

hi

Day 28, 24.04.2018

Particle Physics 3 & Cosmology 5

housekeeping

The end game: next slide

Particle Physics:

Readings: Oerter, Cosmic Horizons, and Hobson

 ***Hobson_quantum_fields.pdf is chapter 17***

Homework #13 is: partly from MasteringPhysics - normal due date
partly on paper...see the blog

Feynman Diagram rules

3 movies in the lecture slide directory - you'll need them for homework
and the final

they are: primitiveDiagrams_X. mp4

where $X = 0,1,2$



last 2 1 weeks & final

Homework #13 will be assigned 4/21 and due 4/28 - normal rotation

On-line final exam will be assigned Sunday, 4/29 and due Tuesday night, May 1

will cover material since midterm plus the last week of class

There is 1 more 10 point quiz (stay tuned)...

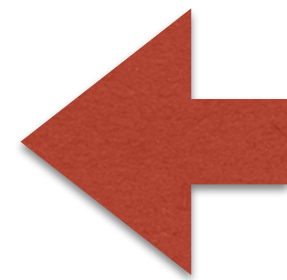
~~only the shadow knows when...~~ actually, watch the blog. Quiz up tomorrow, return Thursday in class.

Remember when I was sick?

been trying to catch up, but not going to make it. Hence:

Final Exam day:

1. You'll arrive at 0745 on May 4, here. I know.
2. I'll provide bagels. You supply liquids.
3. We'll have a quiz.
4. I'll finish with about a 1 hour grand finale, lalapalooza, mind-bending lecture
5. You'll do your Feynman Diagram Project
6. There will be no poster project this year



*I'm did rethink this, do it by
May 4th midnight, but no
presentation*

now hear this:

sirs@msu.edu <sirs@msu.edu>

Inbox - Exchange April 16, 2018 at 7:34 AM

S

SIRS Online Forms

To: brockr@msu.edu <brockr@msu.edu>



To: RAYMOND L BROCK

From: sirs@msu.edu

Student Instruction Rating System (SIRS Online) collects student feedback on courses and instruction at MSU. Student Instructional Rating System (SIRS Online) forms will be available for your students to submit feedback during the dates indicated:

ISP 220 001: 4/16/2018 - 5/16/2018
ISP 220 002: 4/16/2018 - 5/16/2018

Direct students to <https://sirsonline.msu.edu>.

Students are required to complete the SIRS Online form OR indicate within that form that they decline to participate. Otherwise, final grades (for courses using SIRS Online) will be sequestered for seven days following the course grade submission deadline for this semester.

SIRS Online rating summaries are available to instructors and department chairs after 5/16/2018 at <https://sirsonline.msu.edu>. Instructors should provide copies of the rating summaries to graduate assistants who assisted in teaching their course(s). Rating information collected by SIRS Online is reported in summary form only and cannot be linked to individual student responses. Student anonymity is carefully protected.

If you have any questions, please contact Michelle Carlson, (mcarlson@msu.edu, (517)432-5936).

honors project began

https://qstbb.pa.msu.edu/storage/Homework_Projects/honors_project_2018/

contains:

the first instructions: the plan & tutorial

the second instructions – v2 uploaded, added a missing student

the data, assigned by name in the second instructions - see next

dates:

complete first part, March 16

analyze data by April 24 and hand in complete writeup at the final exam

have

I ~~need~~ a Section 2



to test the Z-path uploading machinery and instructions

working on it. I'll be in touch via email.

here's what we've learned

There are three kinds of fields: messenger fields, quark fields, and lepton fields

oscillations - the particles - of quark fields are the constituents of protons and neutrons, but also hundreds of other "particles" that nature will produce

oscillations of lepton fields - electrons and the electron neutrino and the other two lepton pairs, round out "matter"

Messenger fields carry the four known forces from one particle to another

now the jargon

gets a little more
straightforward

now defined:

Hadrons: particles made of quarks.

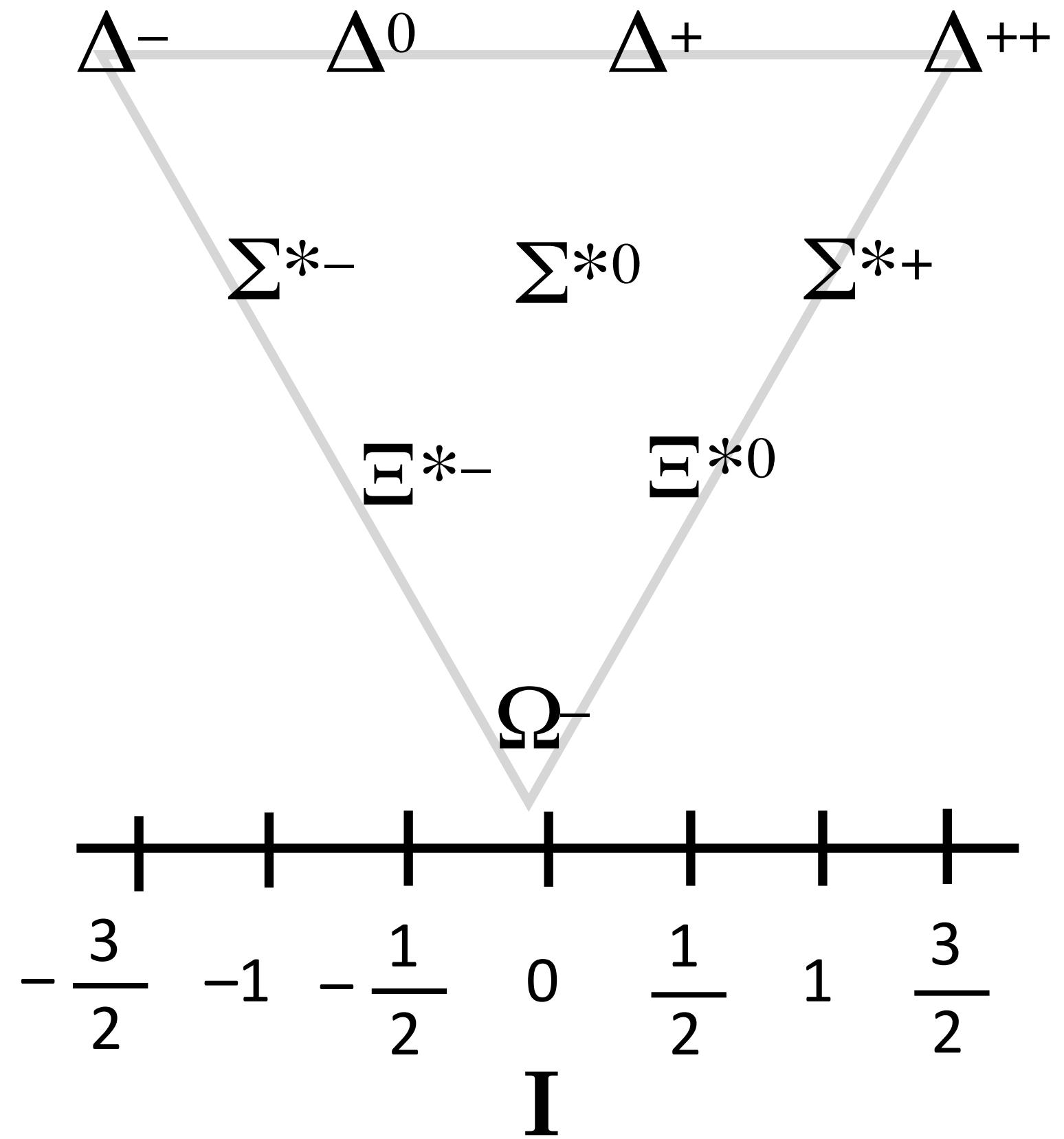
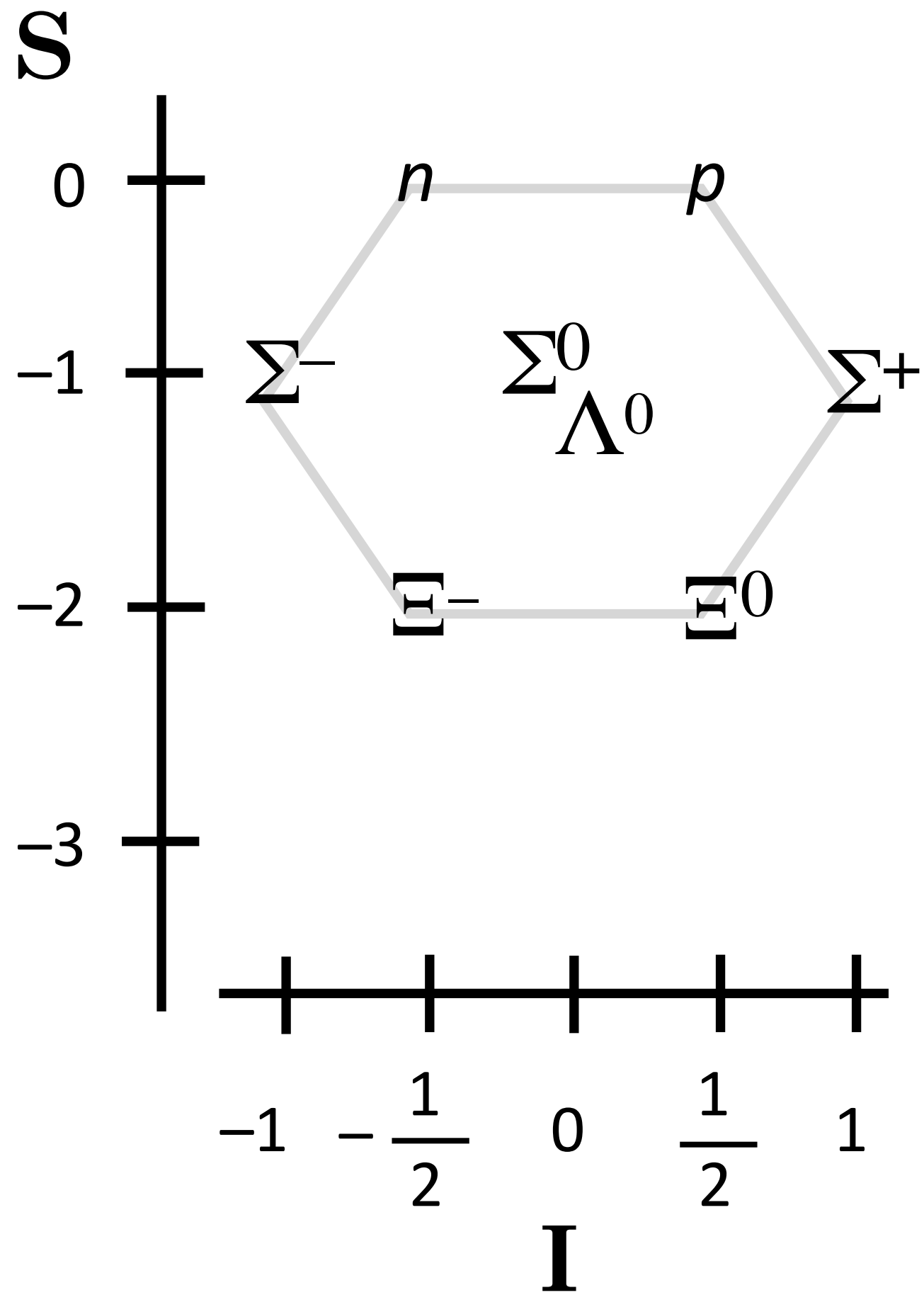
now defined:

Baryons: particles made of 3 quarks.

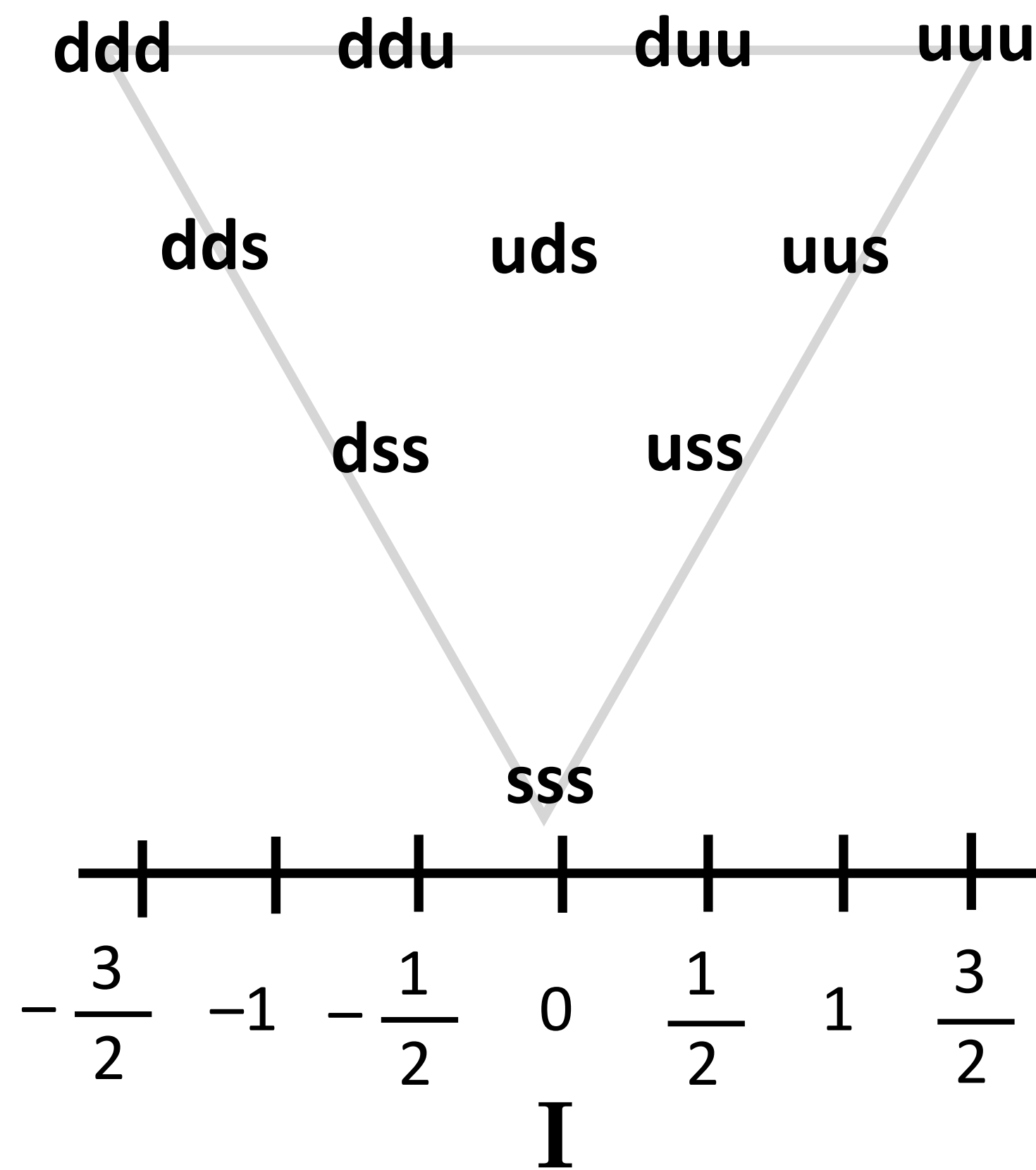
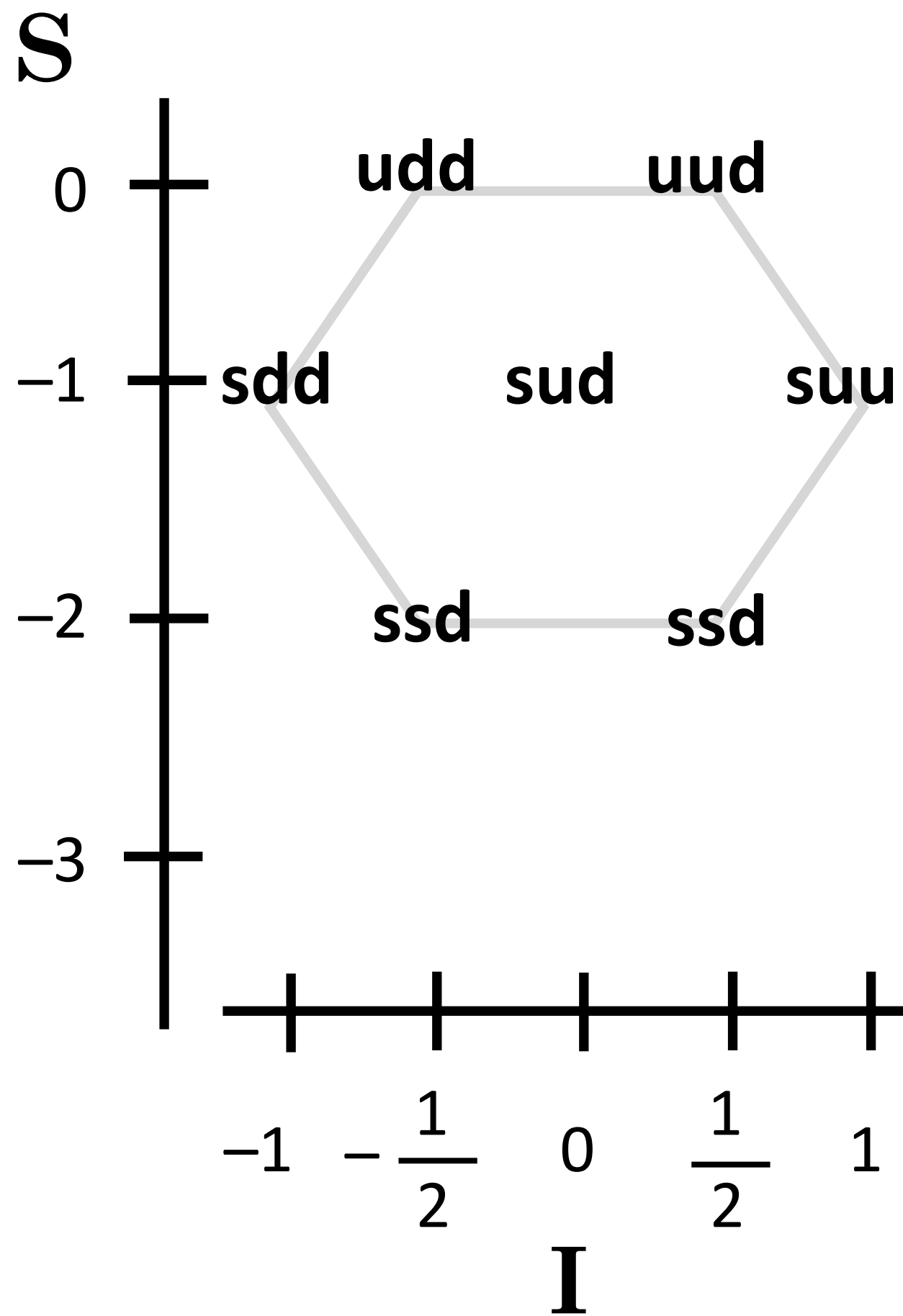
now defined:

Mesons: particles made of 1 quark and 1 antiquark.

