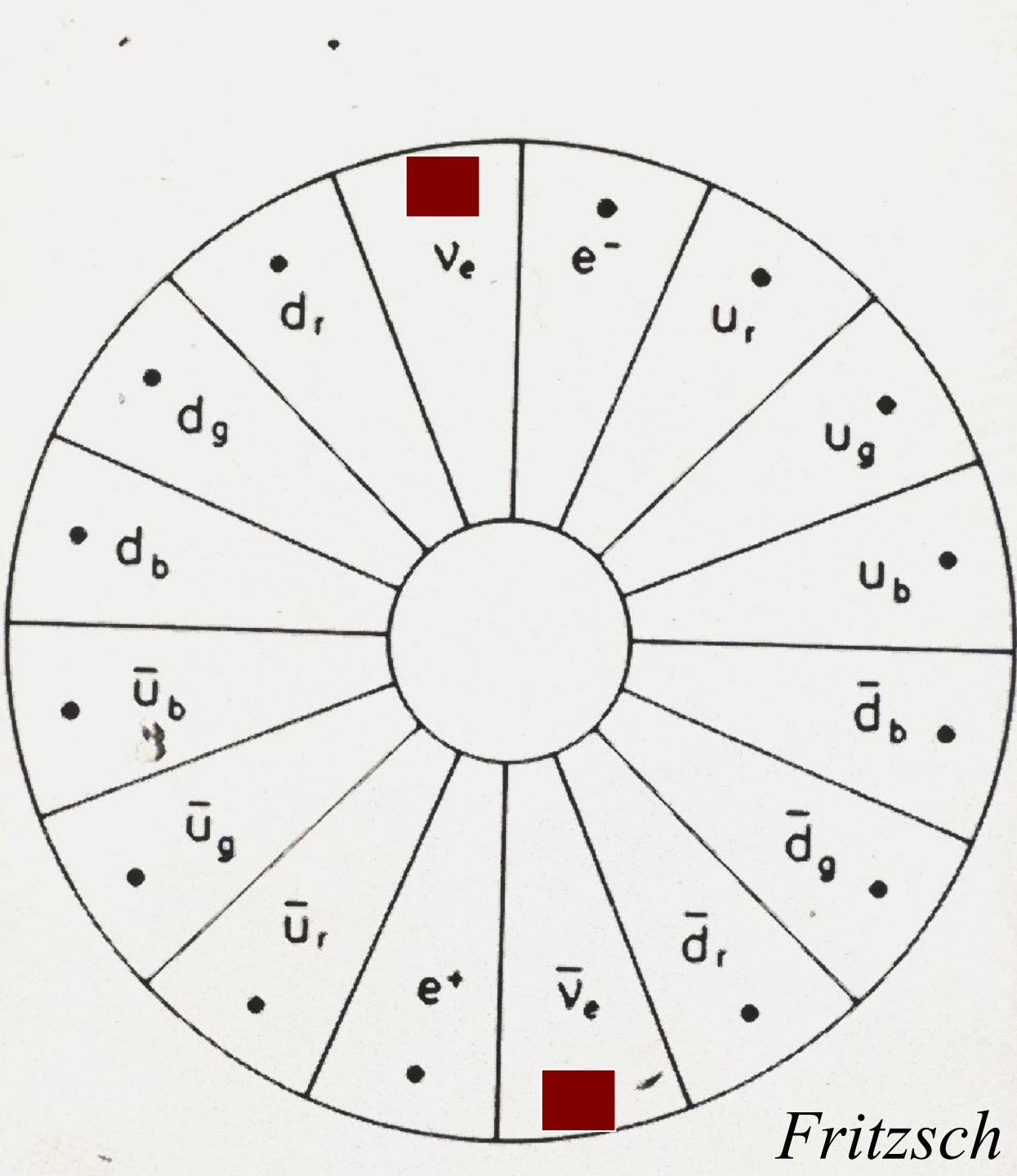
Neutrinos have a mass



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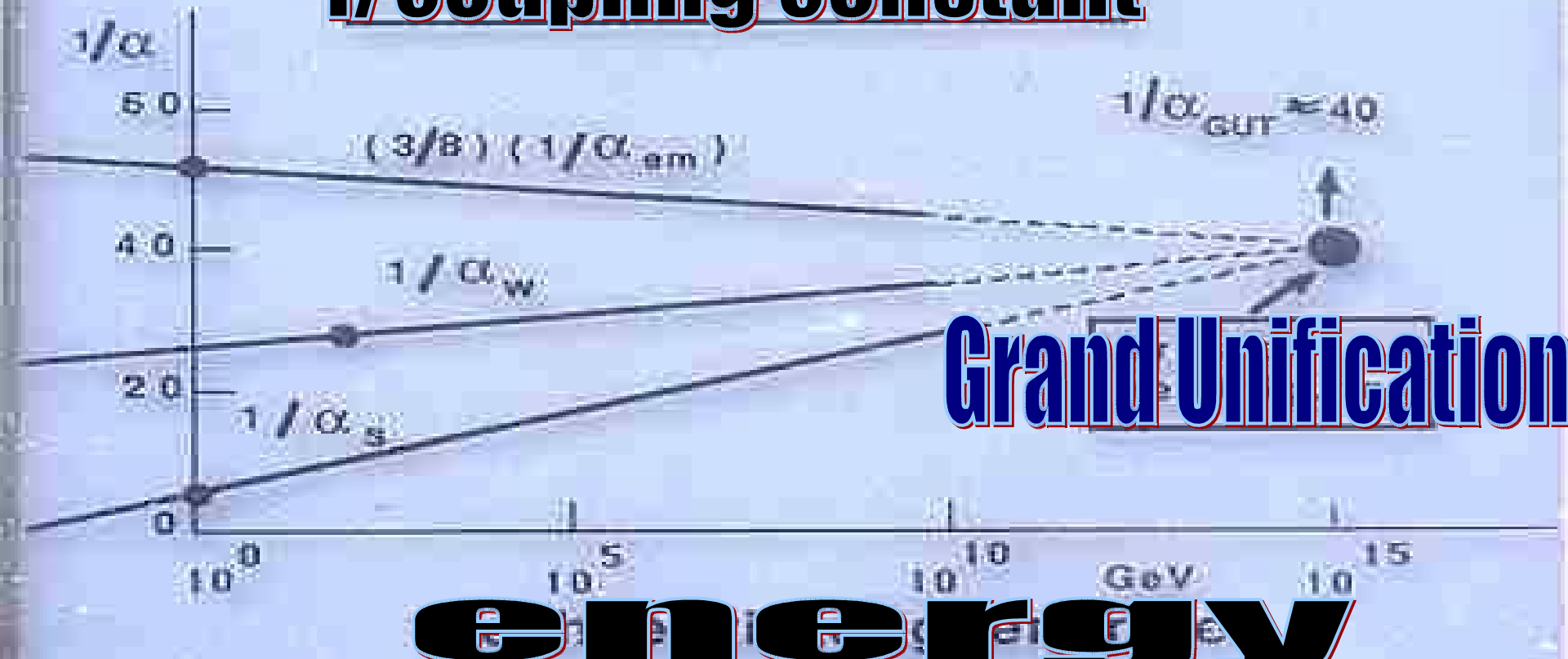
1/coupling constant