the primary baryons



like a glove



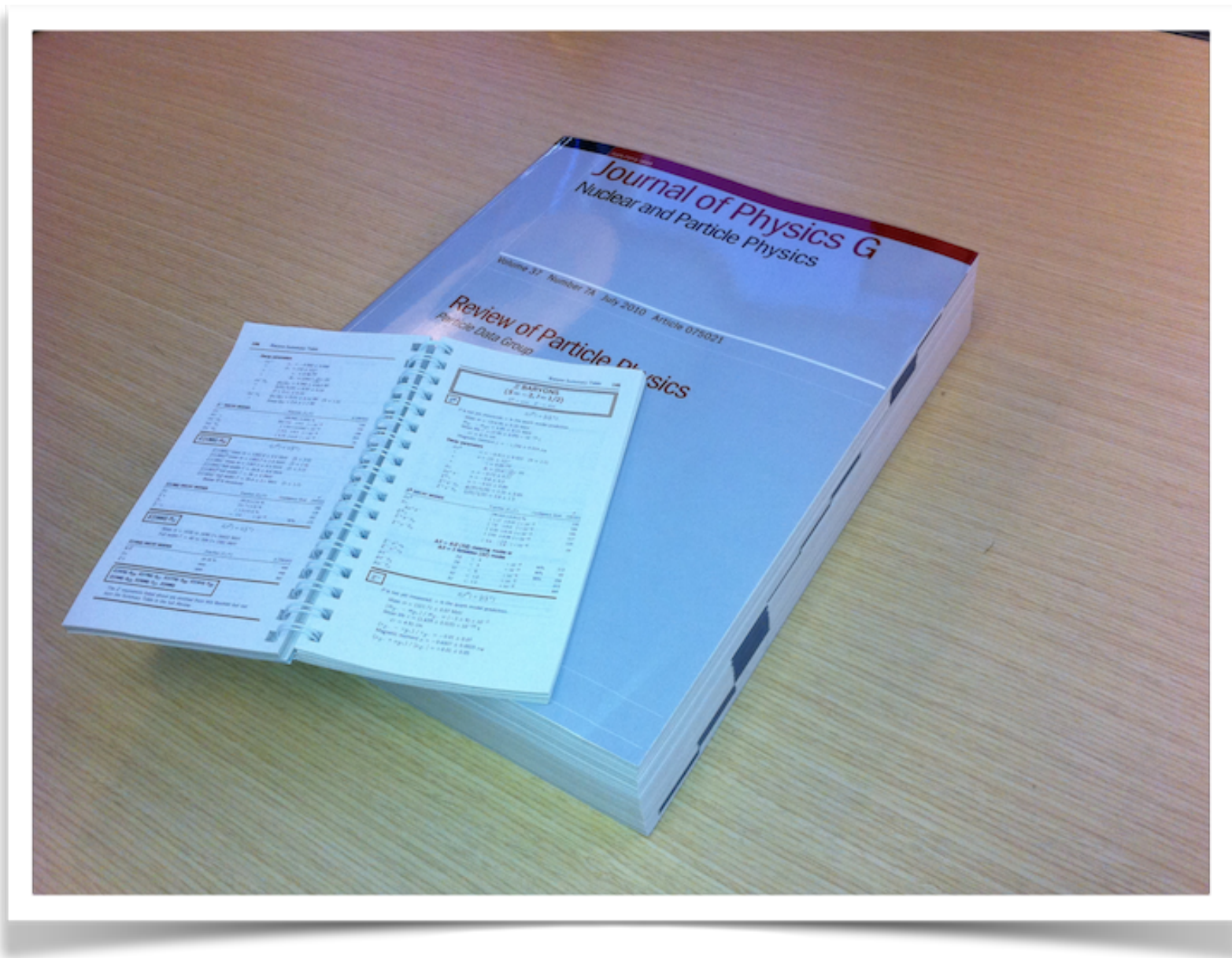
the dominant Baryons

Particle	Symbol	Rest Mass MeV/c ²	spin	Q	B	S	Lifetime	dominant decay modes	quark content
proton	p	938.3	1/2	+1	+1	0	$> 10^{31} \text{y}$		uud
neutron	n	939.6	1/2	0	+1	0	920	$p e^{-} \bar{\nu}_e$	ddu
Lambda	Λ^0	1115.6	1/2	0	+1	-1	2.6×10^{-10}	$p\pi^{-}, n\pi^0$	uds
Sigma	Σ^{+}	1189.4	1/2	+1	+1	-1	0.8×10^{-10}	$p\pi^0, n\pi^{+}$	uus
Sigma	Σ^0	1192.5	1/2	0	+1	-1	6×10^{-20}	$\Lambda^0 \gamma$	uds
Sigma	Σ^{-}	1197.3	1/2	-1	+1	-1	1.5×10^{-10}	$n\pi^{-}$	dds
Delta	Δ^{++}	1232	3/2	+2	+1	0	0.6×10^{-23}	$p\pi^{+}$	uuu
Delta	Δ^{+}	1232	3/2	+1	+1	0	0.6×10^{-23}	$n\pi^{+}, p\pi^0$	uud
Delta	Δ^0	1232	3/2	0	+1	0	0.6×10^{-23}	$n\pi^0$	udd
Delta	Δ^{-}	1232	3/2	-1	+1	0	0.6×10^{-23}	$n\pi^{-}$	ddd
Xi	Ξ^0	1315	1/2	0	+1	-2	2.9×10^{-10}	$\Lambda^0 \pi^0$	uss
Xi	Ξ^{-}	1321	1/2	-1	+1	-2	1.64×10^{-10}	$\Lambda^0 \pi^{-}$	dss
Omega	Ω^{-}	1672	3/2	-1	+1	-3	0.82×10^{-10}	$\Xi^0 \pi^{-}, \Lambda^0 K^{-}$	sss

the dominant Mesons

Particle	Symbol	anti-particle	Rest Mass MeV/c ²	spin	Q	B	S	Lifetime	dominant decay modes	quark content
Pion	π^+	π^-	139.6	0	+1	0	0	2.6×10^{-8}	$\mu^+ \nu_\mu$	$u\bar{d}$
Pi-zero	π^0	π^0	135	0	0	0	0	920	2γ	$\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$
Kaon	K^+	K^-	493.7	0	+1	0	+1	1.24×10^{-8}	$\mu^+ \nu_\mu, \pi^+ \pi^0$	$u\bar{s}$
K-short	K_S^0	K_S^0	497.7	0	0	0	+1	0.89×10^{-10}	$\pi^+ \pi^-, 2\pi^0$	$d\bar{s}, s\bar{d}$
K-long	K_L^0	K_L^0	497.7	0	0	0	+1	5.2×10^{-8}	$\pi^\pm \ell^\mp \nu_\ell$	$d\bar{s}, s\bar{d}$
Eta	η^0	η^0	548.8	0	0	0	0	$< 10^{-18}$	$2\gamma, \pi^+ \pi^- \pi^0$	$u\bar{u}, d\bar{d}, s\bar{s}$
Eta-prime	$\eta^{0'}$	$\eta^{0'}$	958	1	0	0	0	...	$\pi^+ \pi^- \eta$	$u\bar{u}, d\bar{d}, s\bar{s}$
Rho	ρ^+	ρ^-	770	1	+1	0	0	0.4×10^{-23}	$\pi^+ \pi^-, 2\pi^0$	$u\bar{d}$
Rho-naught	ρ^0	ρ^0	770	1	0	0	0	0.4×10^{-23}	$\pi^+ \pi^-$	$u\bar{u}, d\bar{d}$
Omega	ω^0	ω^0	782	1	0	0	0	0.8×10^{-22}	$\pi^+ \pi^- \pi^0$	$u\bar{u}, d\bar{d}$
Phi	ϕ	ϕ	1020	1	0	0	0	20×10^{-23}	$K^+ K^-, K^0 \bar{K}^0$	$s\bar{s}$

6 bits of matter:



$$\begin{pmatrix} u \\ d \end{pmatrix}$$

$$\begin{pmatrix} c \\ s \end{pmatrix}$$

$$\begin{pmatrix} t \\ b \end{pmatrix}$$

quarks are a part of reality

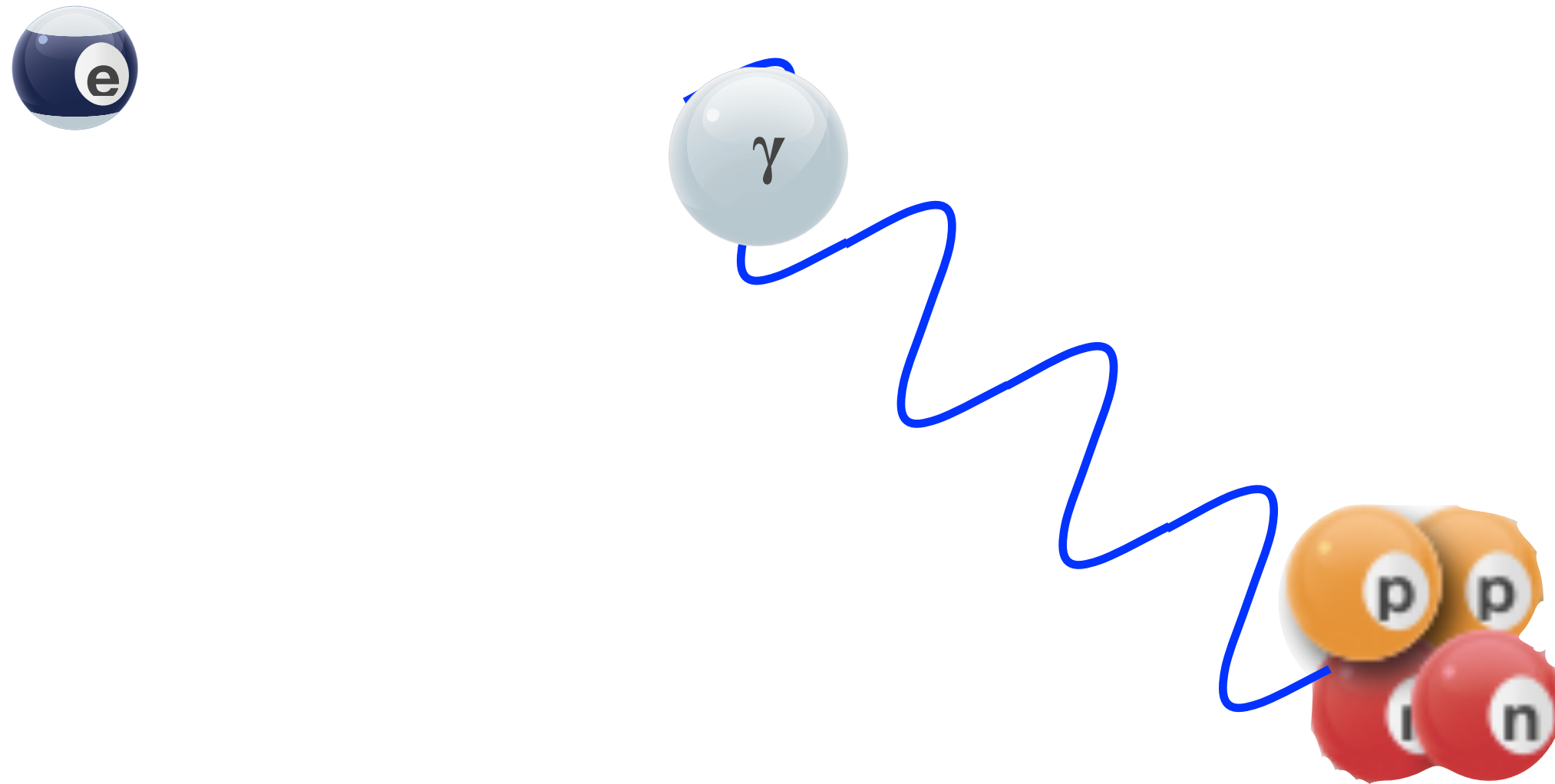
because we can

hit them individually

measure many properties of interactions and particles that
are bang-on

scattering of an electron from a nucleus

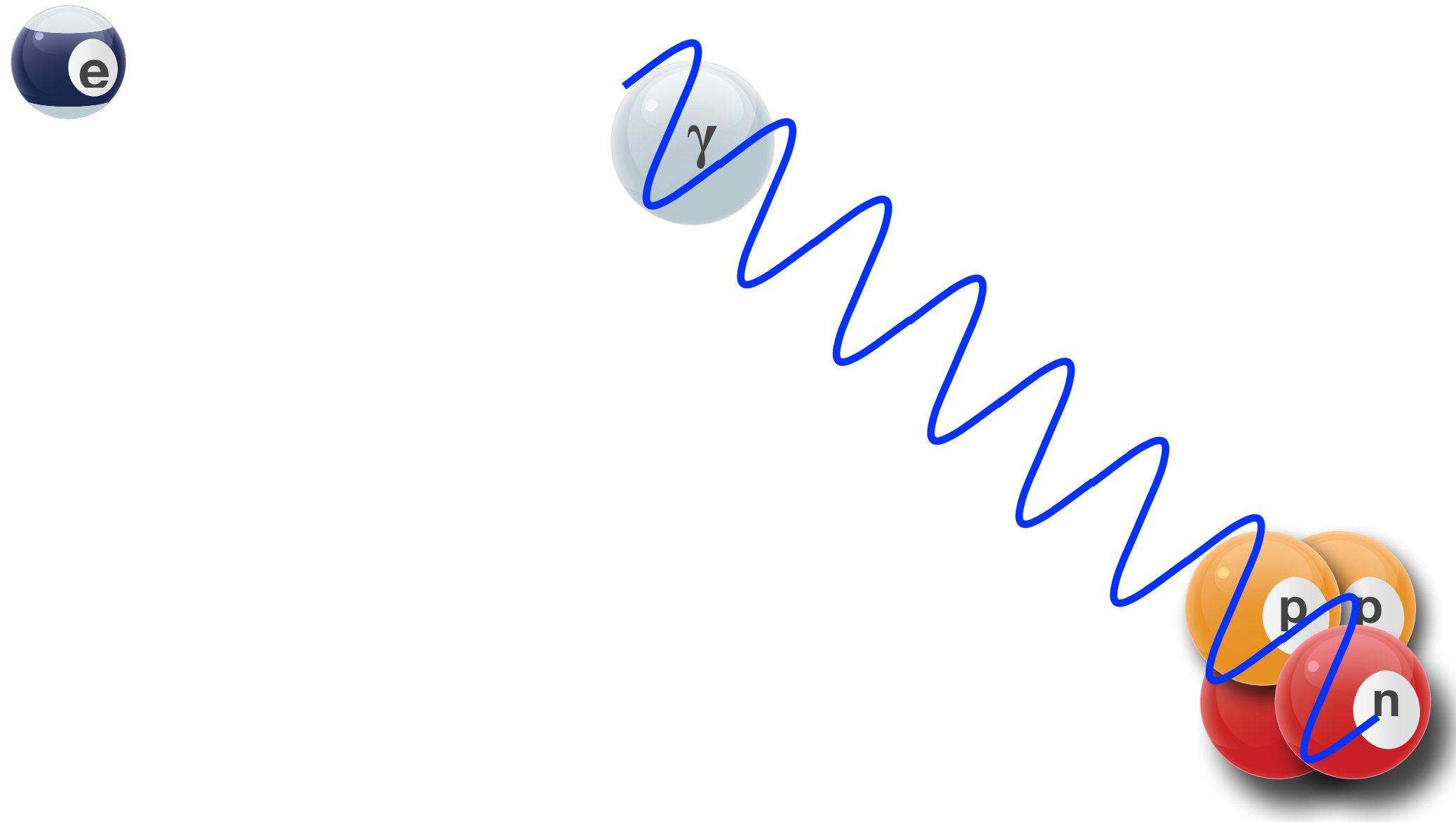
slow electron, long wavelength photon



“sees” the whole nucleus

scattering of an electron from a nucleus

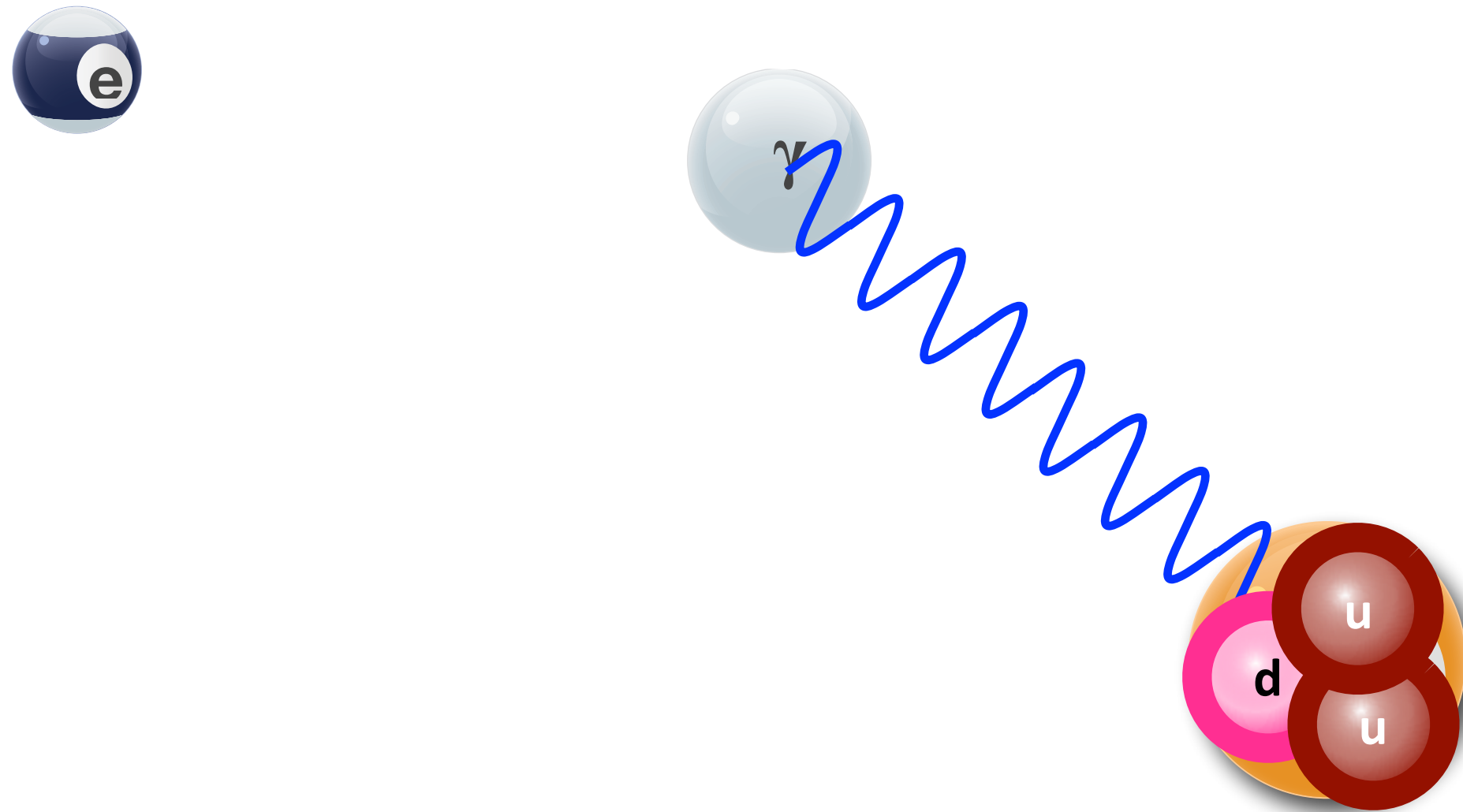
fast electron, medium-short wavelength photon



“sees” an individual proton in the nucleus

scattering of an electron from a nucleus

very fast electron, **very-short** wavelength photon



“sees” an individual quark in a proton or neutron

That’s how we became convinced in 1969 –

the same sort of backwards scattering as Rutherford’s

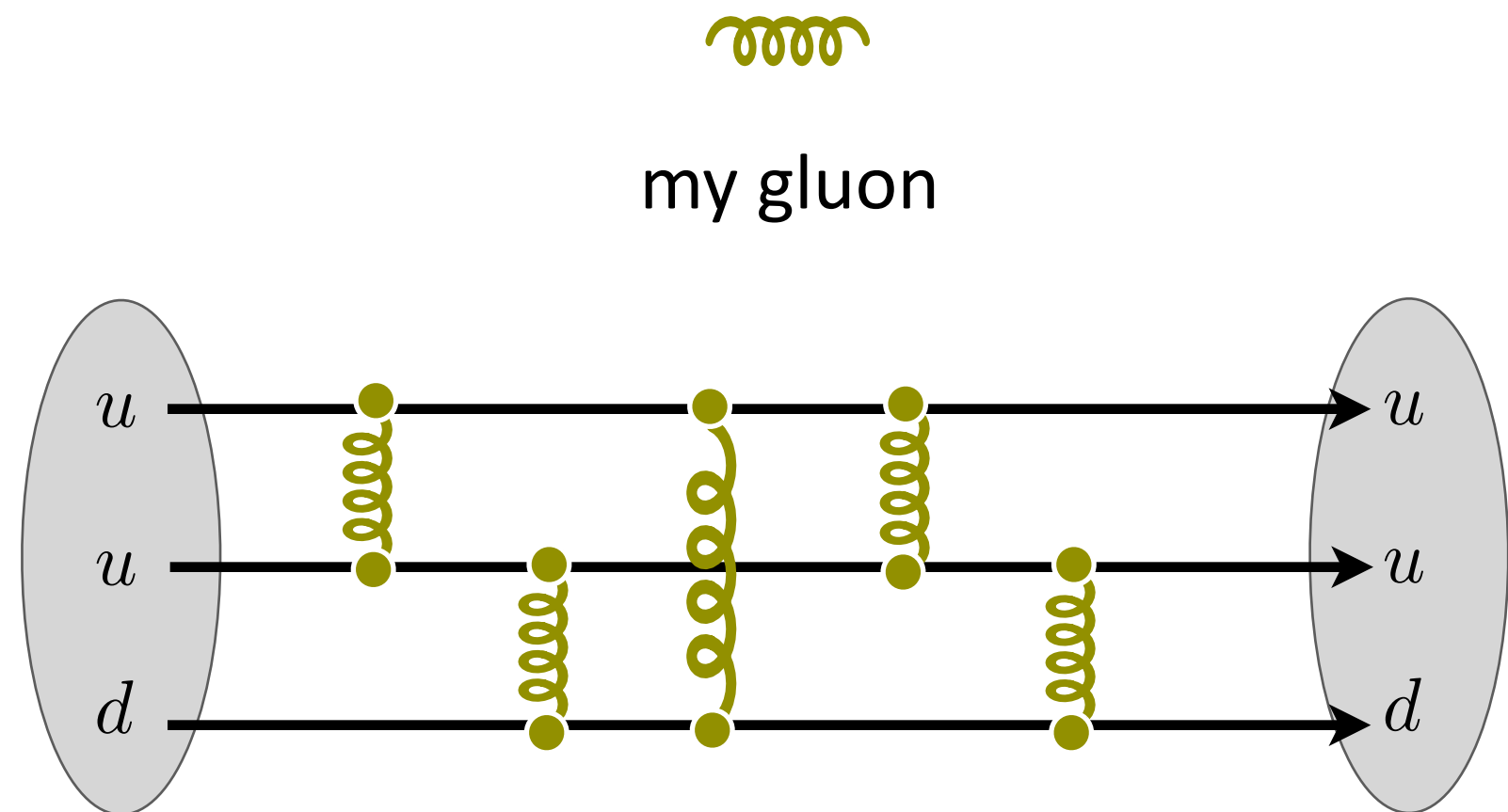
the
messenger
of the
strong
interaction

the Gluon

the glue
that holds
everything
together

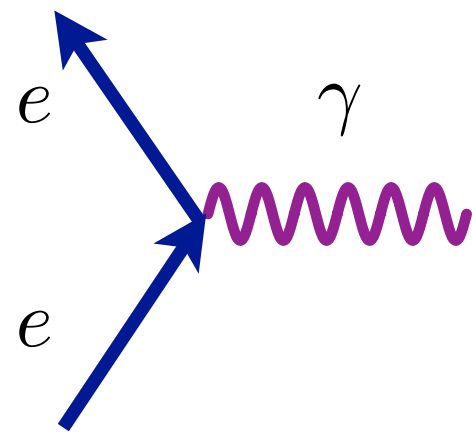
Predicted the existence of the Strong Messenger
Particle:

the **Gluon**

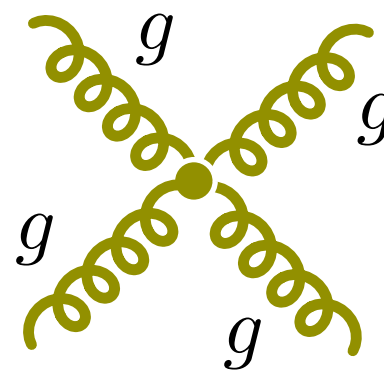
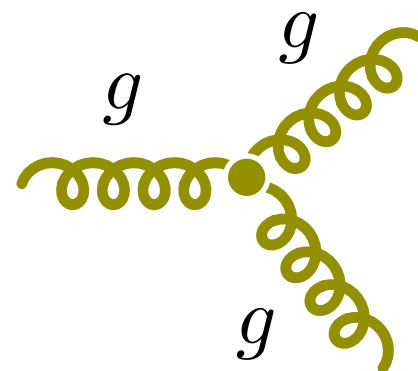
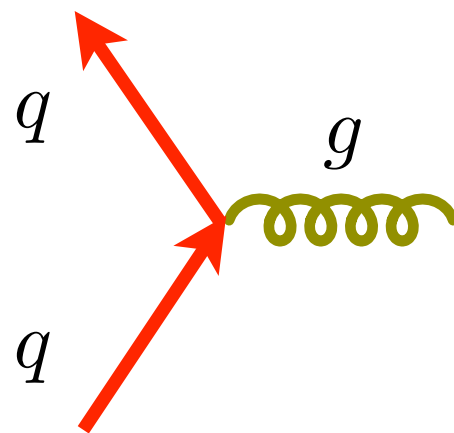


thing 1

they self-interact



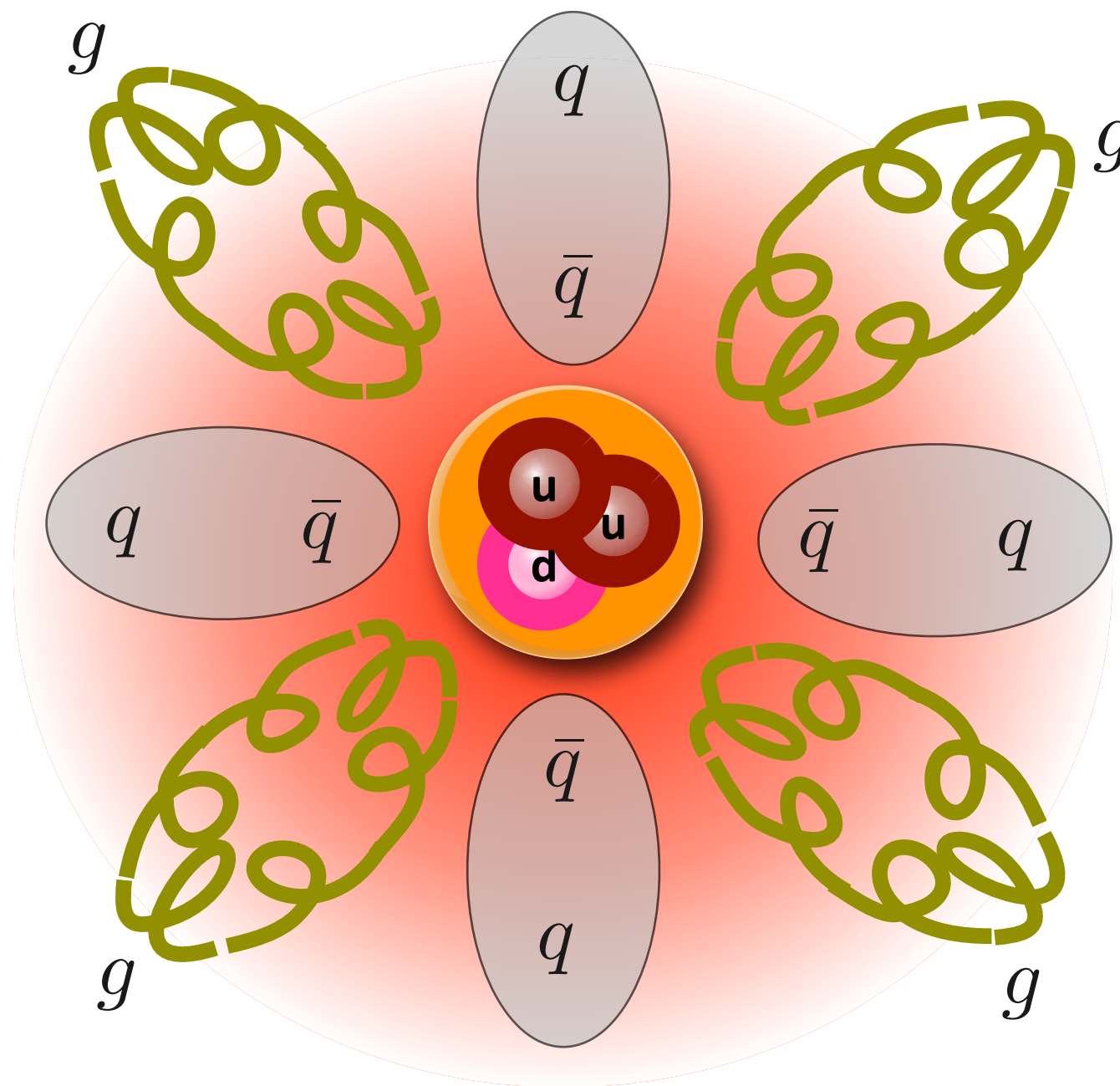
a photon propagates the electromagnetic force...but it does not have an electric charge



the gluon propagates the strong force...and it DOES have a "strong charge"

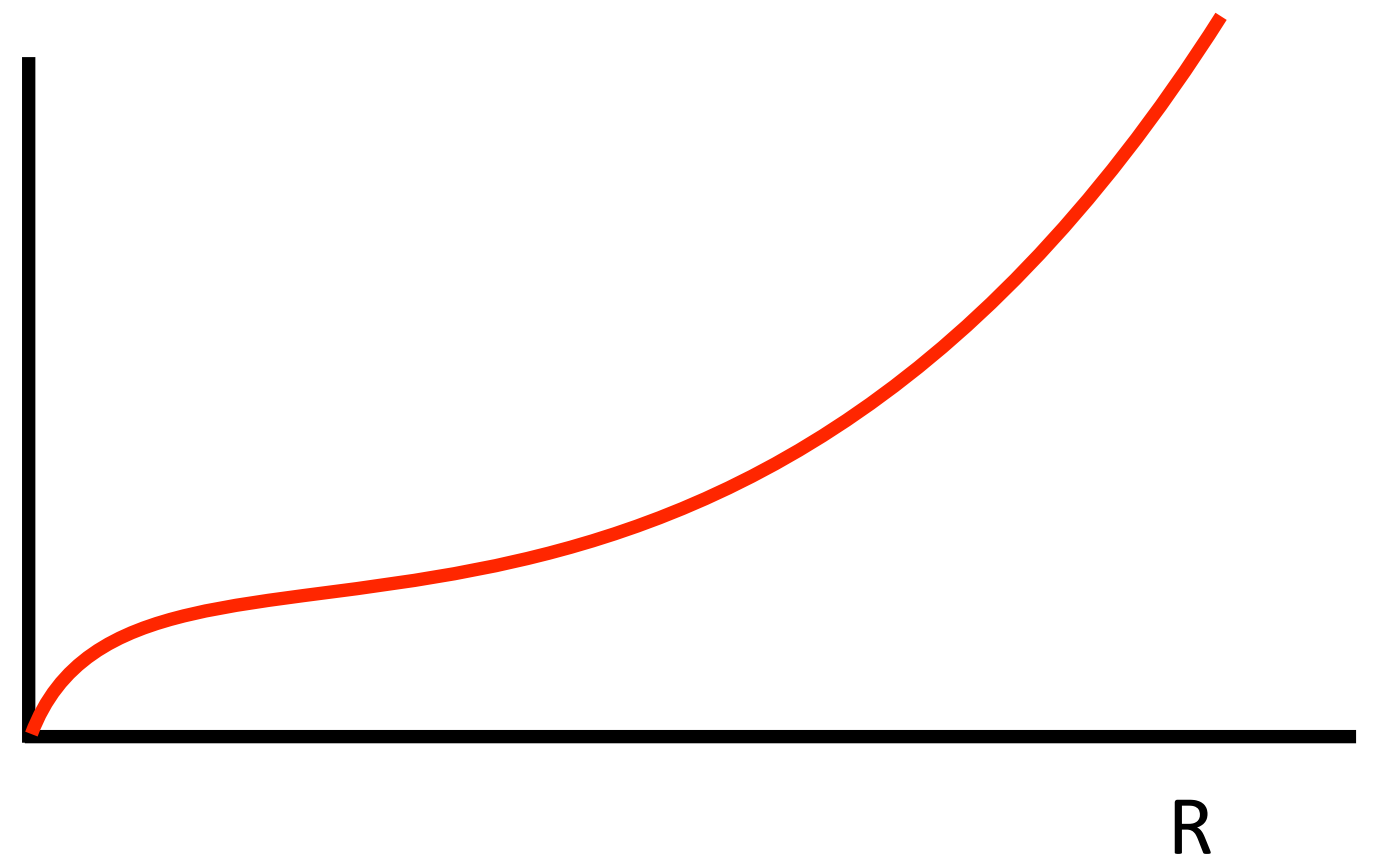
This has significant consequences...almost magical

ah, but
the gluon
is odd




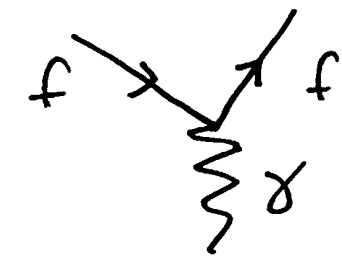
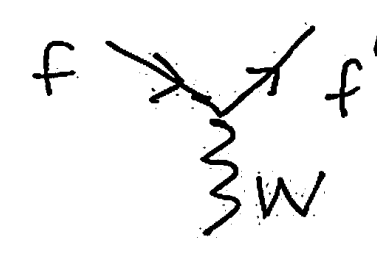
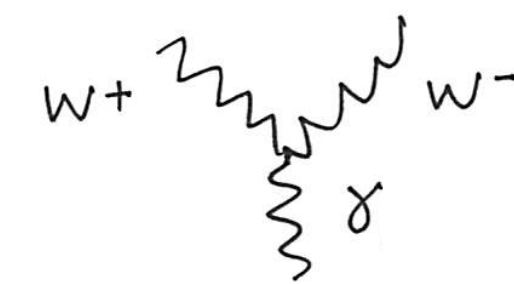
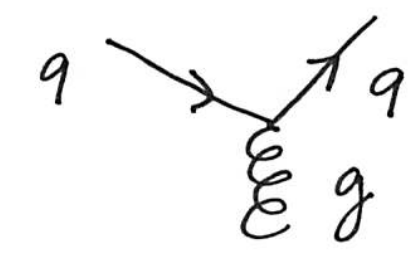

the further
away you get,
the **STRONGER**
the quark-quark
attraction is!

force of
attraction for
gluon fields







fourth and fifth entries into your

table of primitive diagrams

Primitive Diagrams		TIME always: 		
1		QED		
2		Weak Interactions		
3				
6		7		Strong Interactions
4		5		
8		9		Higgs Interactions
10		11		

fermion, spin 1/2, e.g., electron Vector Boson, spin 1, e.g., photon gluon, spin 1 scalar Boson, spin 0, e.g., Higgs Boson

the modern picture




of the elementary particle patterns

circa now

the lepton families...lepton “doublets”

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

and their interactions: **✗** no, **✓** yes.

leptons	ν_e	e	ν_μ	μ	ν_τ	τ
strong  g	✗	✗	✗	✗	✗	✗
electromagnetic  γ	✗	✓	✗	✓	✗	✓
weak  W	✓	✓	✓	✓	✓	✓
gravitational	✓	✓	✓	✓	✓	✓

the modern picture




of the elementary
particle patterns

circa now

the quark families...quark “doublets”

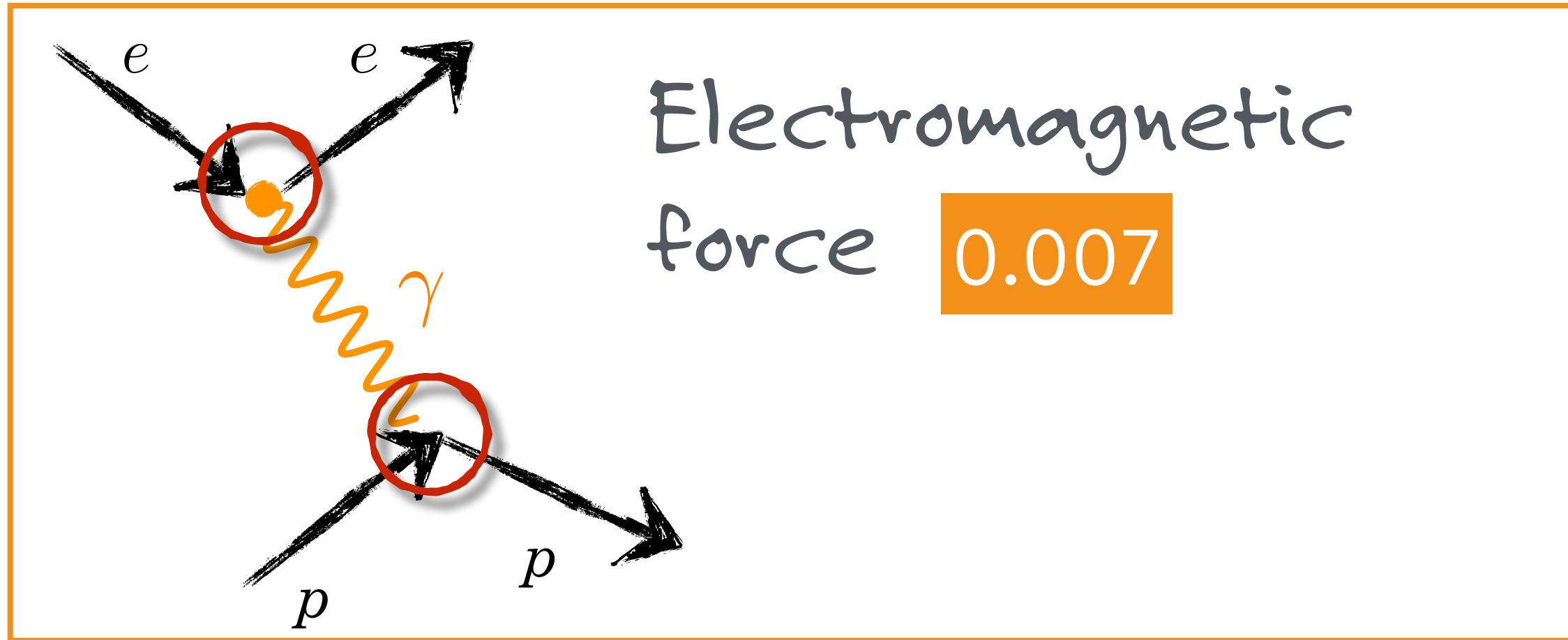
$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

and their interactions: **✗** no, **✓** yes.

quarks	<i>u</i>	<i>d</i>	<i>c</i>	<i>s</i>	<i>t</i>	<i>b</i>
strong  <i>g</i>	✓	✓	✓	✓	✓	✓
electromagnetic  γ	✓	✓	✓	✓	✓	✓
weak  <i>W</i>	✓	✓	✓	✓	✓	✓
gravitational	✓	✓	✓	✓	✓	✓

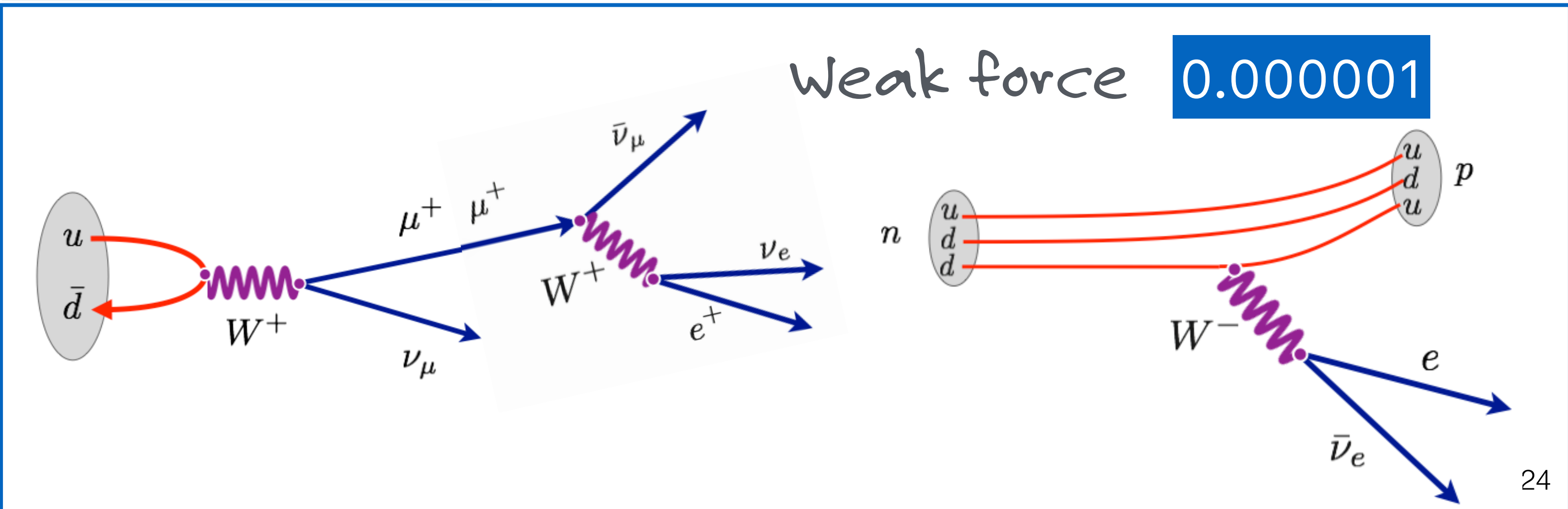
three forces now

of vastly different strengths



Gravitational force?

0.00000000000000000000
00000000000000000001



shifting gears

the weak and electromagnetic forces are one.