Grand Unification

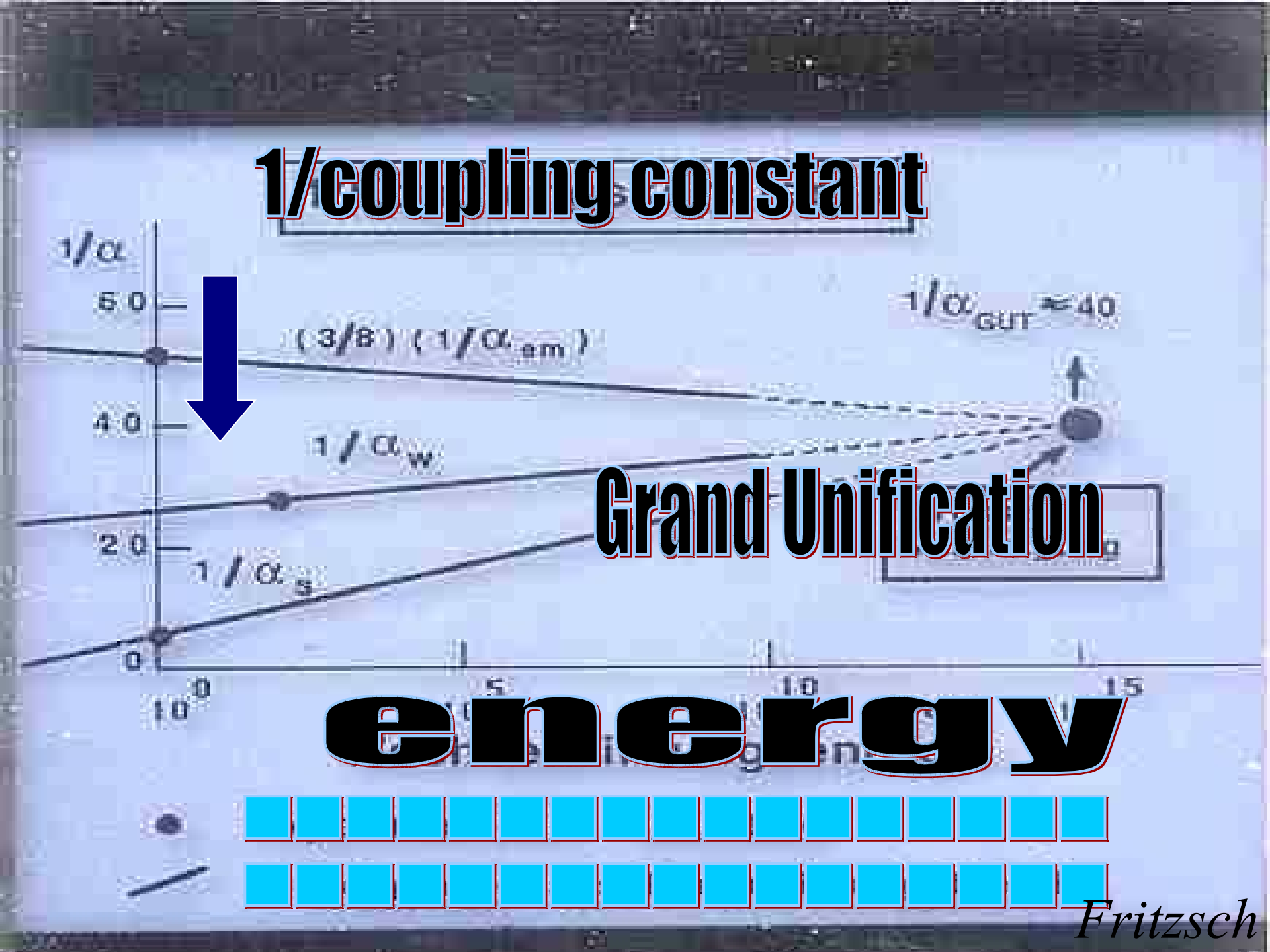
energy

Fritzsch

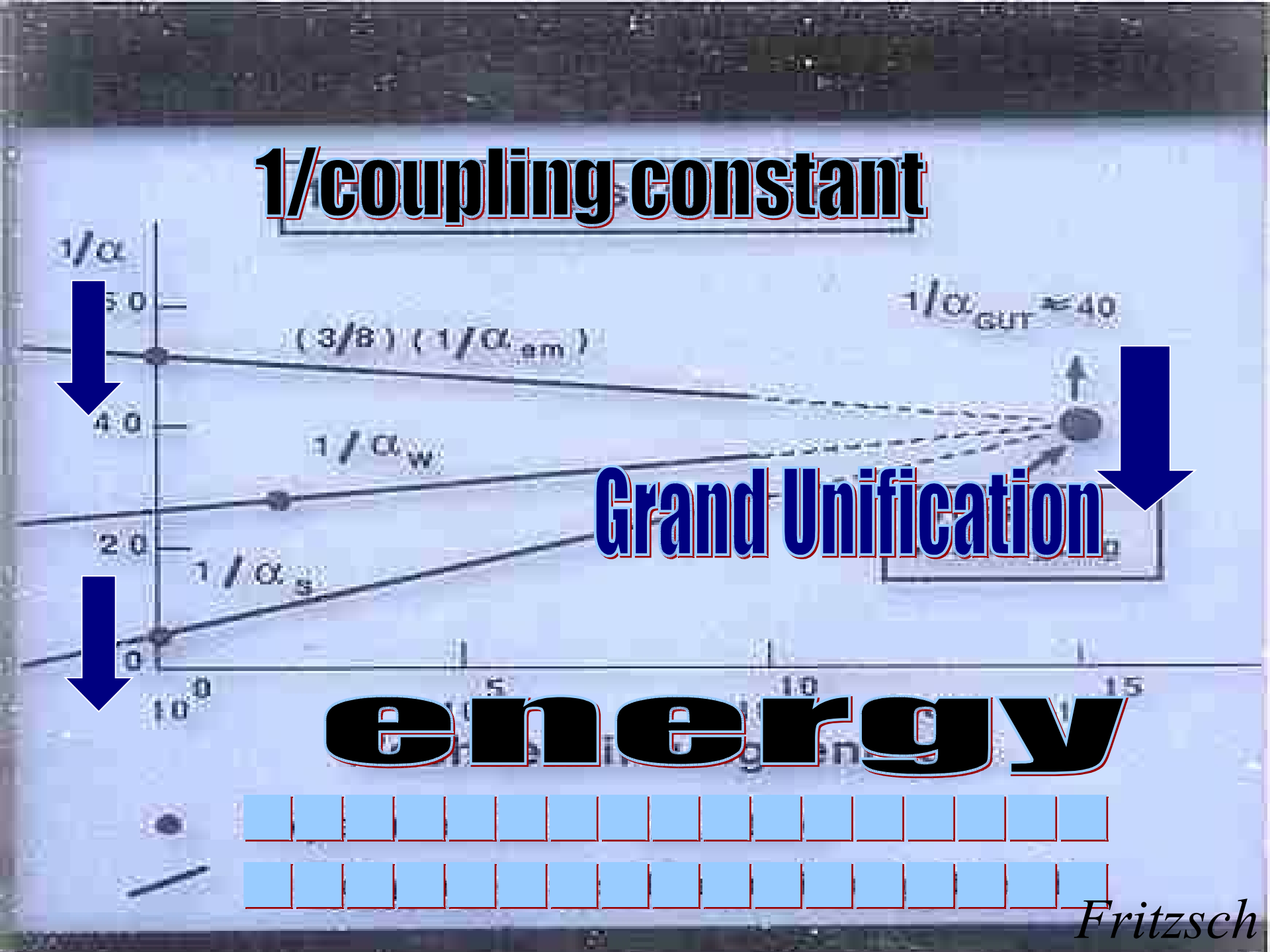
time change of

α?

Fritzsch


1/coupling constant
1/α
60
40
20
0
(3/8) (1/α em)
1/α GUT ≈40
1/α w
1/α s
Grand Unification
energy
10^0
5
10
15