“phase transitions”

not a subject of Particle Physics

we thought

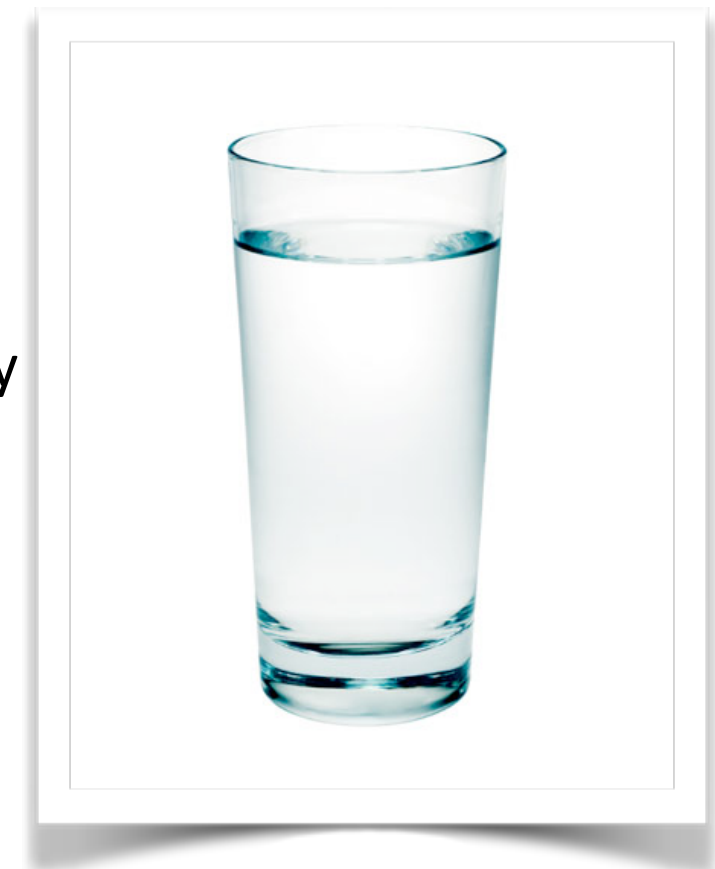
but we stole a theory from materials scientists

think about a phase transition



what a physicist sees
is a change of symmetry

before: every
direction is
identical



when there has been a
symmetry change, that's
essentially the definition of
a phase change:
Pierre Curie

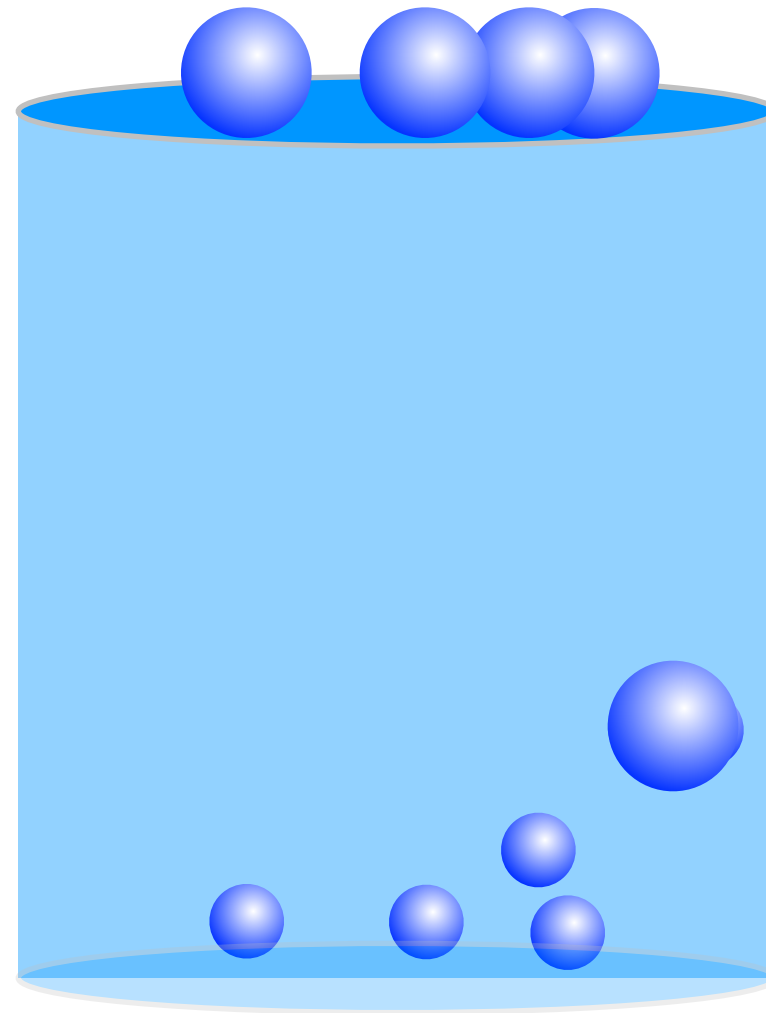


after: now
there are
special
directions

there are
basically
2 kinds

1st Order -
nucleation

2d Order -
continuous



Boiling starts in various
locations inside of liquid
water

Other kinds of phase transitions happen uniformly
throughout the substance.

you
probably
are mostly
familiar
with:
freezing
melting
boiling

**These “2nd Order,” phase transitions are continuous-
everywhere:**

crystallization
changes of density
magnetism
superconductivity
superfluidity
plasma transition
electron gases
Bose gases

a ferromagnet

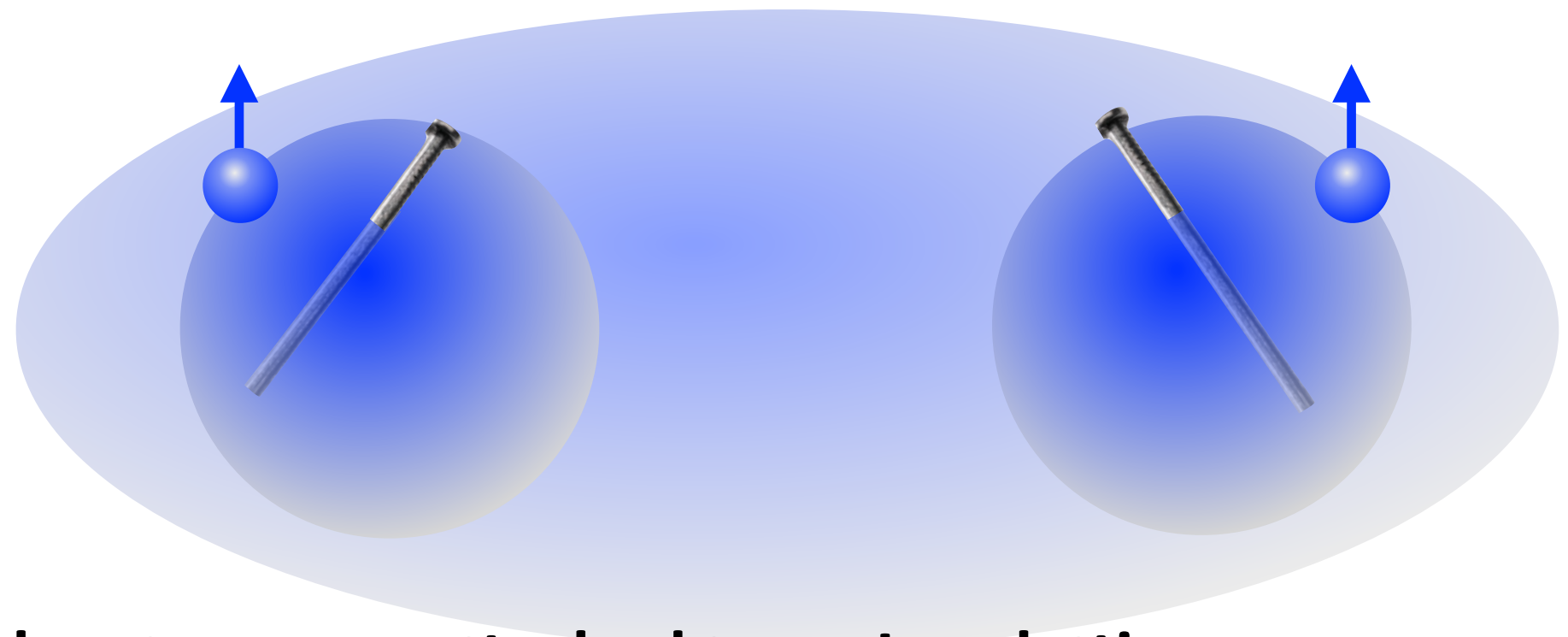
most familiarly:

iron

also: Co, Ni, Li gas

many compounds

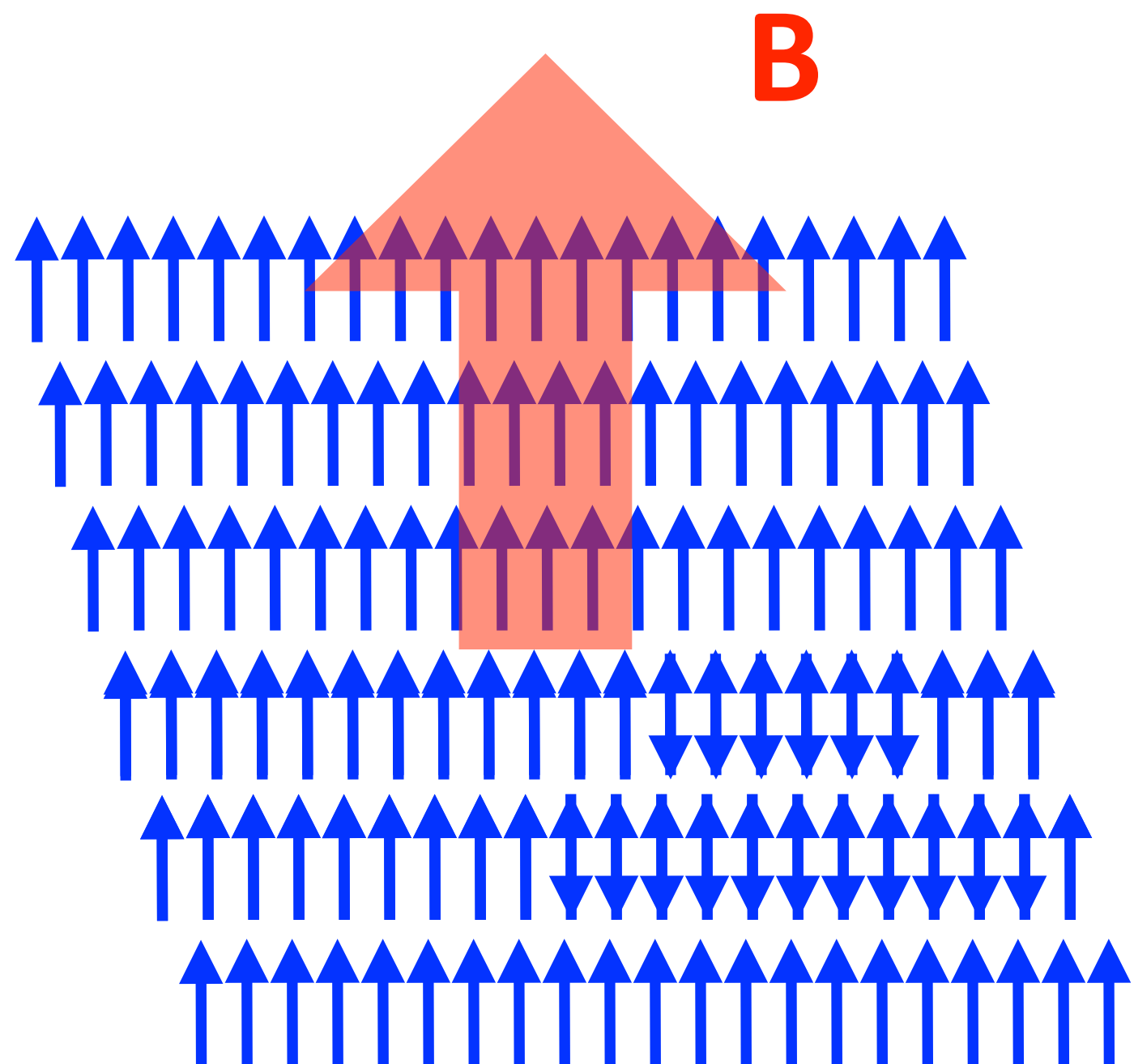
If atoms are far apart...a quantum mechanical effect keeps the spins aligned, minimizing the electrostatic energy



**if the atoms are attached to an Iron lattice...
the spins can add up**

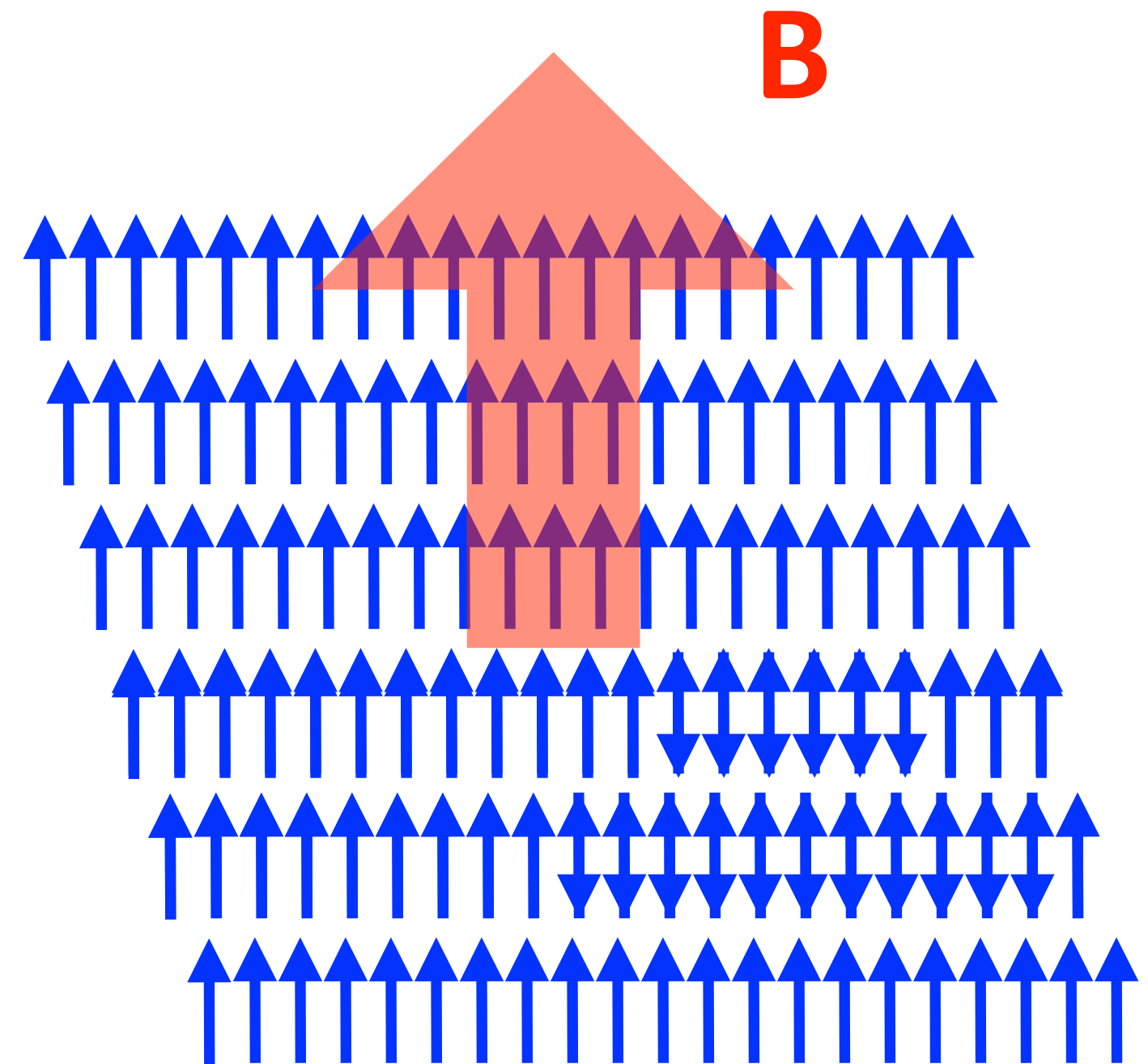
that's a
permanent
ferromagnet

in 2 - dimensions



why

is he talking about phase transitions you're asking yourself?



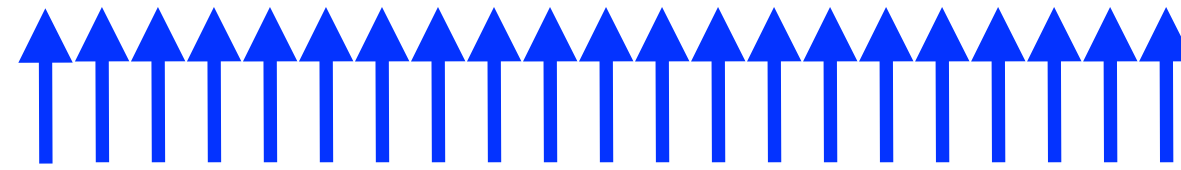
4.2 K - liquifies

2.17 K - superfluid

a little
model of an
ideal
ferromagnet

in one -
dimension

At a low temperature – like room temperature:



M is maximum

M, “magnetization”: a measure of how magnetized

“ground state” – state of lowest energy –
when all electronic magnets are aligned

There is a high temperature – the “Curie Point”:



then the “ground state” – state of lowest energy –
when all electronic magnets are random

M becomes zero

an
important
difference

between these
two situations

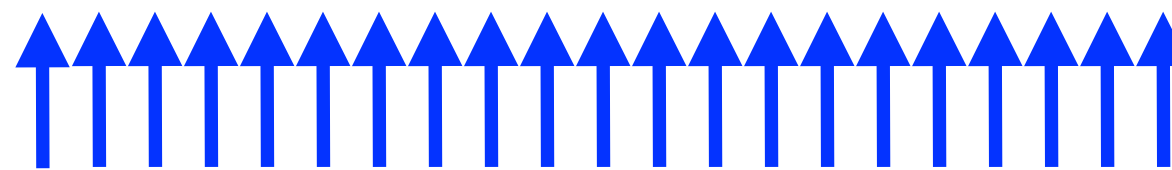
H



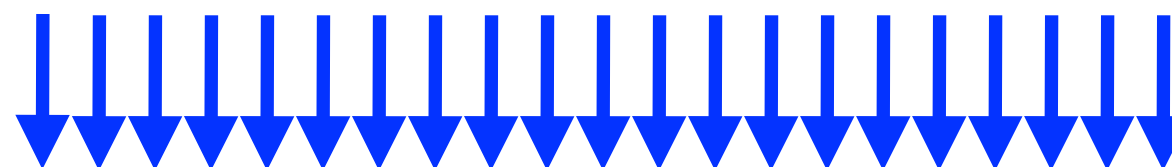
$M = 0$

temperature cools...magnet goes to one of two states:

C

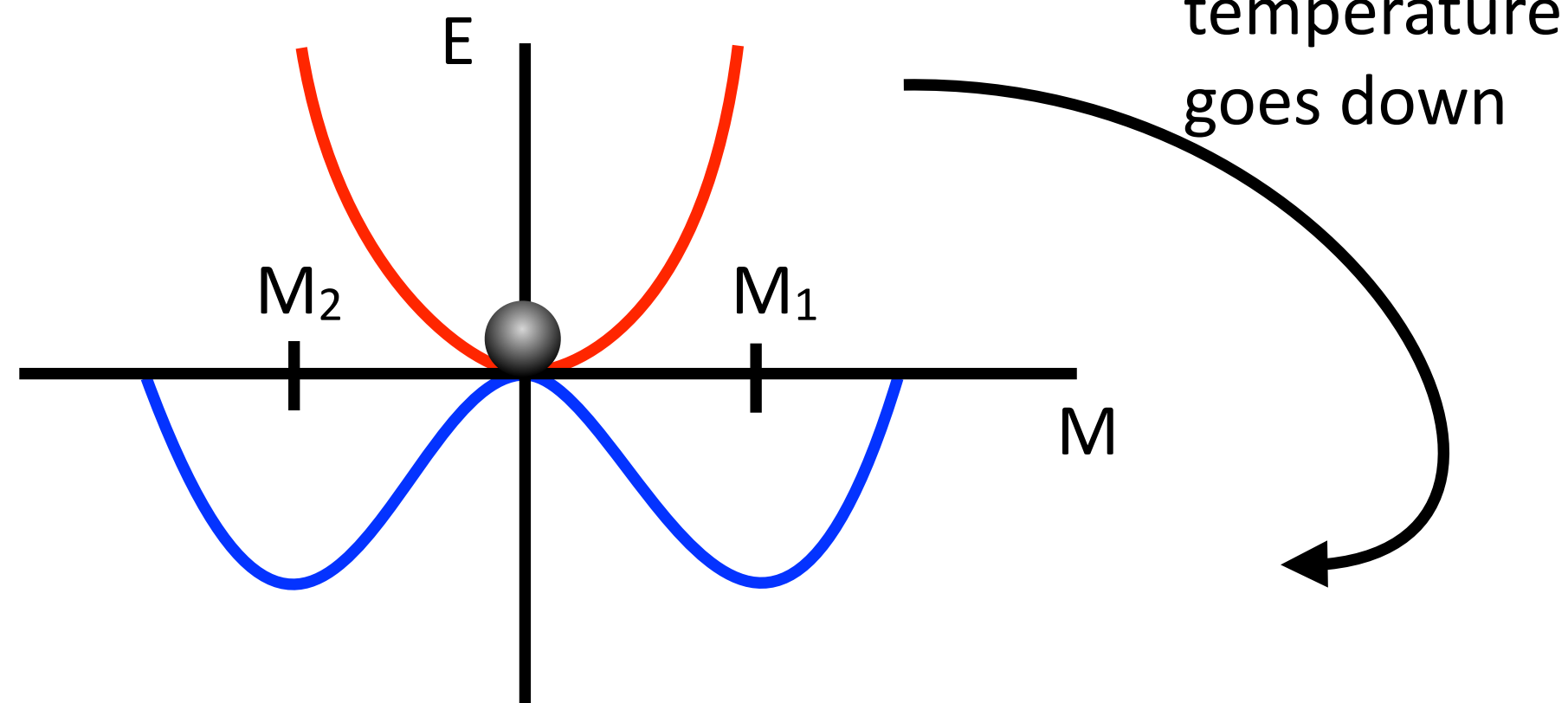


$M_1 \neq 0$



$M_2 \neq 0$

we say that the symmetry is "broken"