Fritzsch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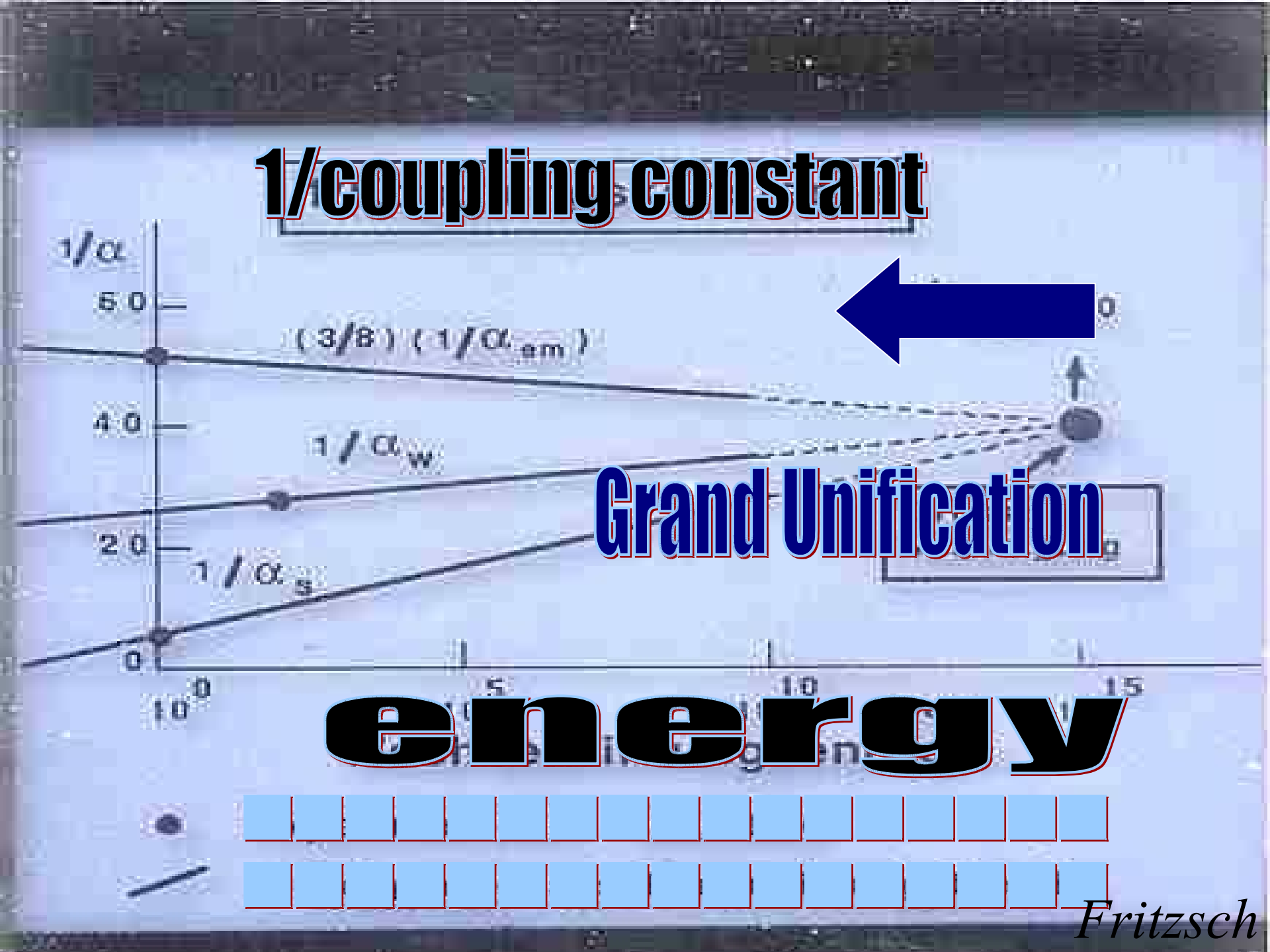
1/coupling constant
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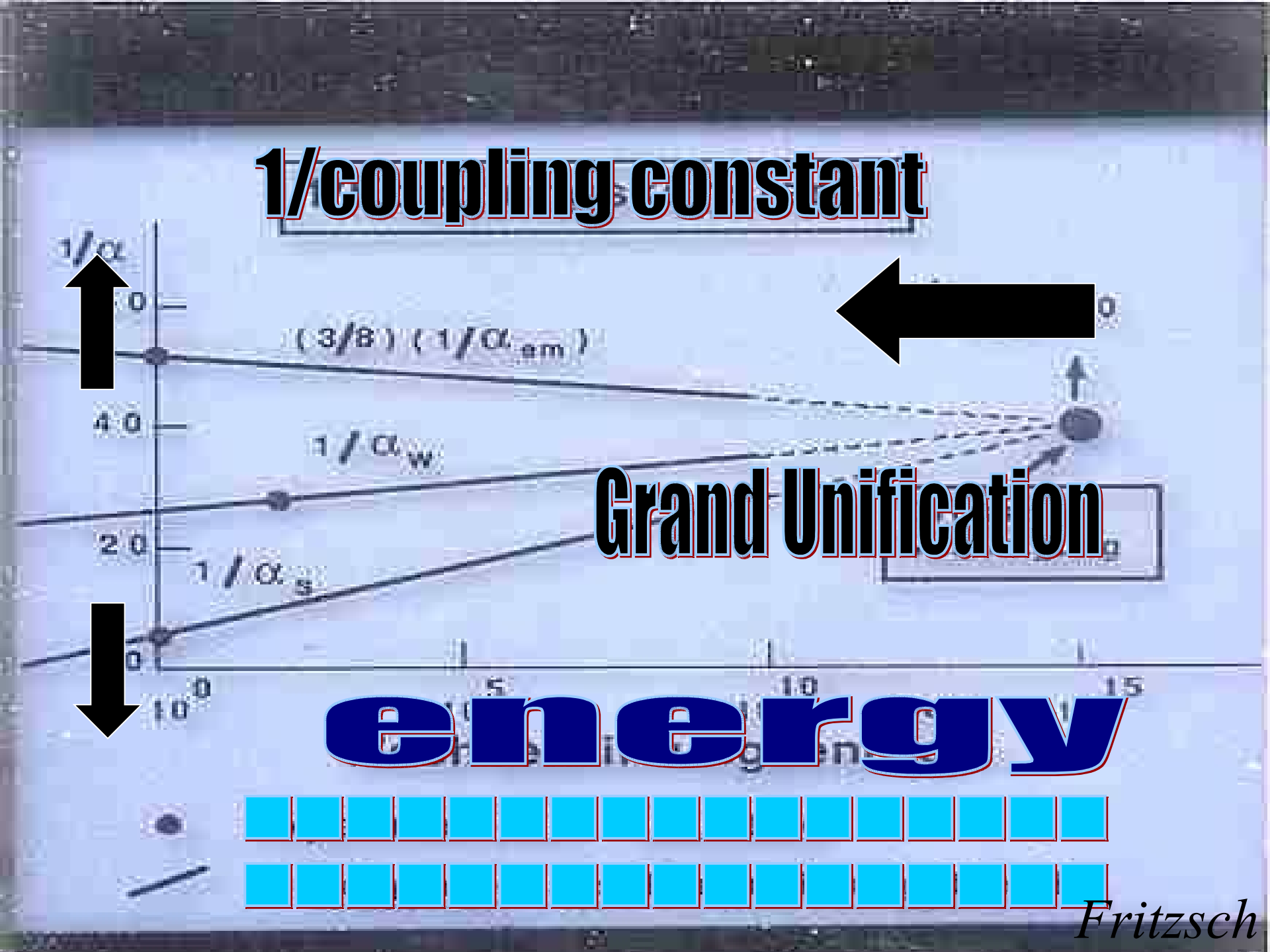
1/coupling constant
Grand Unification
energy
Fritzsch