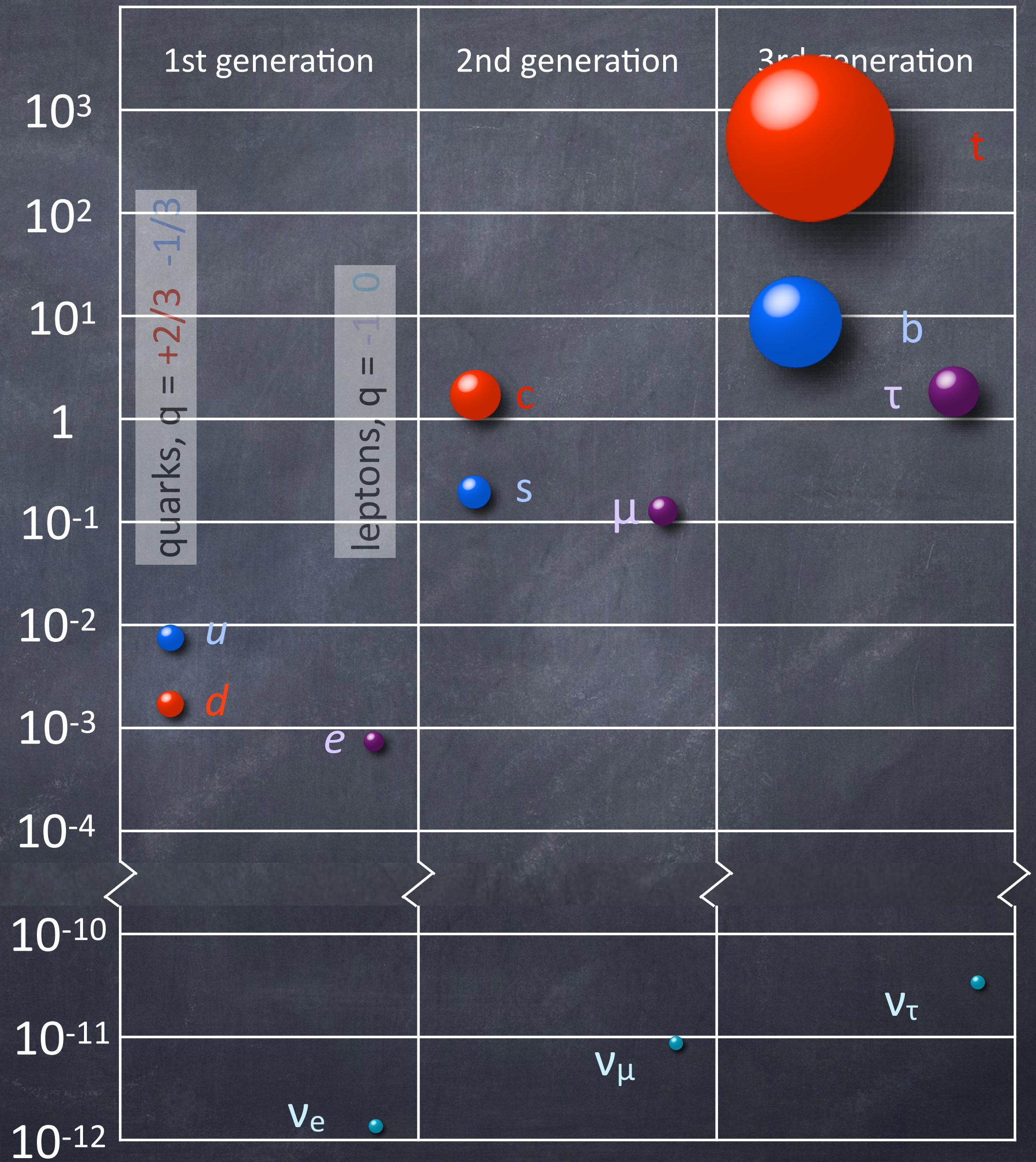
the energy level of the **hot ground state** is higher
than the energy level of the **cold ground state**

this often-told magnet story

evolves into the new story of MASS

quarks & leptons

proton masses



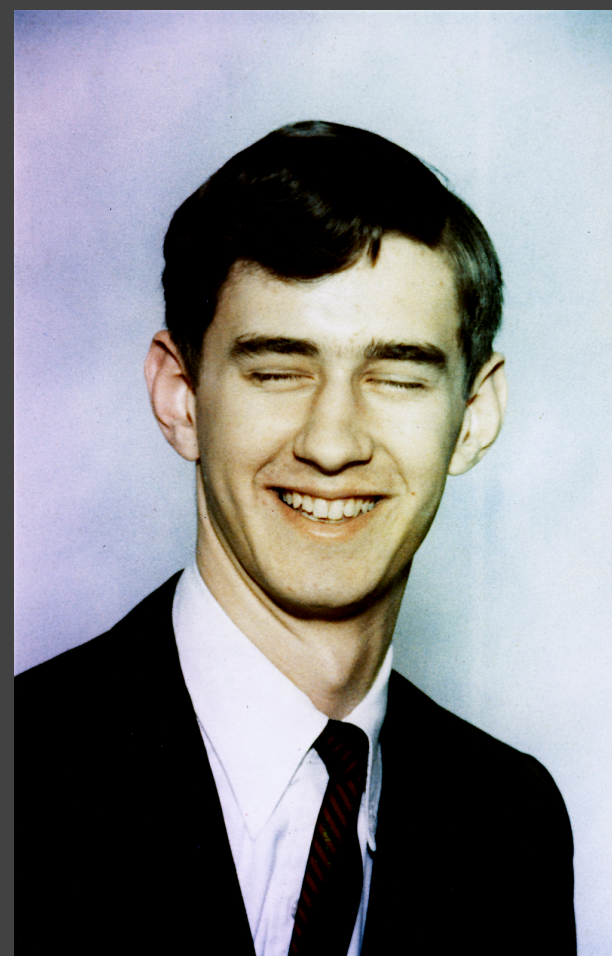
the only mathematical
solution that made sense:

masses of all quarks, leptons, and messenger particles

= 0

until we stole the magnet story and rewrote it into our book

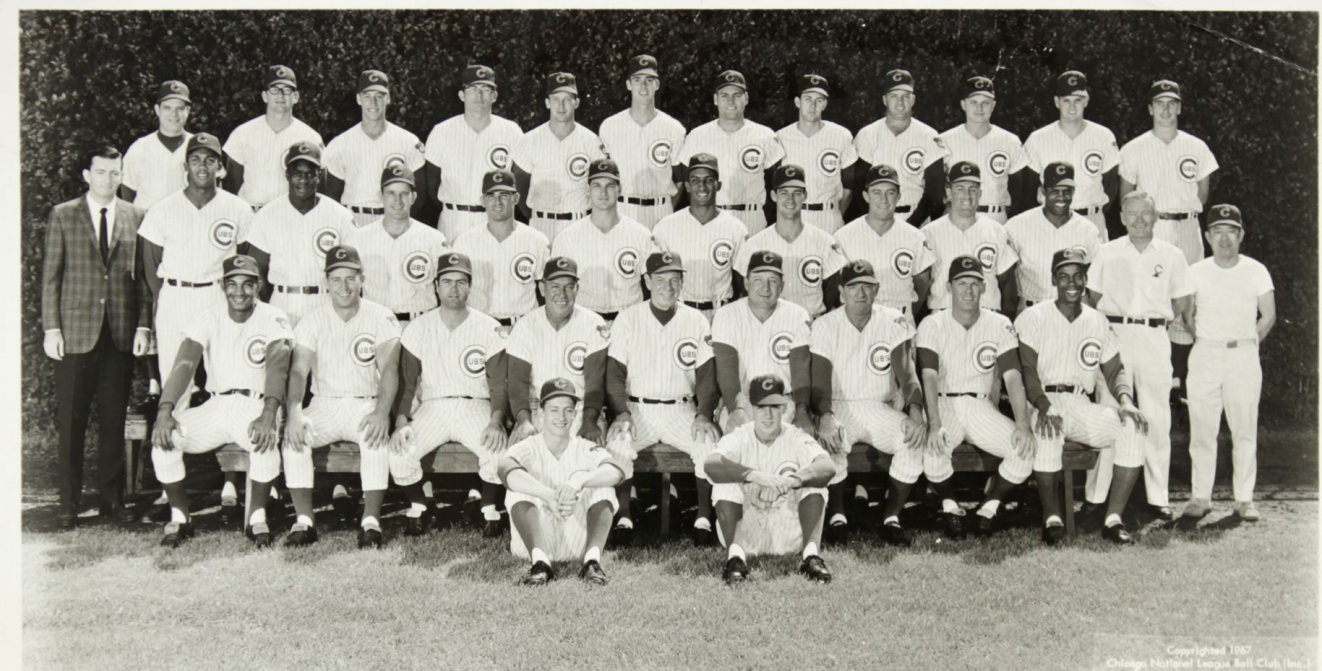
1967



1967



1967



1967 CHICAGO CUBS



FRONT ROW (L to R)

Billy Williams, Ron Santo, Joe Amalfitano (Coach), Pete Reiser (Coach), Ken Kamin (Batboy), Leo Durocher (Manager), Verlon Walker (Coach), Jerry Farrell (Batboy), Joe Becker (Coach), Randy Hundley, Ernie Banks.

MIDDLE ROW (L to R)

Blake Cullen (Traveling Secretary), Ferguson Jenkins, Clarence Jones, John Stephenson, Bill Stoneman, Ray Culp, Adolfo Phillips, Charles Hartenstein, Al Spangler, Norm Gigon, Ted Savage, Al Scheuneman (Trainer), Yosh Kawano (Equipment Manager).

BACK ROW (L to R)

Don Pinkus (Batting Practice Catcher), Jim Ellis, Ken Holtzman, Pete Mikkelsen, Glenn Beckert, Rich Nye, Bob Shaw, Don Kessinger, Lee Thomas, Joe Niekro, Bill Hands, Rob Gardner.

1967

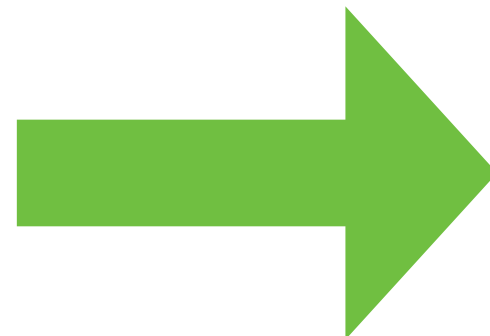
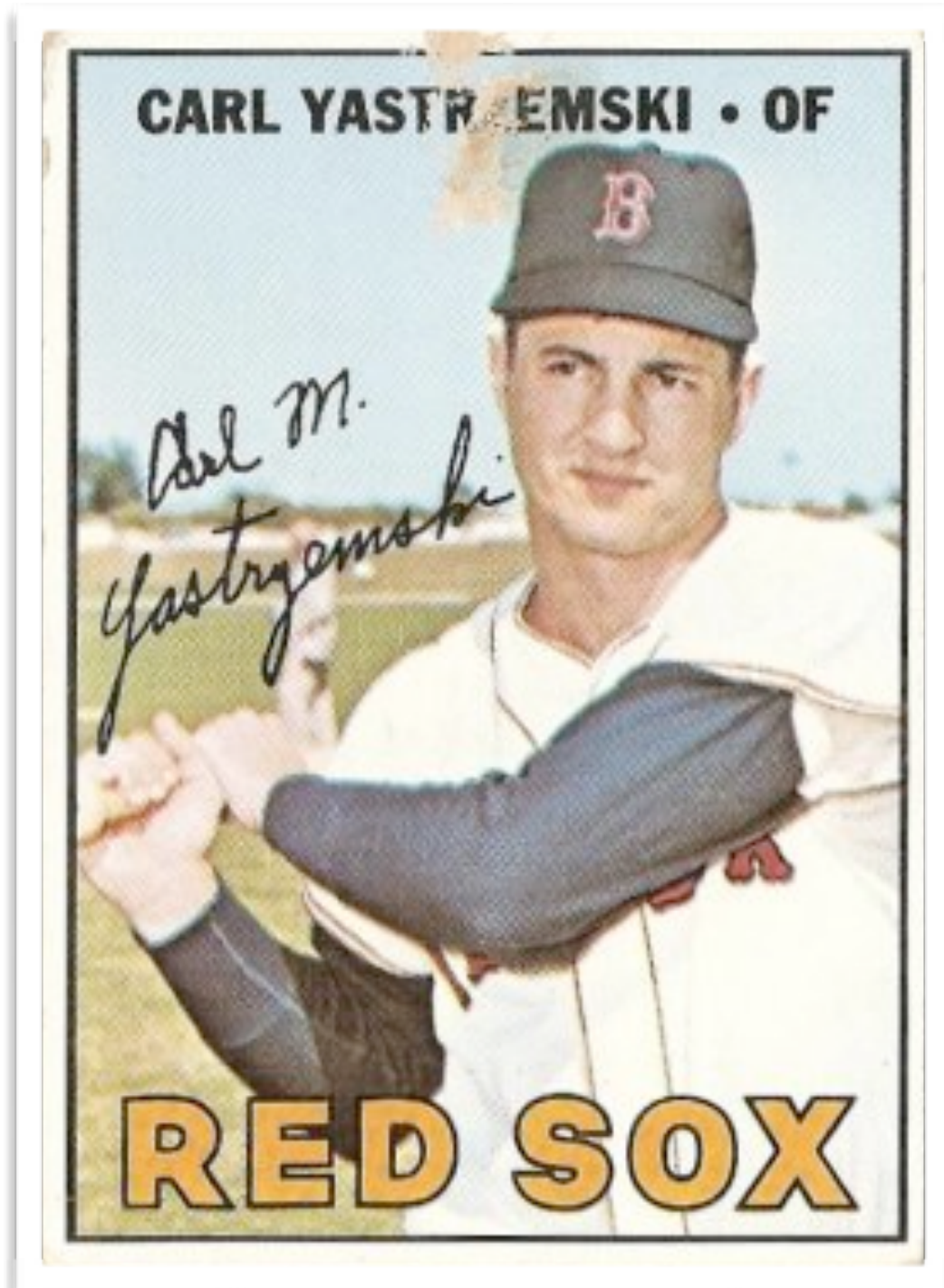




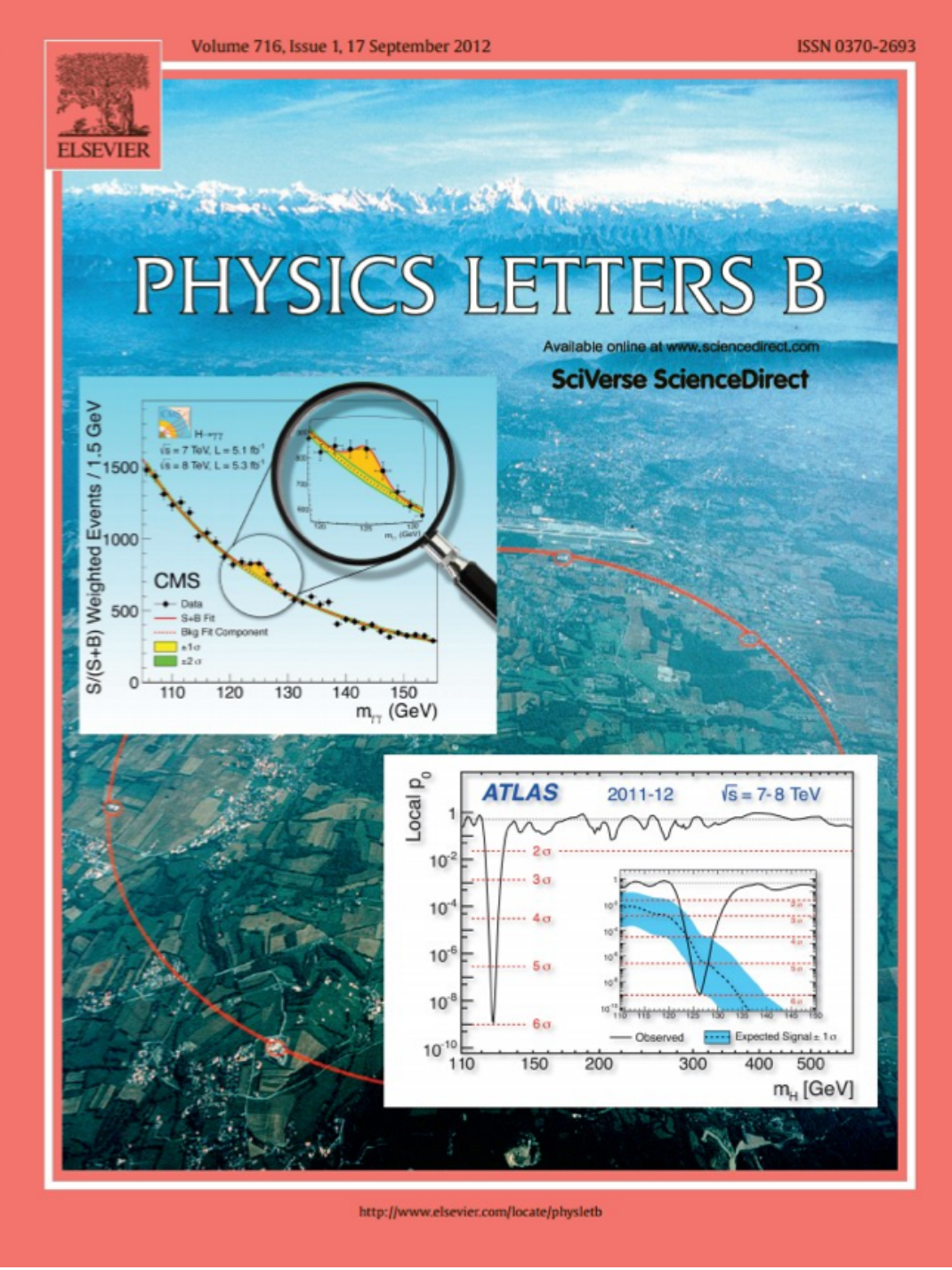
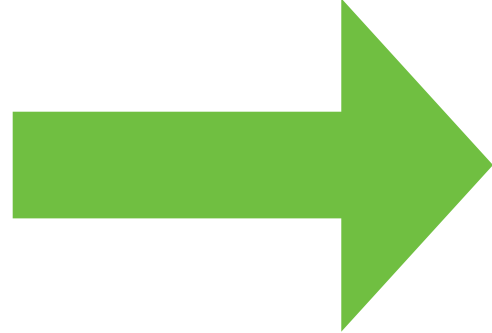
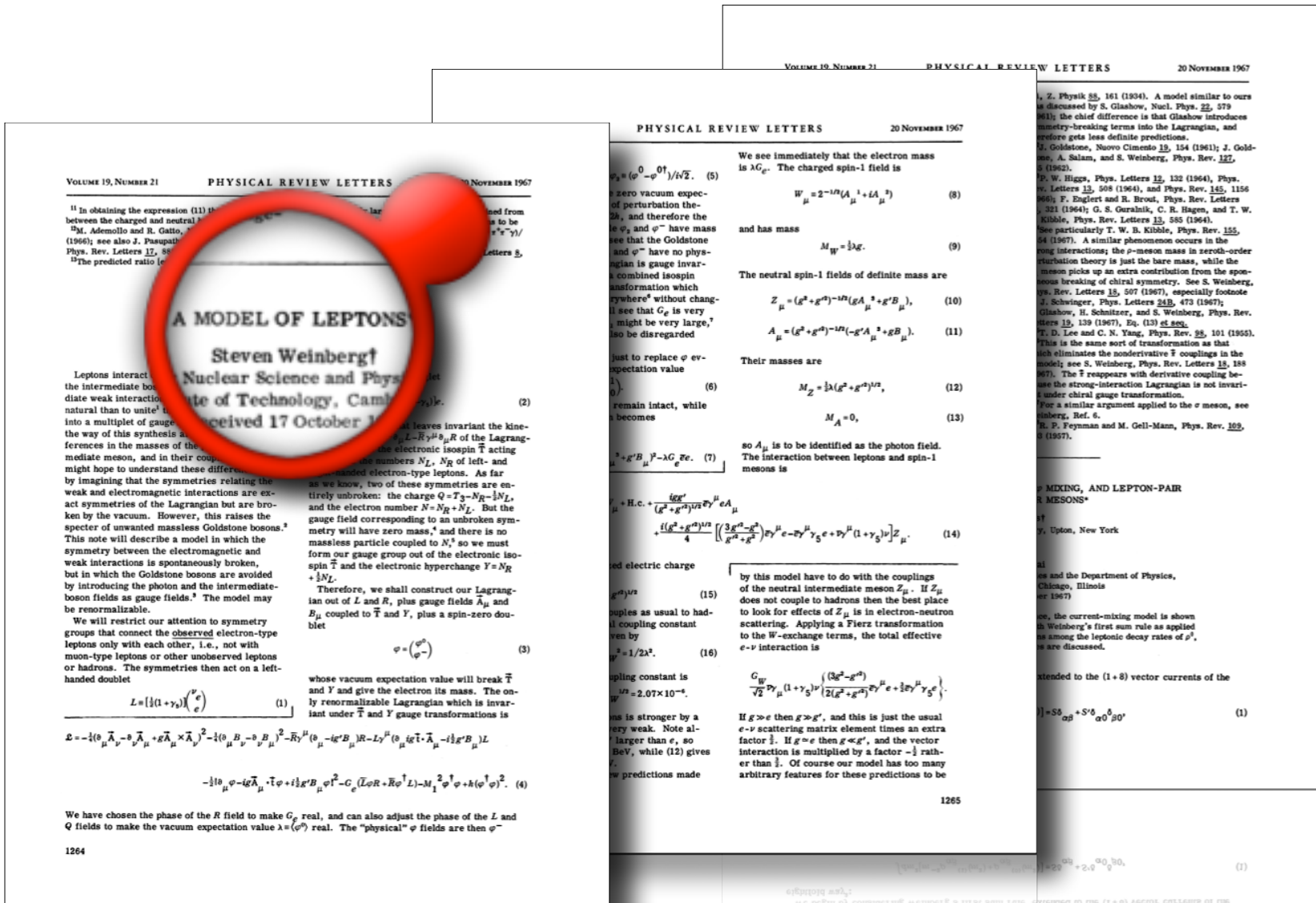


between 1967 - 2012

- history was made



between 1967 - 2012



A MODEL OF LEPTONS

Steven Weinberg†
Nuclear Science and Physics Department,
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

Received 17 October 1966

[†]In obtaining the expression (11) the phase of the R field is chosen to be real, and the phase of the L field is chosen to be $\pi/2$.
[‡]M. Ademollo and R. Gatto, *Nuovo Cimento* **43**, 1460 (1966); see also J. Pasupathy, *Phys. Rev. Letters* **17**, 885 (1966).
[§]The predicted ratio [eq. (13)] is $\frac{1}{2}$.

Leptons interact through the intermediate bosons of the intermediate weak interaction. It is natural than to unite the leptons into a multiplet of gauge fields in the way of this synthesis and to leave invariant the kinetic energy of the leptons. The Lagrangian of the leptons is invariant under the electronic isospin \bar{T} acting on the leptons, and in their coupling to the intermediate meson, and in their coupling to the photon and the intermediate bosons. The numbers N_L , N_R of left- and right-handed electron-type leptons. As far as we know, two of these symmetries are entirely unbroken: the charge $Q = T_3 - N_R - \frac{1}{2}N_L$, and the electron number $N = N_R + N_L$. But the gauge field corresponding to an unbroken symmetry will have zero mass,⁴ and there is no massless particle coupled to N ,⁵ so we must form our gauge group out of the electronic isospin \bar{T} and the electronic hypercharge $Y = N_R + \frac{1}{2}N_L$.

Therefore, we shall construct our Lagrangian out of L and R , plus gauge fields \bar{A}_μ and B_μ coupled to \bar{T} and Y , plus a spin-zero doublet $\varphi = \begin{pmatrix} \varphi^0 \\ \varphi^- \end{pmatrix}$ whose vacuum expectation value will break \bar{T} and Y and give the electron its mass. The only renormalizable Lagrangian which is invariant under \bar{T} and Y gauge transformations is

$$L = \frac{1}{2}(1 + \gamma_5) \begin{pmatrix} \nu \\ e \end{pmatrix} \quad (1)$$

$$\mathcal{L} = -\frac{1}{4}(\partial_\mu \bar{A}_\nu - \partial_\nu \bar{A}_\mu + g \bar{A}_\mu \times \bar{A}_\nu)^2 - \frac{1}{4}(\partial_\mu B_\nu - \partial_\nu B_\mu)^2 - \bar{R} \gamma^\mu (\partial_\mu - ig' B_\mu) R - L \gamma^\mu (\partial_\mu - ig \bar{T} \cdot \bar{A}_\mu - i \frac{1}{2} g' B_\mu) L - \frac{1}{2} (\partial_\mu \varphi - ig \bar{A}_\mu \cdot \bar{T} \varphi + i \frac{1}{2} g' B_\mu \varphi)^2 - G_e (\bar{L} \varphi R + \bar{R} \varphi^\dagger L) - M_1^2 \varphi^\dagger \varphi + h(\varphi^\dagger \varphi)^2. \quad (4)$$

We have chosen the phase of the R field to make G_e real, and can also adjust the phase of the L and Q fields to make the vacuum expectation value $\lambda = \langle \varphi^0 \rangle$ real. The "physical" φ fields are then φ^-

$$\varphi_\pm = (\varphi^0 - \varphi^{\pm})/i\sqrt{2}. \quad (5)$$

The zero vacuum expectation value of perturbation theory, and therefore the φ_\pm and φ^- have mass 2λ , and see that the Goldstone bosons φ_\pm and φ^- have no physical mass. The Lagrangian is gauge invariant under a combined isospin transformation which leaves invariant the kinetic energy of the leptons. We see that G_e is very small, and might be very large,⁷ and is also disregarded.

$$\langle \varphi^0 \rangle = \lambda \quad (6)$$

remain intact, while φ^- becomes

$$\langle \varphi^- \rangle = \lambda \quad (7)$$

$$\mathcal{L} + \text{H.c.} + \frac{ig'g}{(g^2 + g'^2)^{1/2}} \bar{e} \gamma^\mu e A_\mu + \frac{i(g^2 + g'^2)^{1/2}}{4} \left[\left(\frac{3g'^2 - g^2}{g'^2 + g^2} \right) \bar{e} \gamma^\mu e - \bar{e} \gamma^\mu \gamma_5 e + \nu \gamma^\mu (1 + \gamma_5) \nu \right] Z_\mu. \quad (14)$$

$$W_\mu^\pm = \frac{1}{\sqrt{2}} (A_\mu^\pm + iB_\mu^\pm) \quad (15)$$
$$M_W^2 = 1/2 \lambda^2 \quad (16)$$

The coupling constant is $G_W = 1/2 \lambda^2 = 2.07 \times 10^{-6}$. The interaction is stronger by a factor $1/2$ than e , so G_W is larger than e , so G_W is $1/2$ rather than $1/2$. Of course our model has too many arbitrary features for these predictions to be

We see immediately that the electron mass is λG_e . The charged spin-1 field is

$$W_\mu^\pm = 2^{-1/2} (A_\mu^\pm + iB_\mu^\pm) \quad (8)$$

$$M_W = \frac{1}{2} \lambda g. \quad (9)$$

The neutral spin-1 fields of definite mass are

$$Z_\mu = (g^2 + g'^2)^{-1/2} (gA_\mu^3 + g'B_\mu^3), \quad (10)$$

$$A_\mu = (g^2 + g'^2)^{-1/2} (-g'A_\mu^3 + gB_\mu^3). \quad (11)$$

$$M_Z = \frac{1}{2} \lambda (g^2 + g'^2)^{1/2}, \quad (12)$$

$$M_A = 0, \quad (13)$$

so A_μ is to be identified as the photon field. The interaction between leptons and spin-1 mesons is

by this model have to do with the couplings of the neutral intermediate meson Z_μ . If Z_μ does not couple to hadrons then the best place to look for effects of Z_μ is in electron-neutron scattering. Applying a Fierz transformation to the W -exchange terms, the total effective $e-\nu$ interaction is

$$\frac{G_W}{\sqrt{2}} \bar{\nu} \gamma_\mu (1 + \gamma_5) \nu \left\{ \frac{(3g^2 - g'^2)}{2(g^2 + g'^2)} \bar{e} \gamma^\mu e + \frac{1}{2} \bar{e} \gamma^\mu \gamma_5 e \right\}.$$

If $g \gg e$ then $g \gg g'$, and this is just the usual $e-\nu$ scattering matrix element times an extra factor $1/2$. If $g \sim e$ then $g \ll g'$, and the vector interaction is multiplied by a factor $-1/2$ rather than $1/2$. Of course our model has too many arbitrary features for these predictions to be

Z. Physik **85**, 161 (1934). A model similar to ours is discussed by S. Glashow, Nucl. Phys. **22**, 579 (1961); the chief difference is that Glashow introduces symmetry-breaking terms into the Lagrangian, and therefore gets less definite predictions.
J. Goldstone, Nuovo Cimento **19**, 154 (1961); J. Goldstone, A. Salam, and S. Weinberg, Phys. Rev. **127**, 965 (1962).
P. W. Higgs, Phys. Letters **12**, 132 (1964), Phys. Rev. Letters **13**, 508 (1964), and Phys. Rev. **145**, 1156 (1966); F. Englert and R. Brout, Phys. Rev. Letters **3**, 321 (1964); G. S. Guralnik, C. R. Hagen, and T. W. Kibble, Phys. Rev. Letters **13**, 585 (1964). See particularly T. W. B. Kibble, Phys. Rev. **155**, 846 (1967). A similar phenomenon occurs in the strong interactions; the ρ -meson mass in zeroth-order perturbation theory is just the bare mass, while the ρ -meson picks up an extra contribution from the spontaneous breaking of chiral symmetry. See S. Weinberg, Phys. Rev. Letters **18**, 507 (1967), especially footnote 3. J. Schwinger, Phys. Letters **24B**, 473 (1967); Glashow, H. Schnitzer, and S. Weinberg, Phys. Rev. Letters **19**, 139 (1967), Eq. (13) et seq.
T. D. Lee and C. N. Yang, Phys. Rev. **98**, 101 (1955). This is the same sort of transformation as that which eliminates the nonderivative $\bar{\psi} \psi$ couplings in the model; see S. Weinberg, Phys. Rev. Letters **18**, 188 (1967). The $\bar{\psi} \psi$ reappears with derivative coupling because the strong-interaction Lagrangian is not invariant under chiral gauge transformation.
For a similar argument applied to the σ meson, see Weinberg, Ref. 6.
R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 1439 (1957).

LEPTON-PAIR MIXING, AND LEPTON-PAIR MESONS*

Y. Upton, New York

Department of Physics, University of Chicago, Chicago, Illinois 60637 (Received October 1967)

In this note, the current-mixing model is shown





Standard
Model

of particle physics

the story of the
Higgs Boson
a story about nothing.



This quickly became a story
of a particular epoch in the early Universe
which itself underwent a phase transition

Not in your average hunk of iron

the "system"?

the entire Universe

the phase transition?

everywhere in the Universe

that's right. the whole enchilada



there was a phase change in the entire Universe

at about 1 picosecond after the big bang

there were PRIMORDIAL fields and particles before (**hot**)

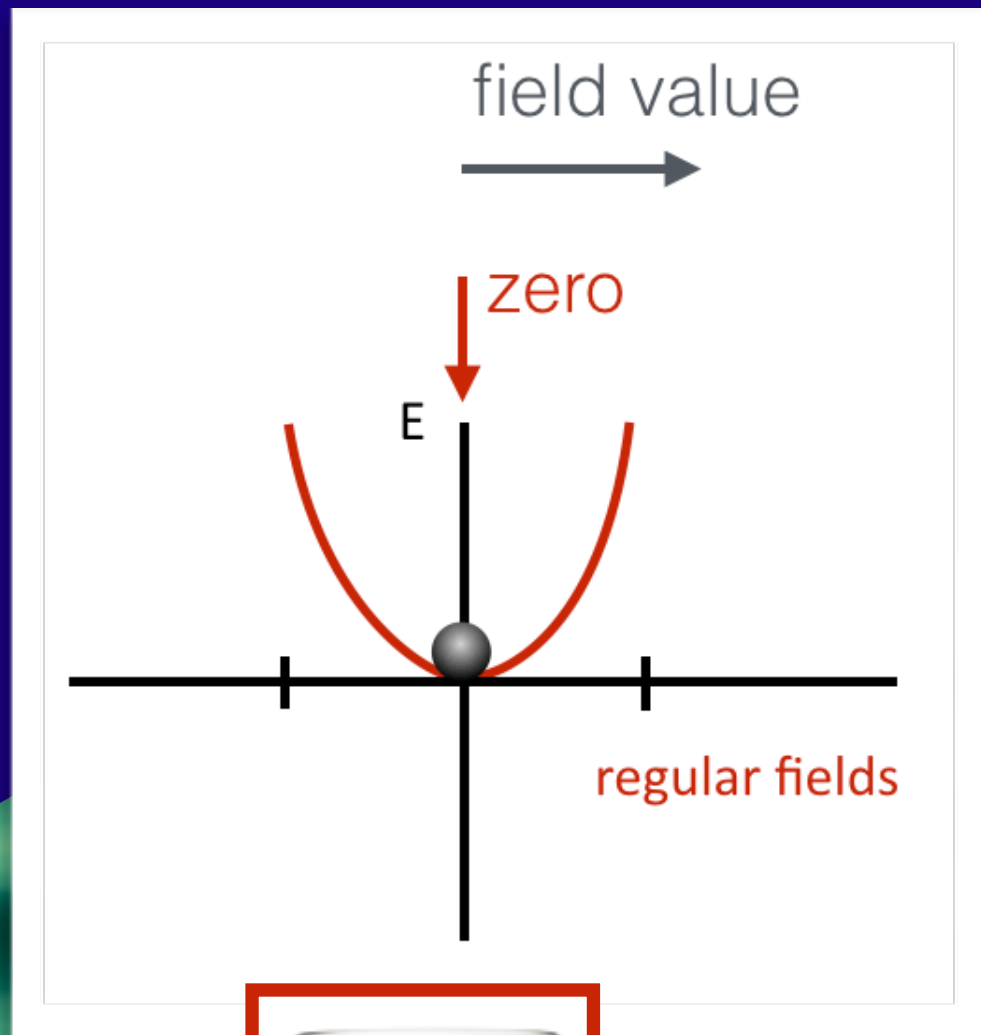
and different fields and particles after (**cold**)


we live in the resulting "cold" universe

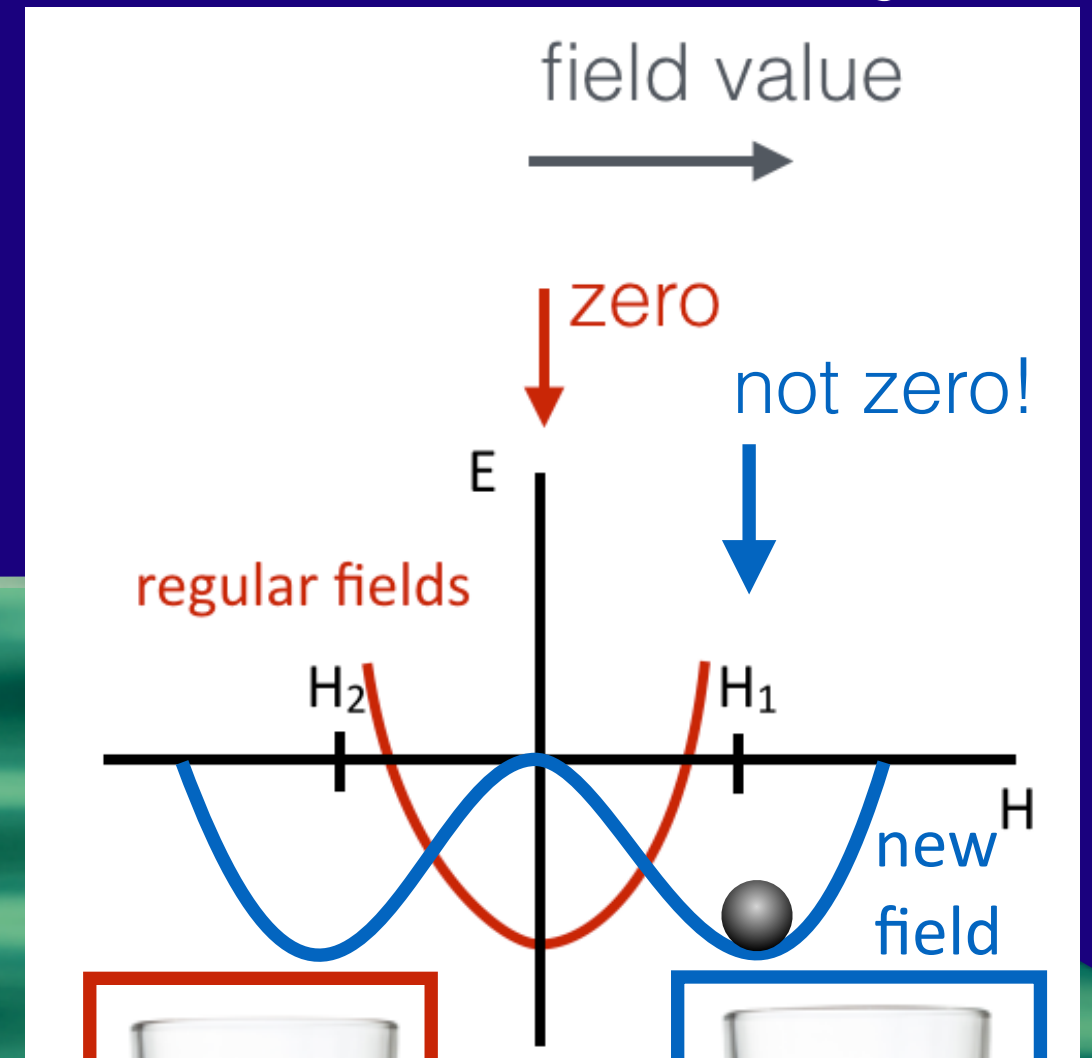



10⁻¹²s after the big bang

universe condensed: a phase change



H  $M = 0$
like a hot, non-magnet



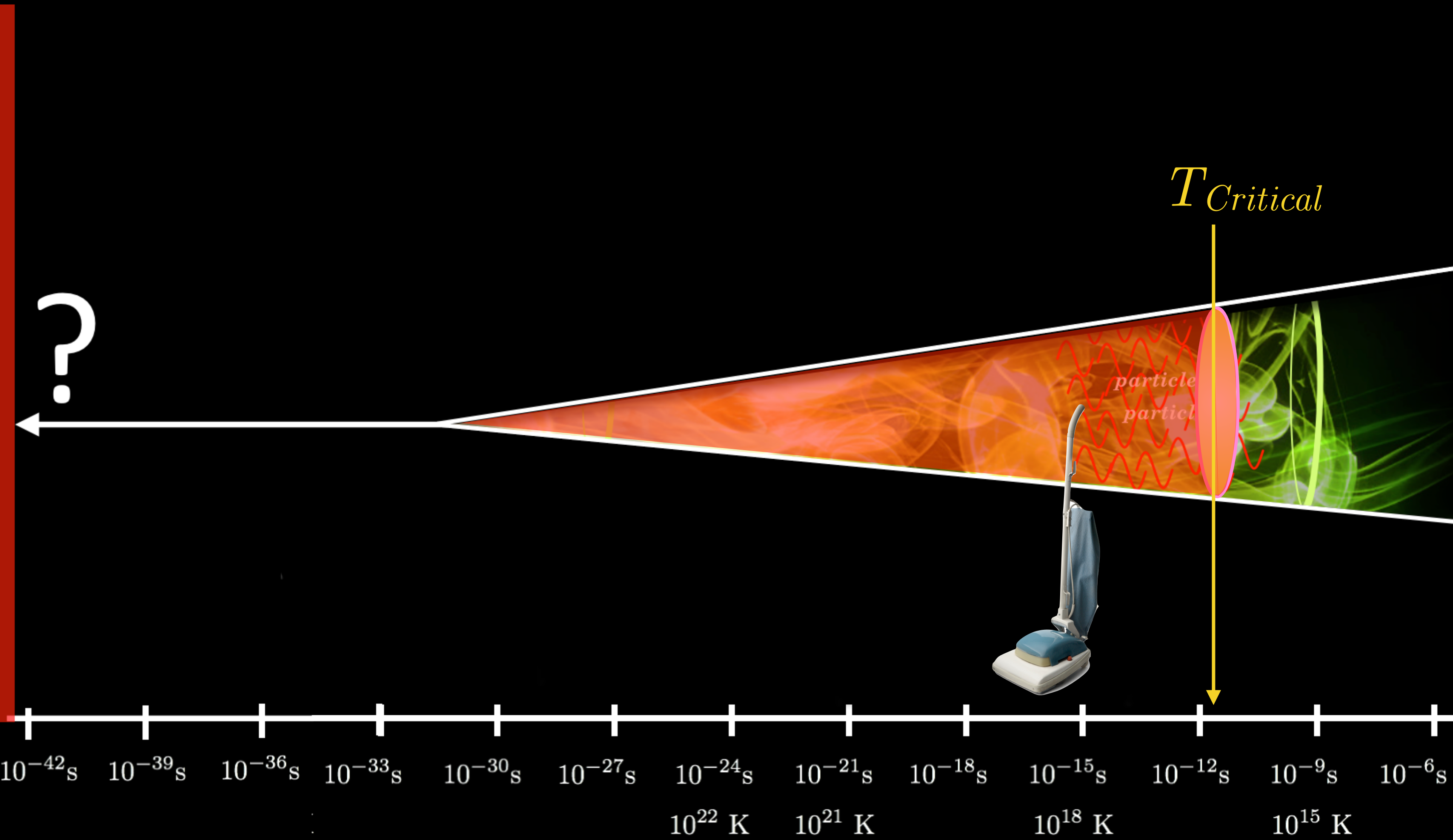
C  $M_1 \neq 0$
like a regular magnet

the big story of the
Standard Model

is the story of mass.