$$d\alpha / d\ \alpha t^2 = \frac{8}{3} d : \alpha_s c \alpha (s^2 \frac{1}{\pi} n_2 \quad s)_u \quad t \quad t \Lambda d \quad _G \quad d \quad \Lambda t :$$

Calmet, Fritzsch Langacker, Segre **2002**

no change of unification scale

$$d\alpha / d\ \alpha^2 t \doteq \frac{8}{3} d\alpha_s / d\ \alpha t$$

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$d\Lambda /\ \ d.\ \Lambda 3\square\ t\ 8\quad \not{d}\ \ 8\alpha\ \ \underline{d}\_\quad \not{\alpha}$

Magnetic moments of atomic nuclei would change accordingly, per year

$3\ \ ,*9\ \ 1^{1}\ (\ $

Fritzsch

change of unification scale

$$\dot{\Lambda} / \Lambda \approx (-31)\dot{\alpha} / \alpha$$

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experiments:

MPQ Munich

NIST Boulder

Fritzsch

Time:

measured by Cesium clocks

Hyperfine transition ➔ magnetic moment of the cesium nucleus.

Would be affected by time change of QCD scale

Cesium: 9 192 631 770 Hz

(definition of time)

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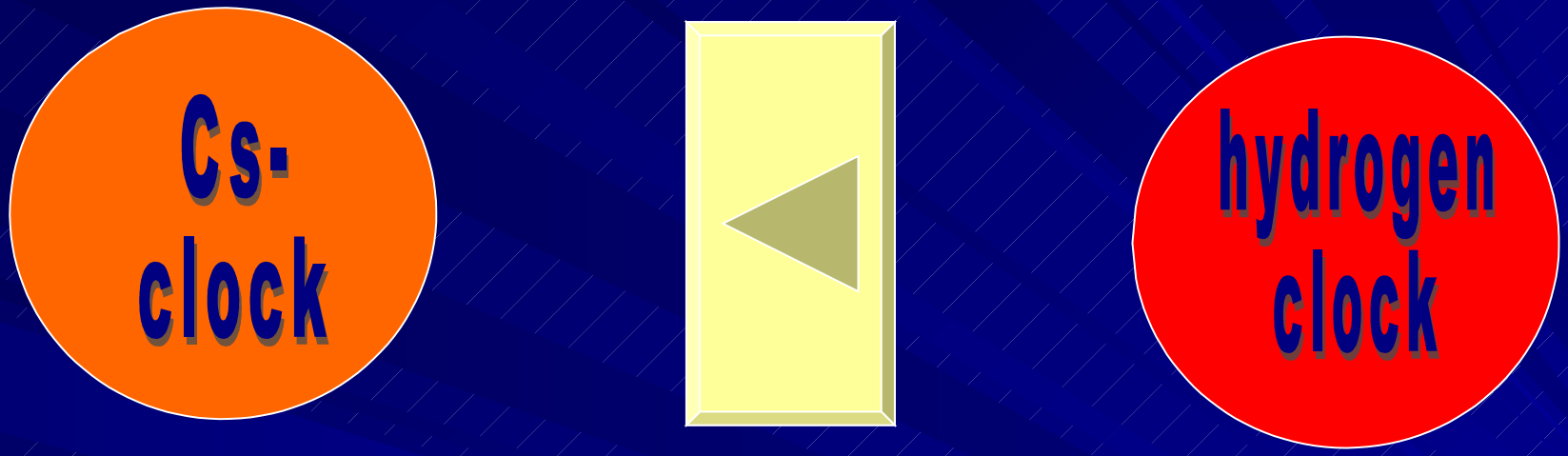
comparison:



difference: 3 Cs oscillations per day

Experiment
(T. Hänsch, MPQ)