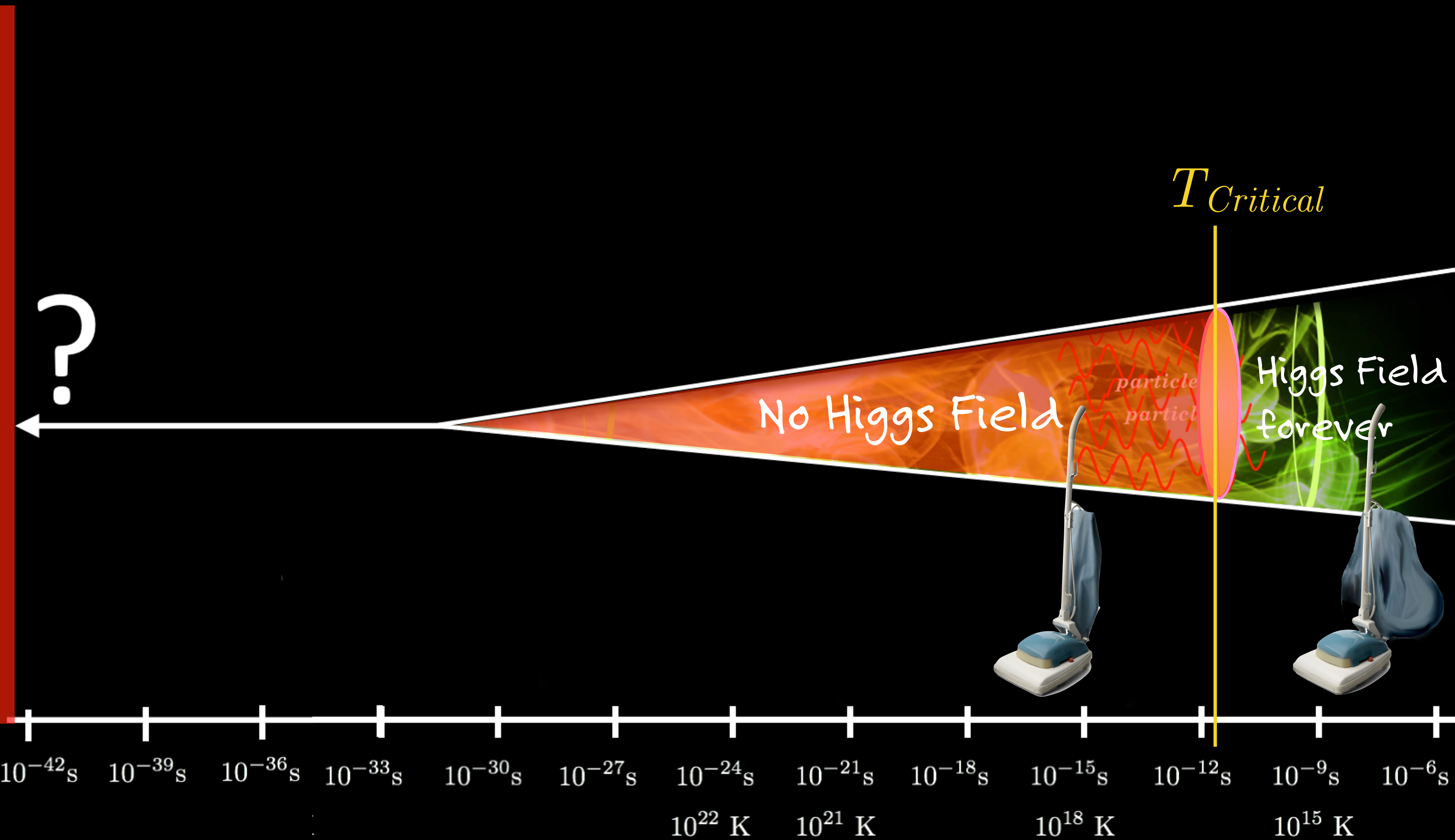


elementary particle epoch



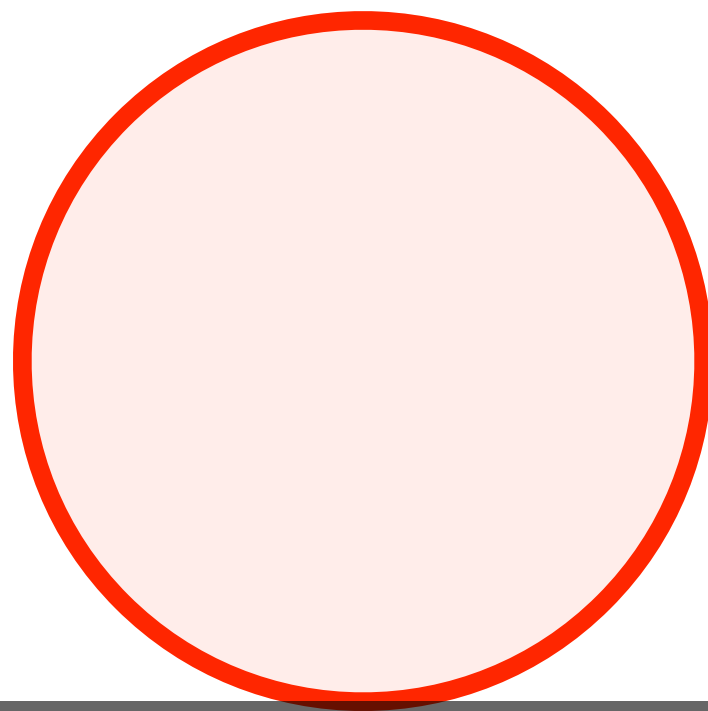


elementary particle epoch





a Higgs
metaphor

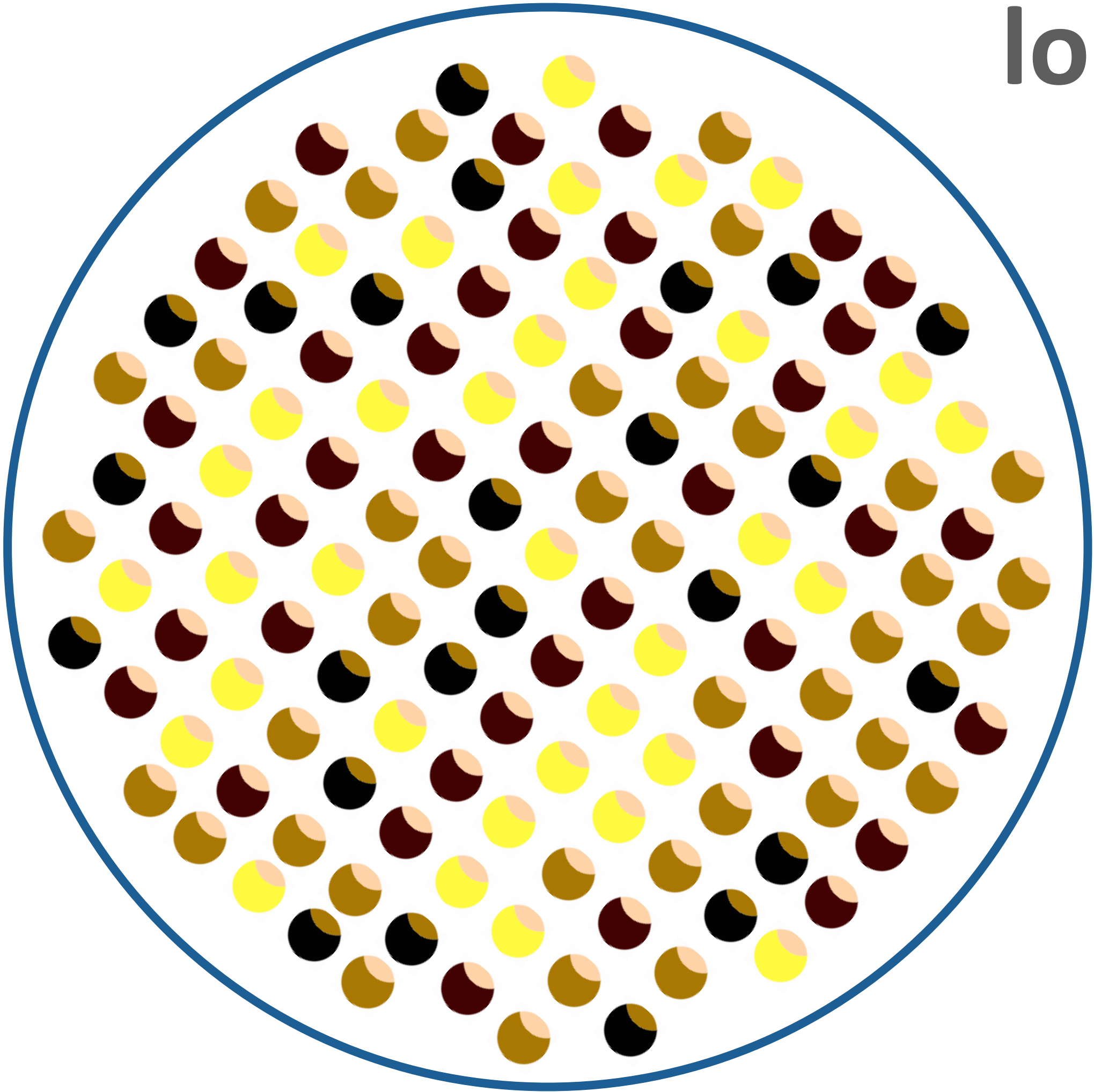


the hot universe: no Higgs Field

A large, solid red circle is centered on the page. Below the circle, there is a dark red shadow that appears to be cast onto a horizontal grey band. The text "a cooled universe: Higgs Field" is written in white, bold, sans-serif font across the grey band, partially overlapping the shadow of the red circle.

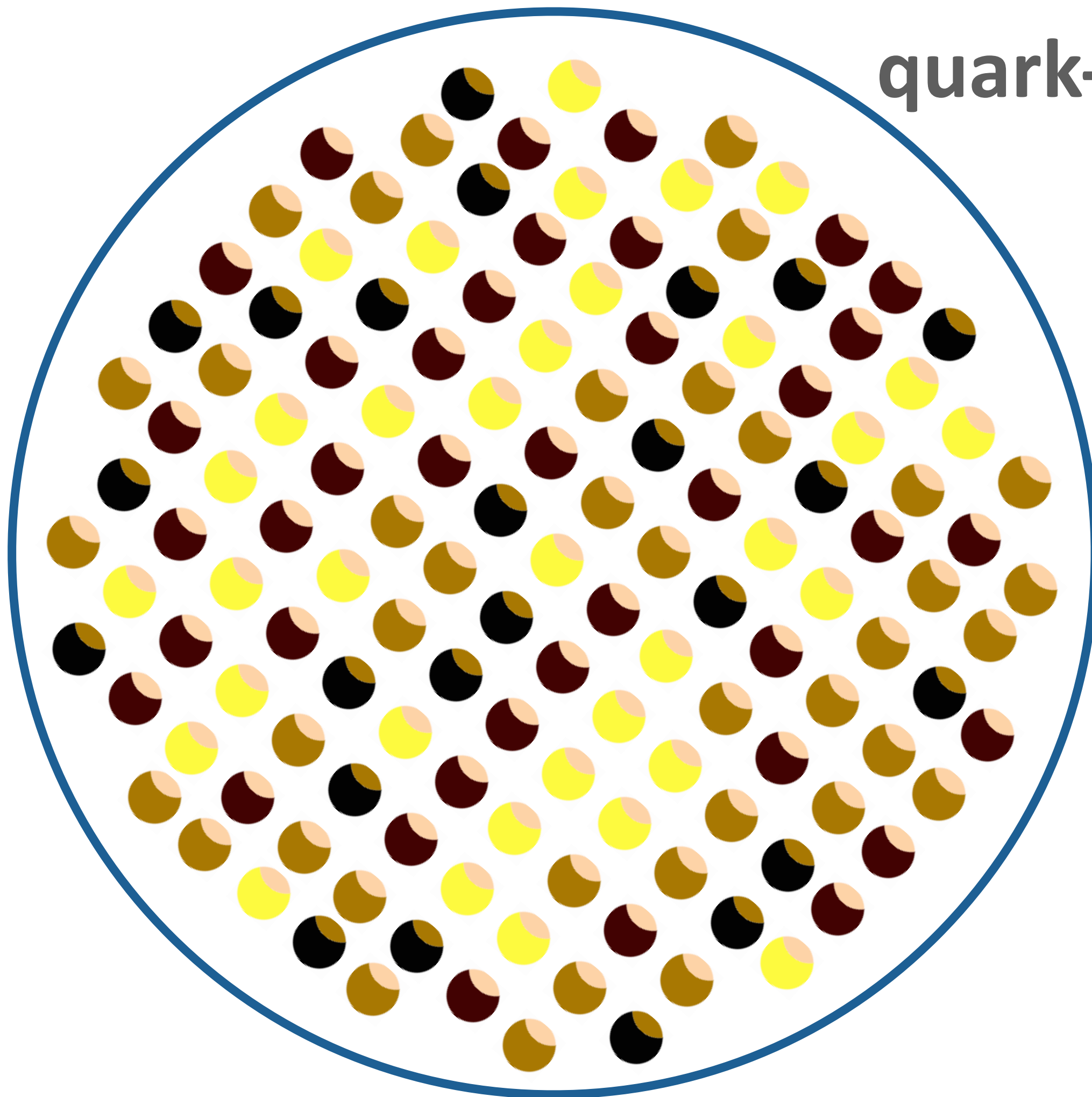
a cooled universe: Higgs Field

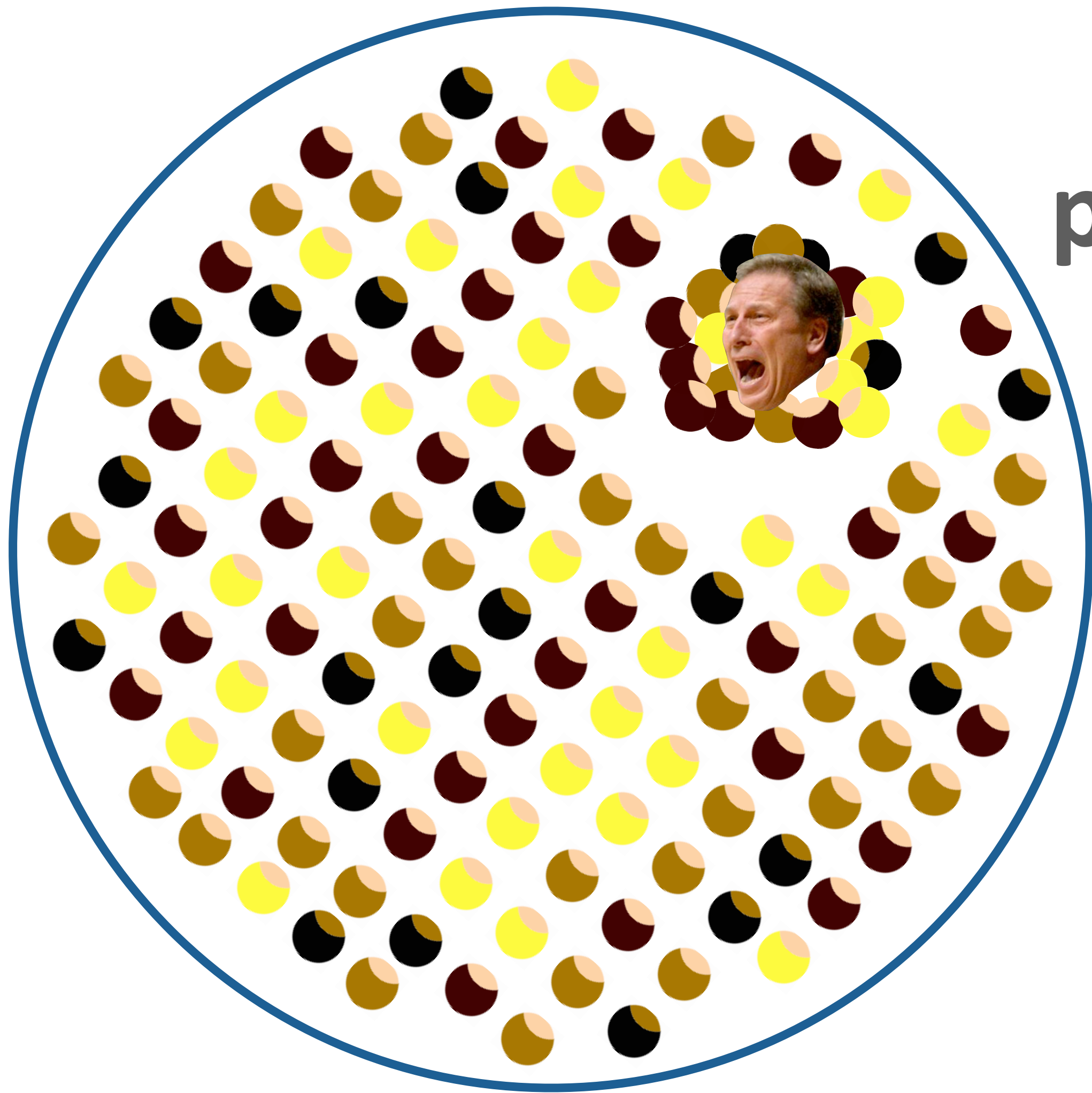
loud





quark-Tom-Izzo

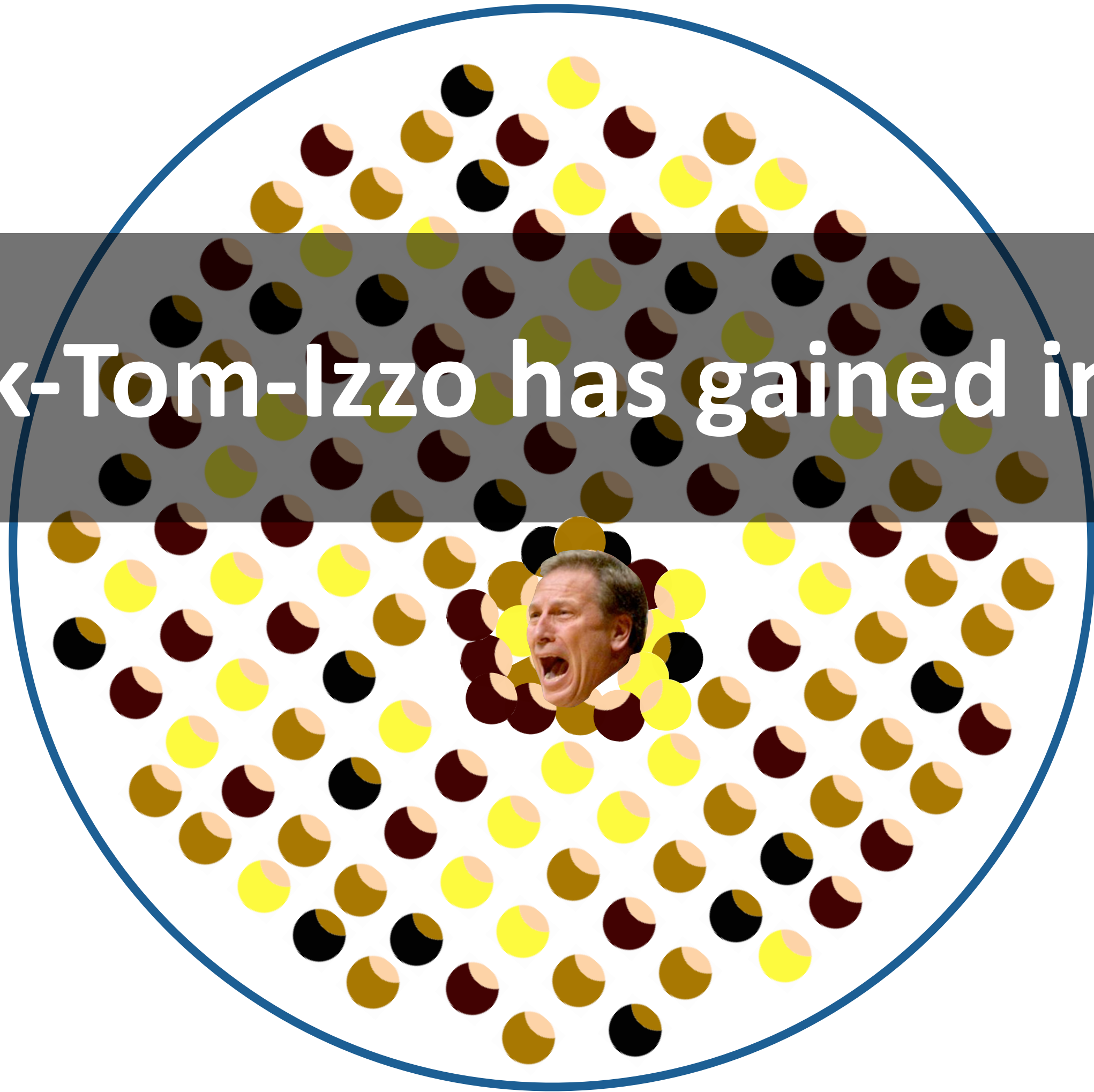




popular



quark-Tom-Izzo has gained inertia



quark-Tom-Izzo has mass.



mass



was born

in the Higgs Field

“rumor” travels: Higgs Particle





So:

The Higgs
Boson is not
just another
particle.