Fritzsch

Fritzsch

MPQ-experiment

486 nm dye laser in hydrogen spectrometer

Reference: cesium clock Pharao LPTF Paris

Hydrogen: 1s-2s transition

2 466 061 413 187 127 (18) Hz

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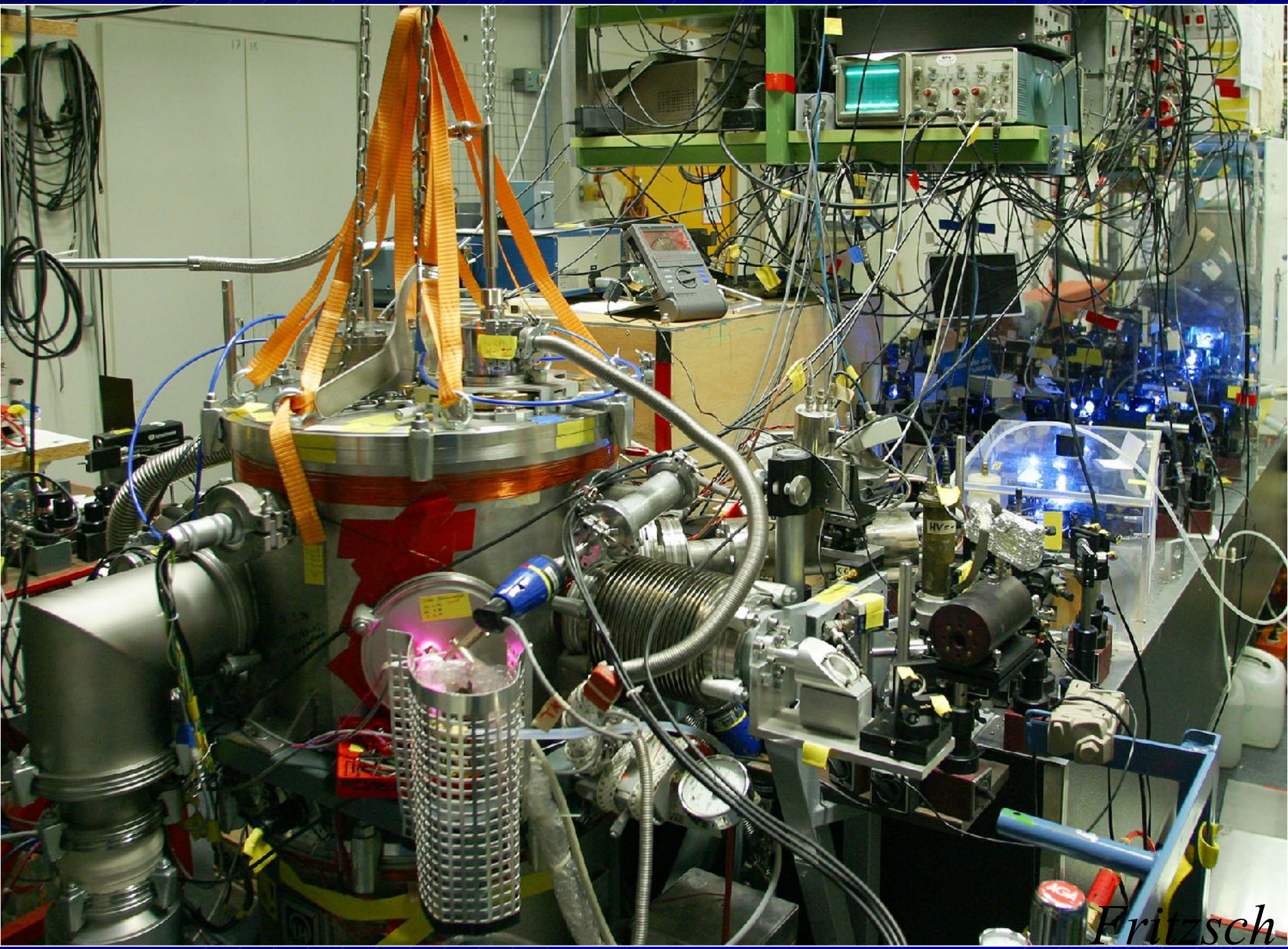
Fritzsch

result of Haensch:

$d\mu / : (\mu d 2 = \xi \square 4 \ 6 t \ . \ 8 \ ) y t^{1} \ 0^{5-}$

Fritzsch

experiment :

$d\mu/\ :\ (\mu d2=\#\square\ 4\ 6\ .\ 8\ )\ y1^{1}\ 0^{5-}$

expected:

$d\mu/d\ :\mu t\approx 2\quad 1^{-1}\ (\ $

==> excluded!

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Simultaneous change of the unified coupling constant and the unification scale?

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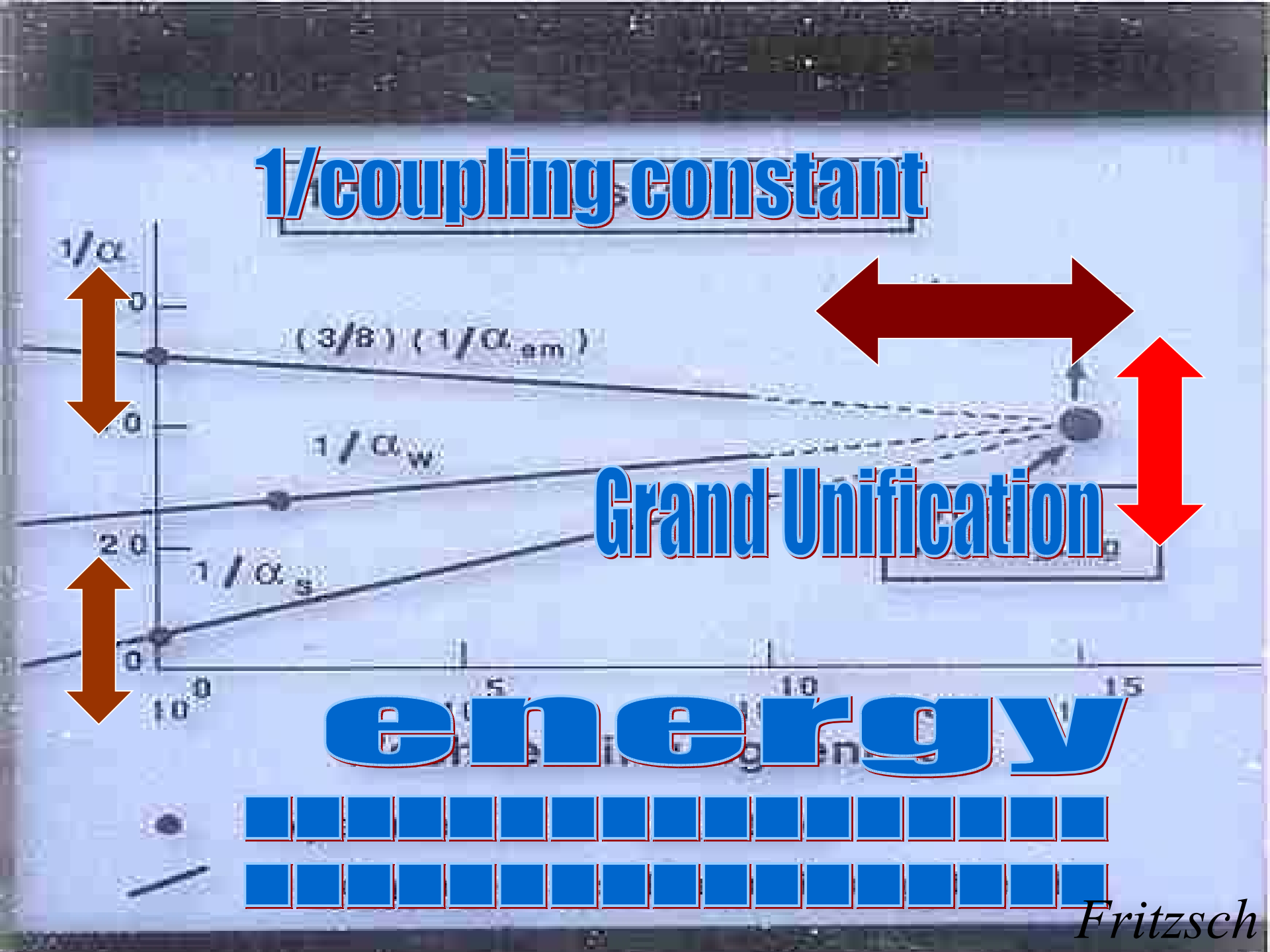
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1/α w
1/α s
10^0
5
10
15
Grand Unification
energy

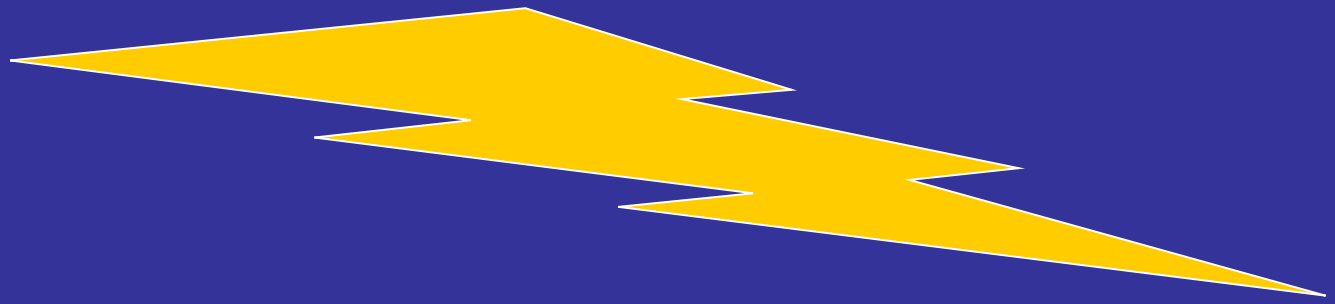
Fritzsch

Simultaneous change of unif. coupling and unif. scale
Partial Cancellation of effect?
(expected in superstring models)

$$\frac{8}{3}\,d\alpha_s/dt \quad t\alpha_s^2 \quad t\alpha_s^2 \quad t\alpha\, c + \frac{1}{\pi}\left(-\frac{1}{2}\right) n_t \quad s \quad t_G \quad d \quad t\,\Lambda t :$$

cancellation

Fritzsch



$$\dot{\Lambda} / \Lambda \leq 10^{-14} \quad / \, year$$

Fritzsch

Hänsch et al.

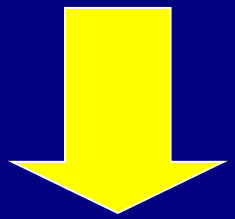
$\sim 3 \times 10^{-15}$/year

Fritzsch


Reinhold et al., 2006
VLT Chile
Fritzsch

Reinhold et al. PRL 96 (2006)
2 quasars, 12 bn. years away

time variation of ratio
proton mass / electron mass



$$\Delta\mu/\mu(20.6)\,10^{-5}$$

Fritzsch

$$\Rightarrow \Delta\Lambda / \Lambda 03 \qquad 1^{-1}\, 0^{5} y \not{e}$$

(if the electron mass is taken to be constant)

Fritzsch

$=> \Delta\Lambda / \Lambda 03 \quad 1^{-1} \, 0^{5} y \, \not{d}$

==> Hänsch

Fritzsch

The masses of atomic nuclei will depend on time!

energy not strictly conserved

Fritzsch


does alpha depend on space?

Webb et al, 2010:

VLT and Keck

small space dependence of fine-structure constant

Fritzsch

Conclusions:

28 constants of nature

24 constants ➔ mass parameters

Grand unification relates the elm., strong and weak interactions.

Fritzsch

The time variation of alpha leads to a time variation of the QCD scale.

The MPQ Experiment rules out the simplest model.

An effect seems to be present, about a factor 10 less than naively expected, consistent with the observed variation of the electron-proton mass ratio.

Fritzsch

Necessary:

Both unification scale and
unified coupling
must change in time.

(expected in superstring
models)

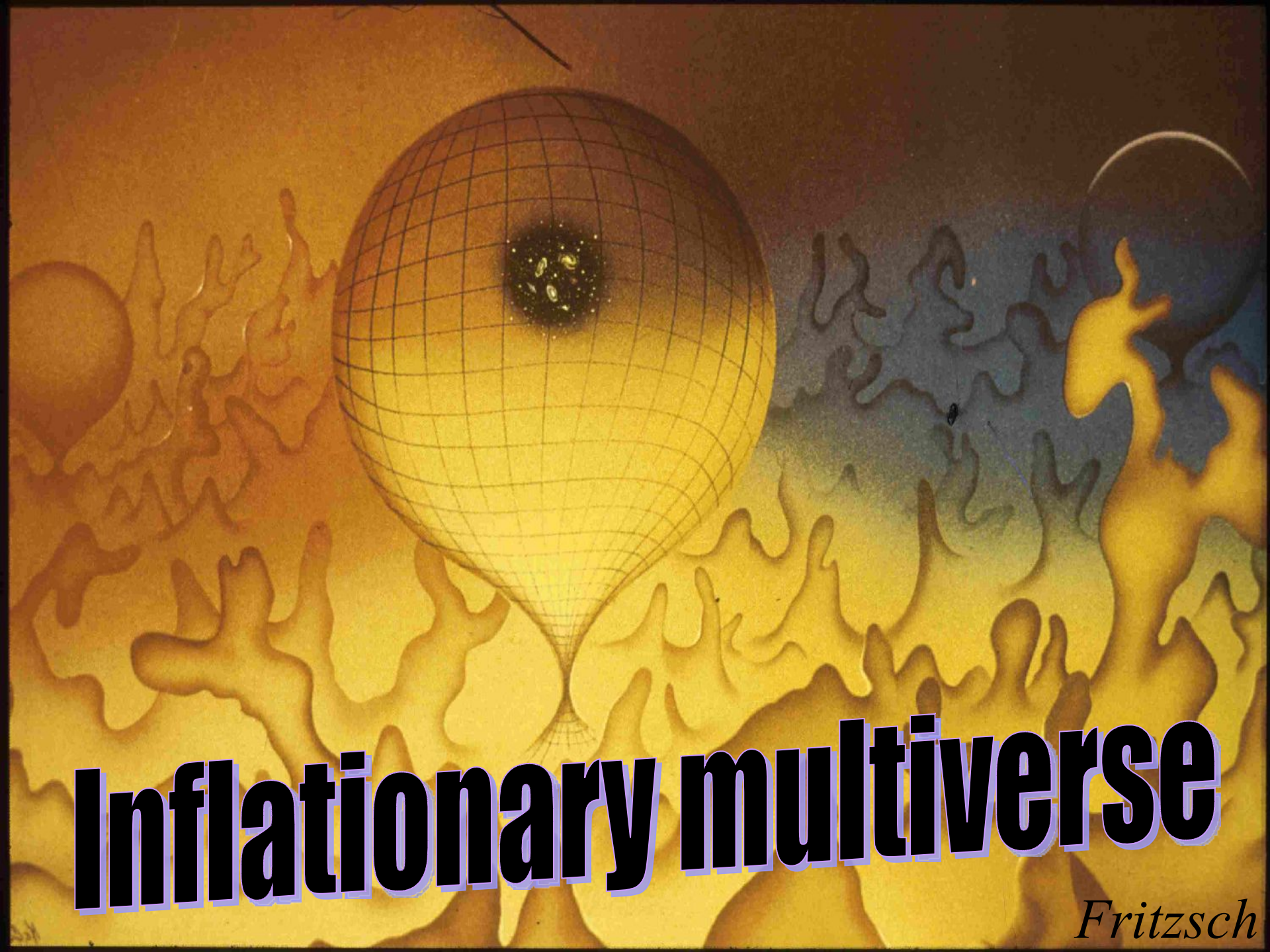
Fritzsch

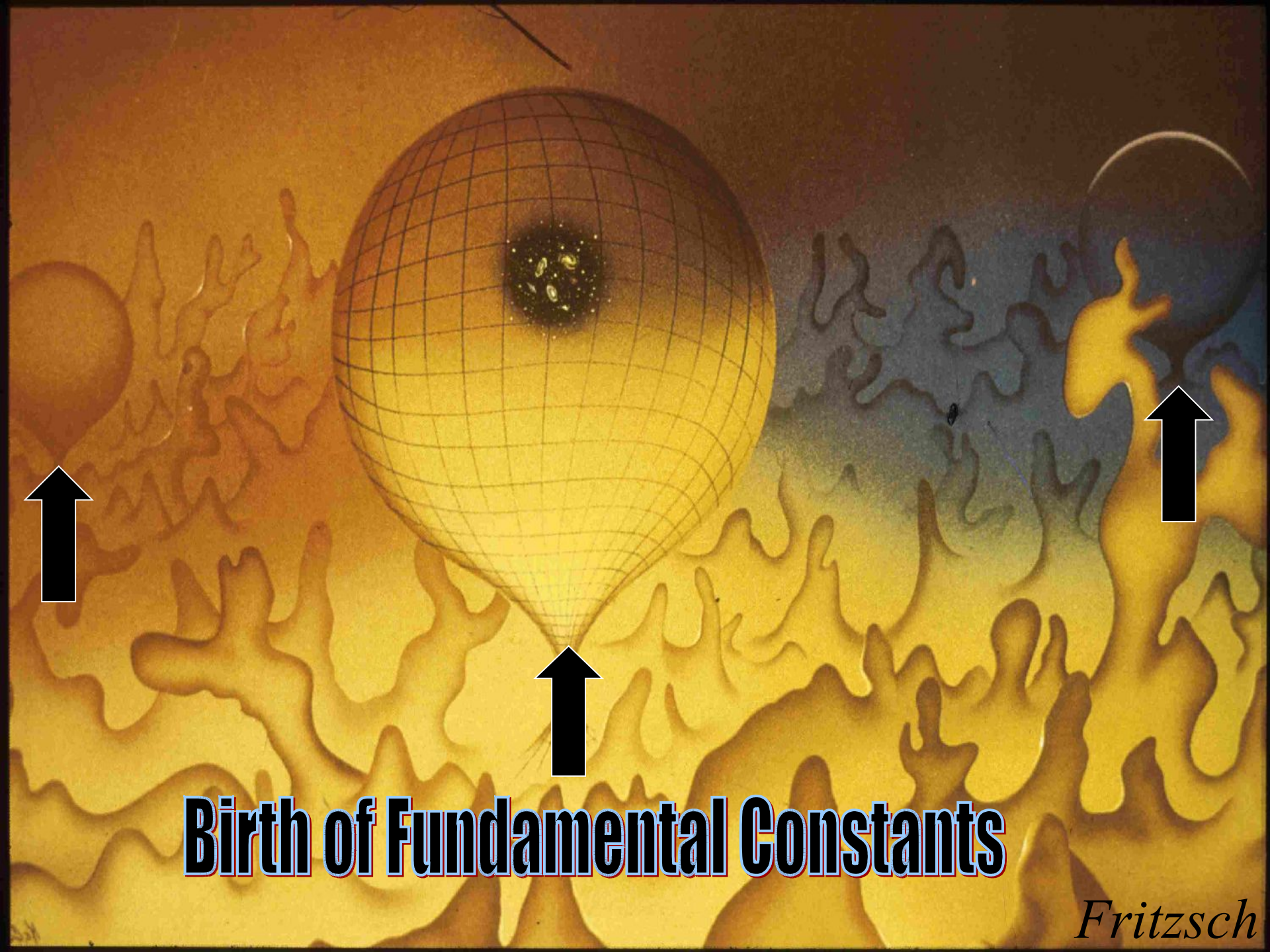
Perhaps all fundamental constants are not constant, but functions of time?

==> cosmology?

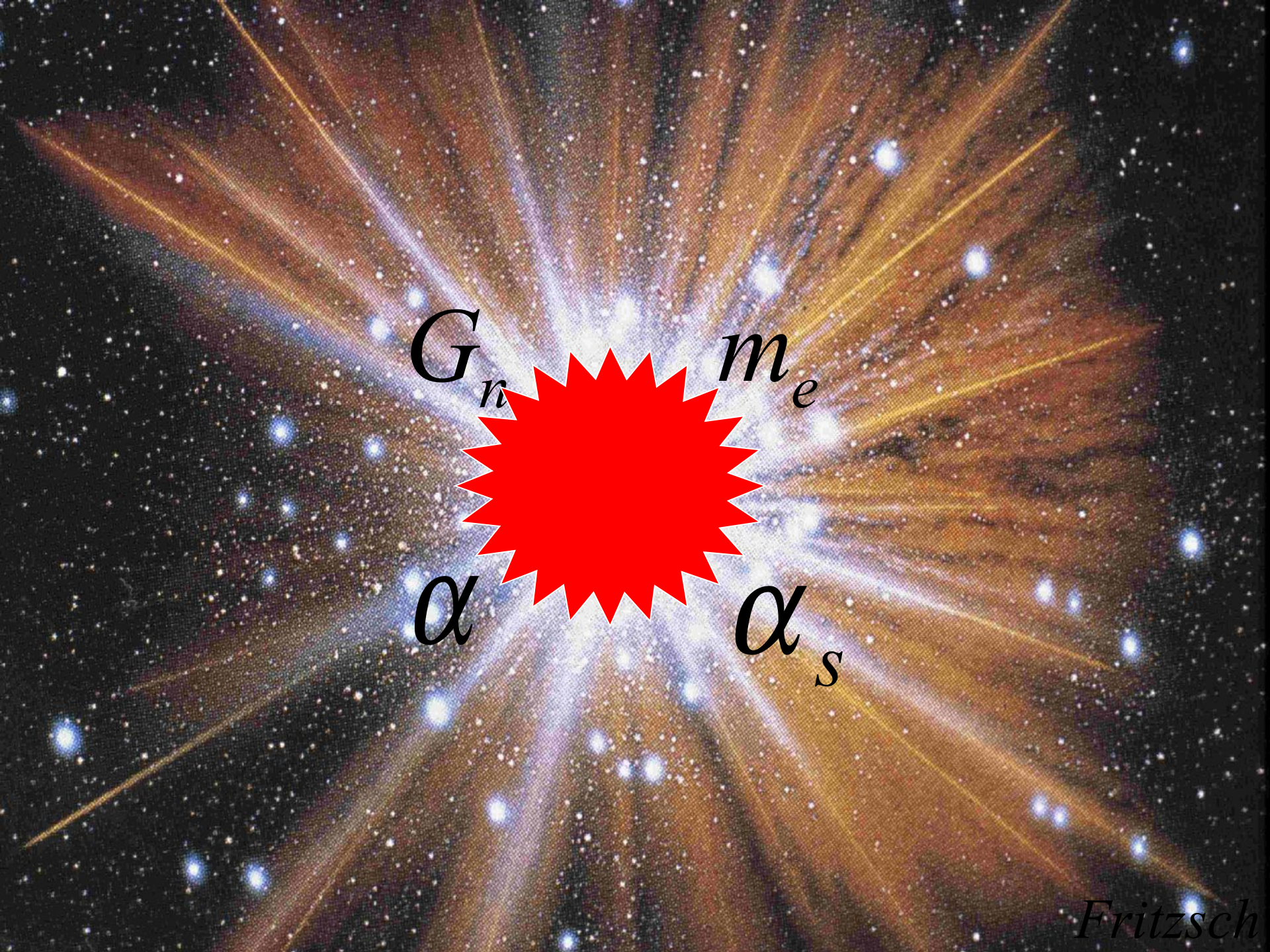
Fritzsch


Universe
⇒ Multiverse
Fritzsch

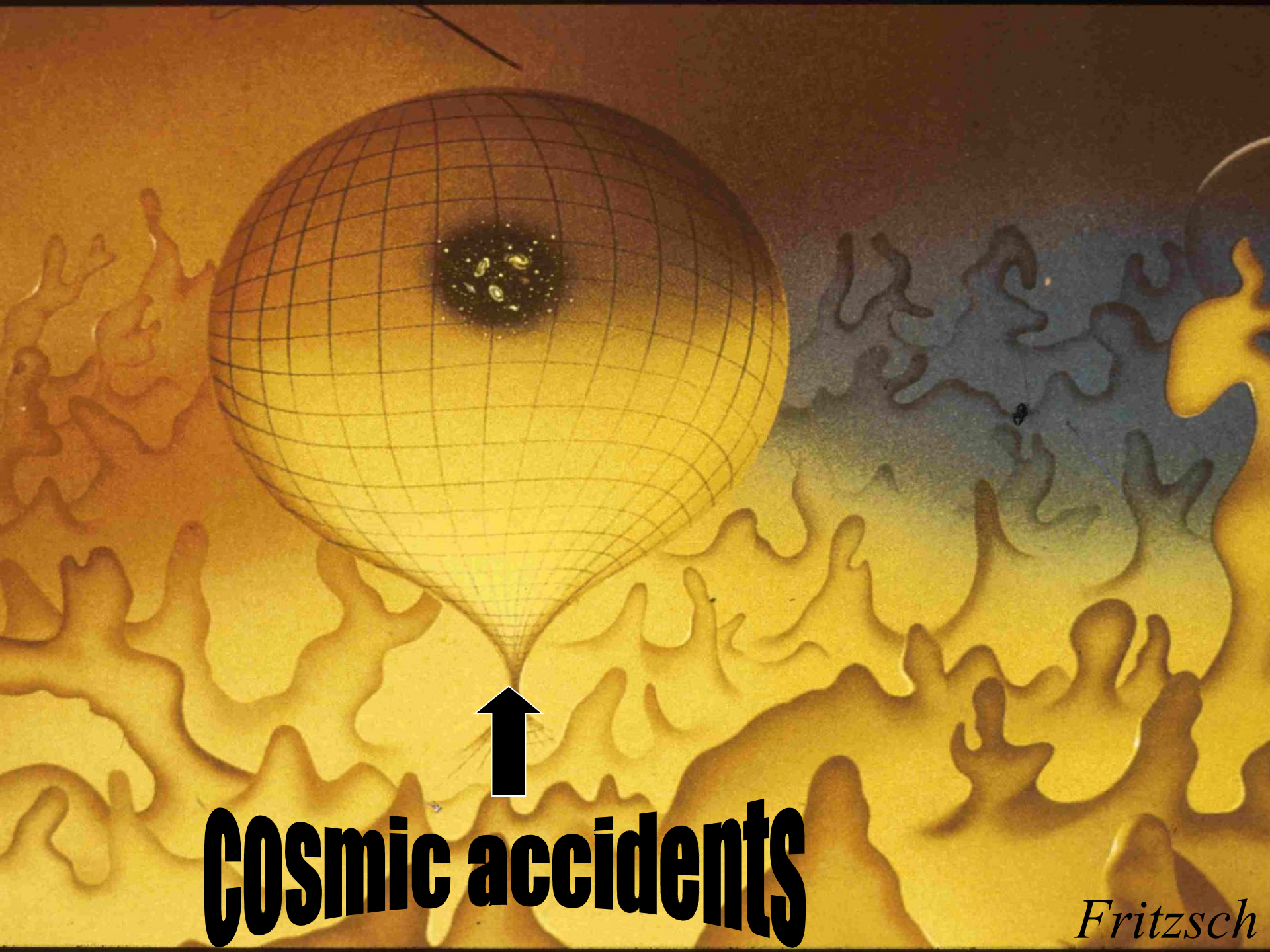

Inflationary multiverse
Fritzsch


Birth of Fundamental Constants
Fritzsch

Fritzsch



Fritzsch


Cosmic accidents
Fritzsch