more details now

what's really in the model

the story of the Weak and
Electromagnetic Fields

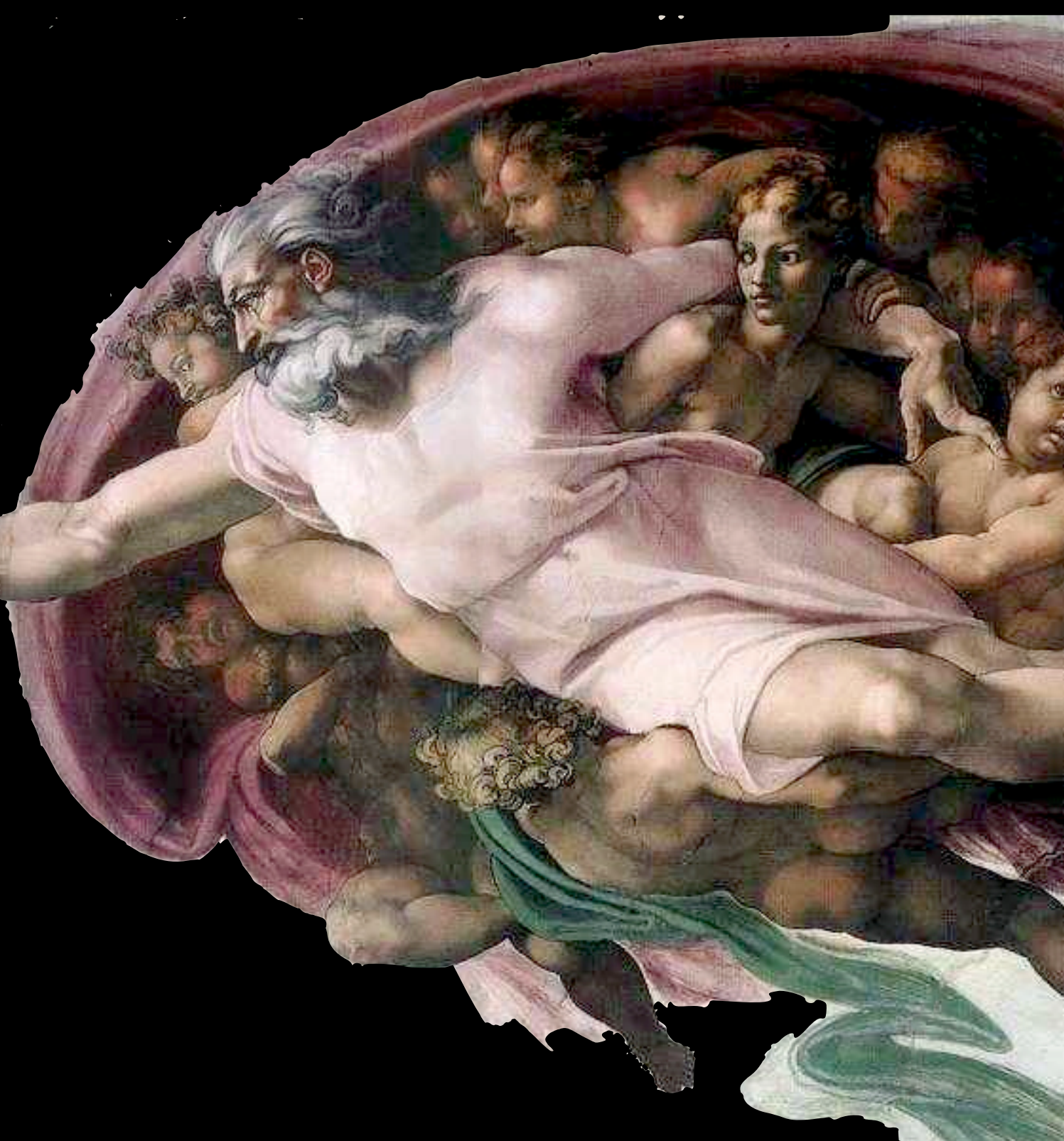
the unification of forces



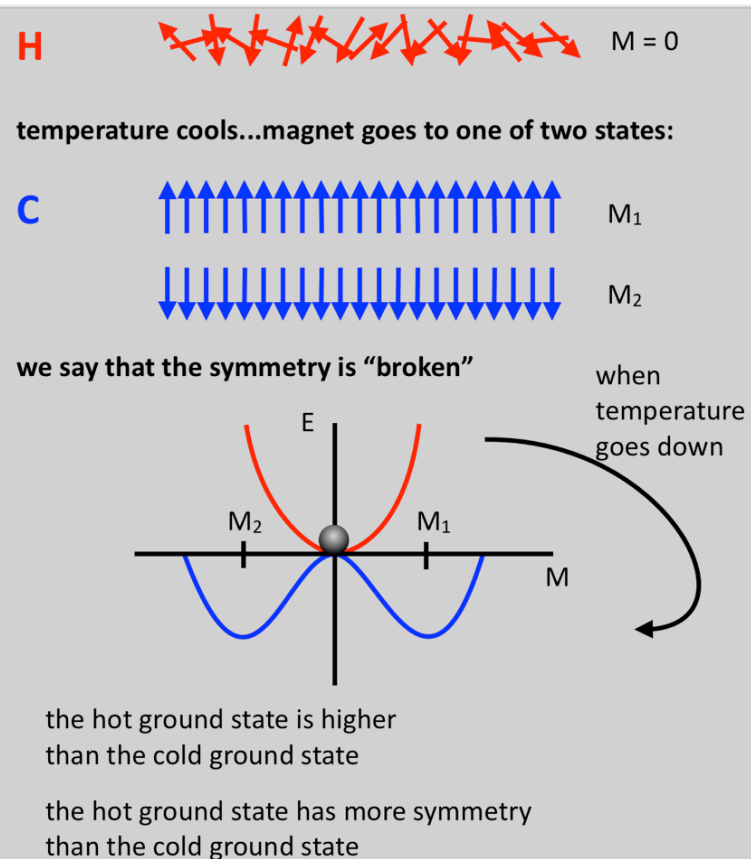
from a hot phase in the universe

cool it all at once

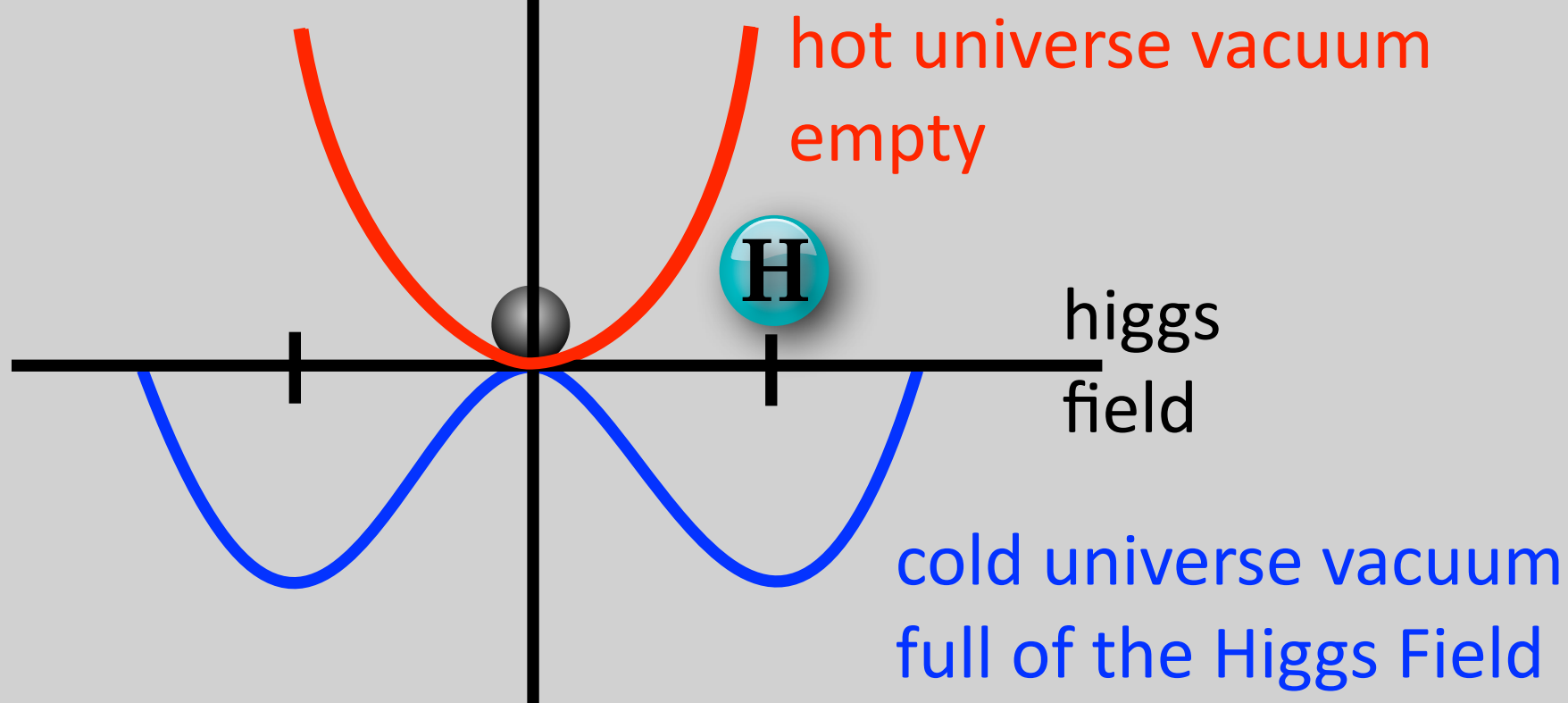
@ 10^{-12} seconds after the BB



an important difference between these two situations



E (entire universe)



H



M = 0

like a hot, non-magnet

C



M₁ ≠ 0

like a regular magnet

a^0



B^0



B^+



B^-



$$\phi \begin{pmatrix} + & - & - & - & - & - \\ 0 & - & - & - & - & - \end{pmatrix}$$

$$\phi^* \begin{pmatrix} - & - & - & - & - & - \\ 0 & - & - & - & - & - \end{pmatrix}$$

γ

Z

W^\pm

H^0

The remaining primordial scalar is the Higgs Field.

t = the beginning 0 s

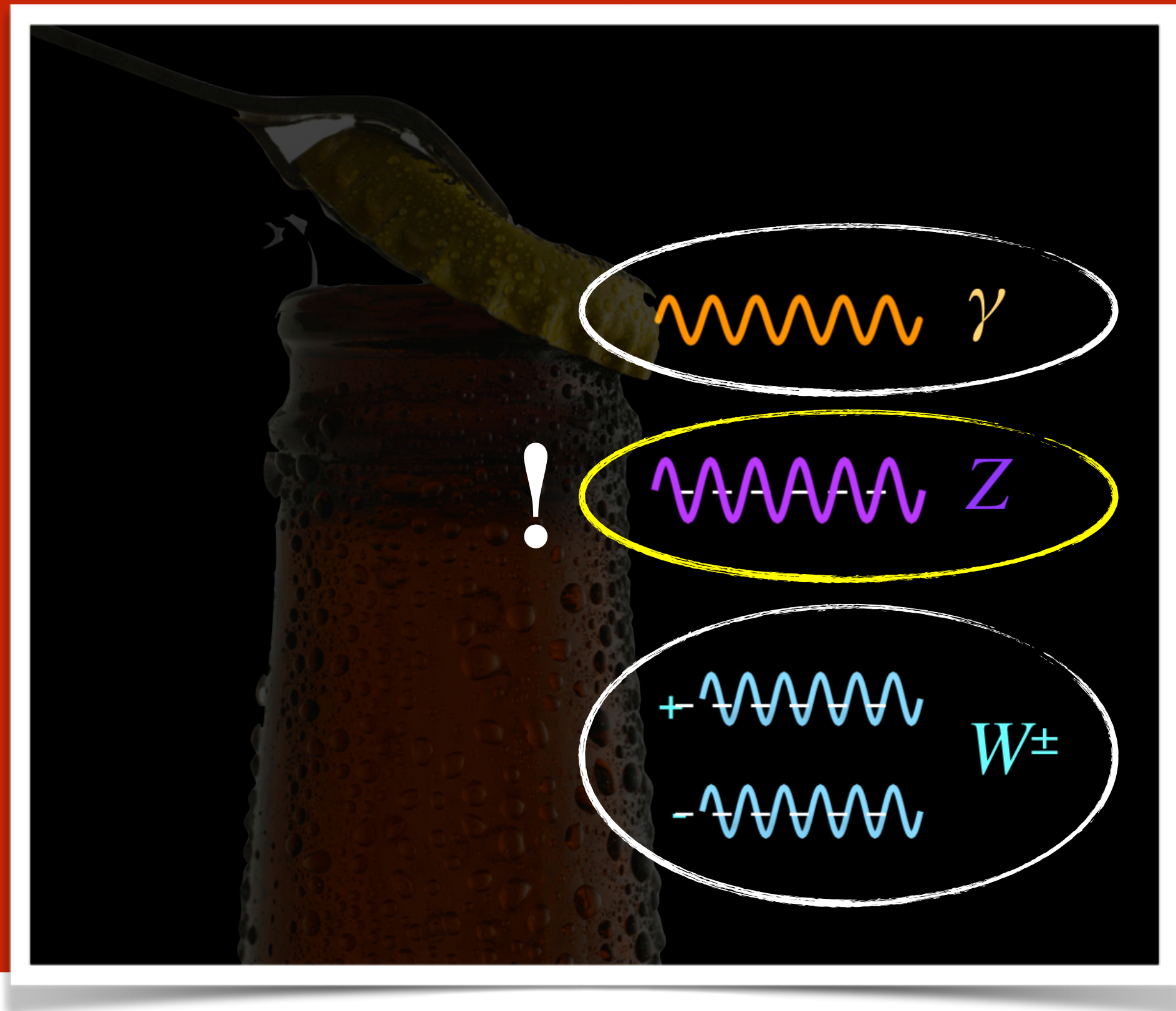
t = 10⁻¹² s

t = 10⁺¹⁸ s

3 of the primordial Higgs fields combine
with 2 of the primordial messengers - and
that gives them mass in the mathematics

what's this
about?

messengers got
fat

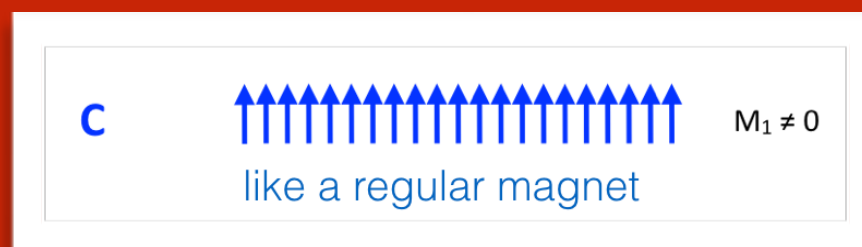


this is quite remarkable

If the idea is right:

the electromagnetic and weak forces

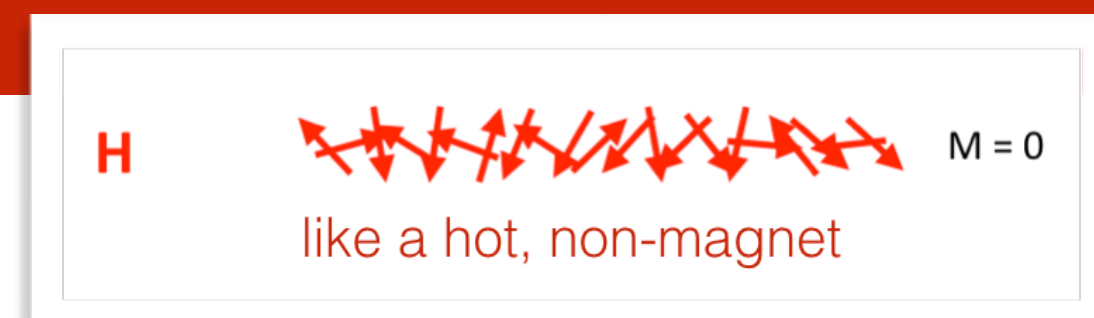
that are so different today



are actually a "cold-phase" of a single, unified force

that existed only when the Universe was very, very hot

"Electroweak
Force"



definite predictions

of Weinberg's
model

- ✓ 0. The weak and electromagnetic interactions are two aspects of the same force
- ✓ 1. The W Boson should exist
- ✓ 2. An additional “Z Boson” should exist

Many physics reactions relate M_w to M_z
- ✓ 3. This Z Boson and the γ are intimately related

any reaction with a photon, must also happen with a Z^0
4. The Higgs Boson should exist

particle:

***W* Boson**

symbol:

W

charge:

$\pm 1e$

mass:

$80.399 \pm 0.023 \text{ GeV}/c^2 = 80.4 \text{ p}$

spin:

1

category:

weak Vector Boson

particle:

Z Boson

symbol:

Z

charge:

0

mass:

$91.1876 \pm 0.0021 \text{ GeV}/c^2 = 91.2 \text{ p}$

spin:

1

category:

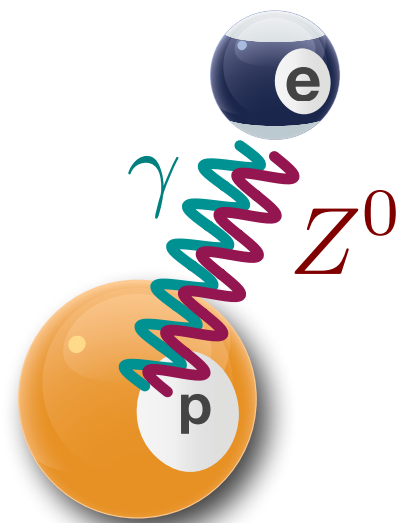
weak Vector Boson

Photon and Z always mix

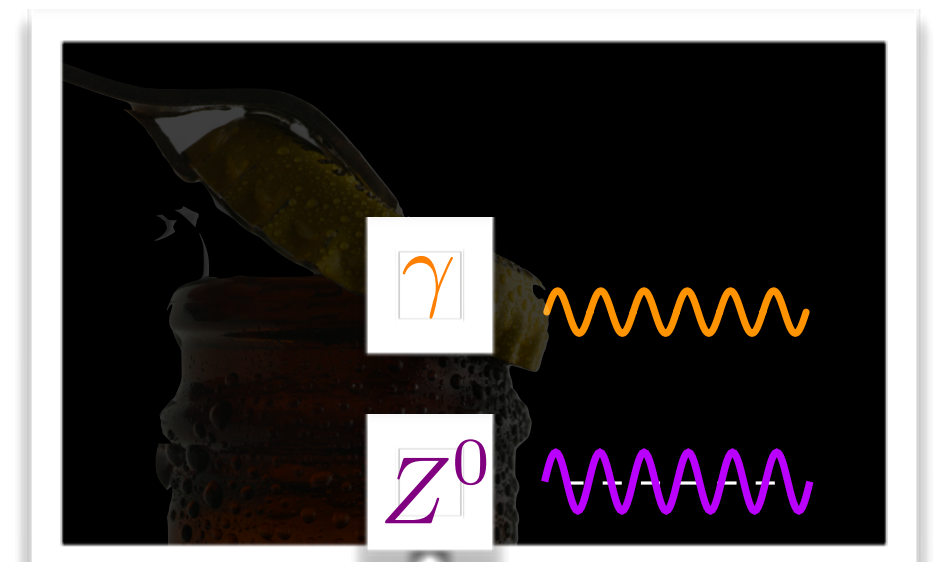
Z, very weakly

3. The Z Boson and the γ are intimately related


any reaction with a photon, must also happen with a Z^0

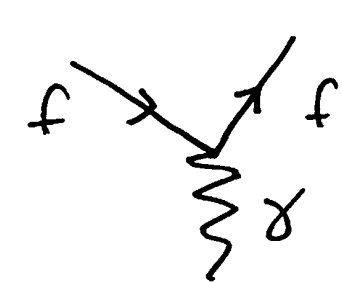
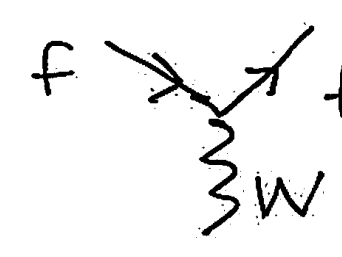
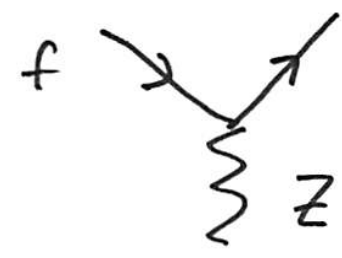
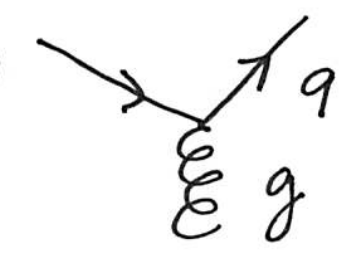


very delicate effects
observed in atomic systems
due to the Z Boson



sixth and seventh entries into your table of primitive diagrams

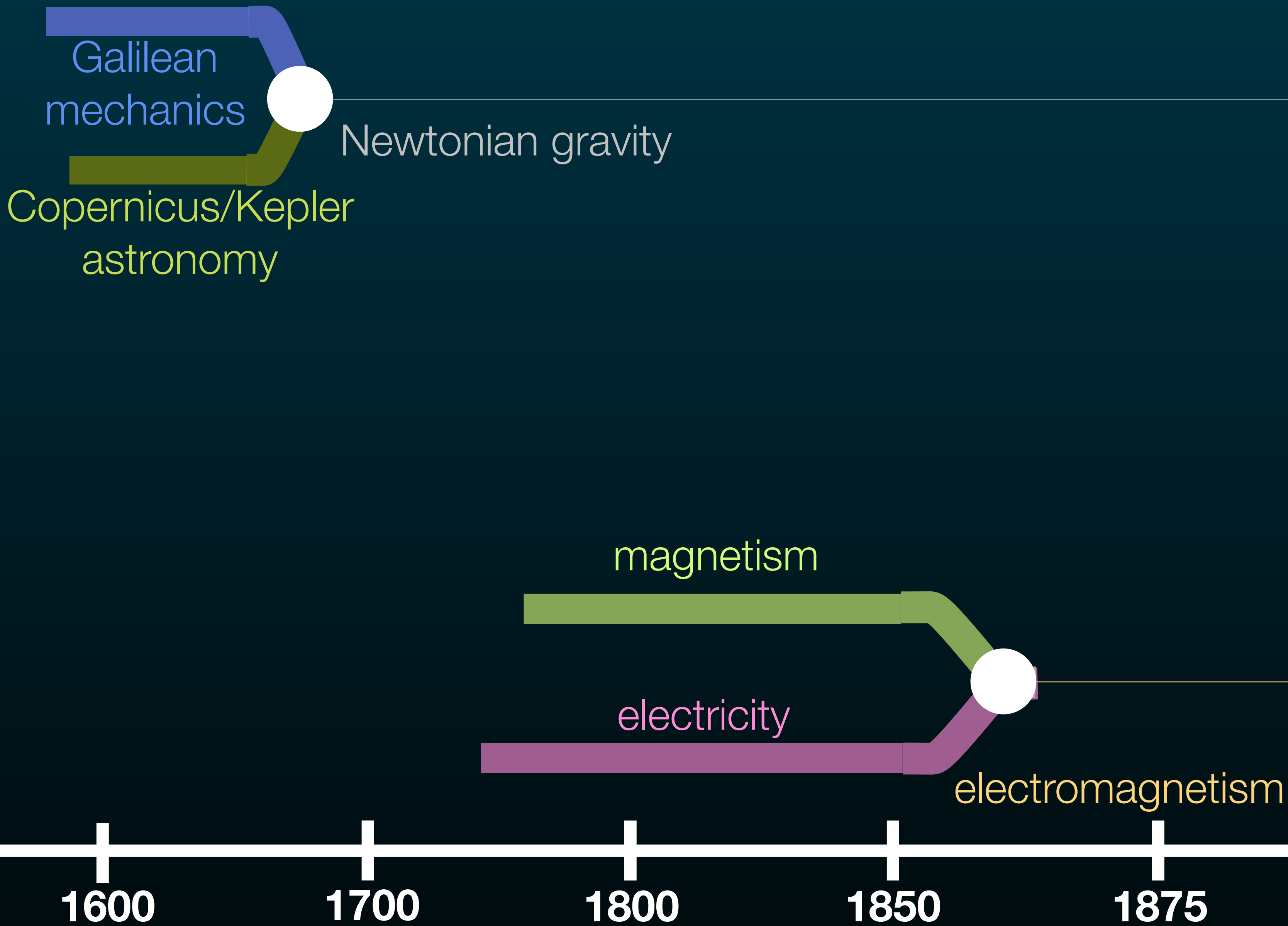
Primitive Diagrams TIME always: 

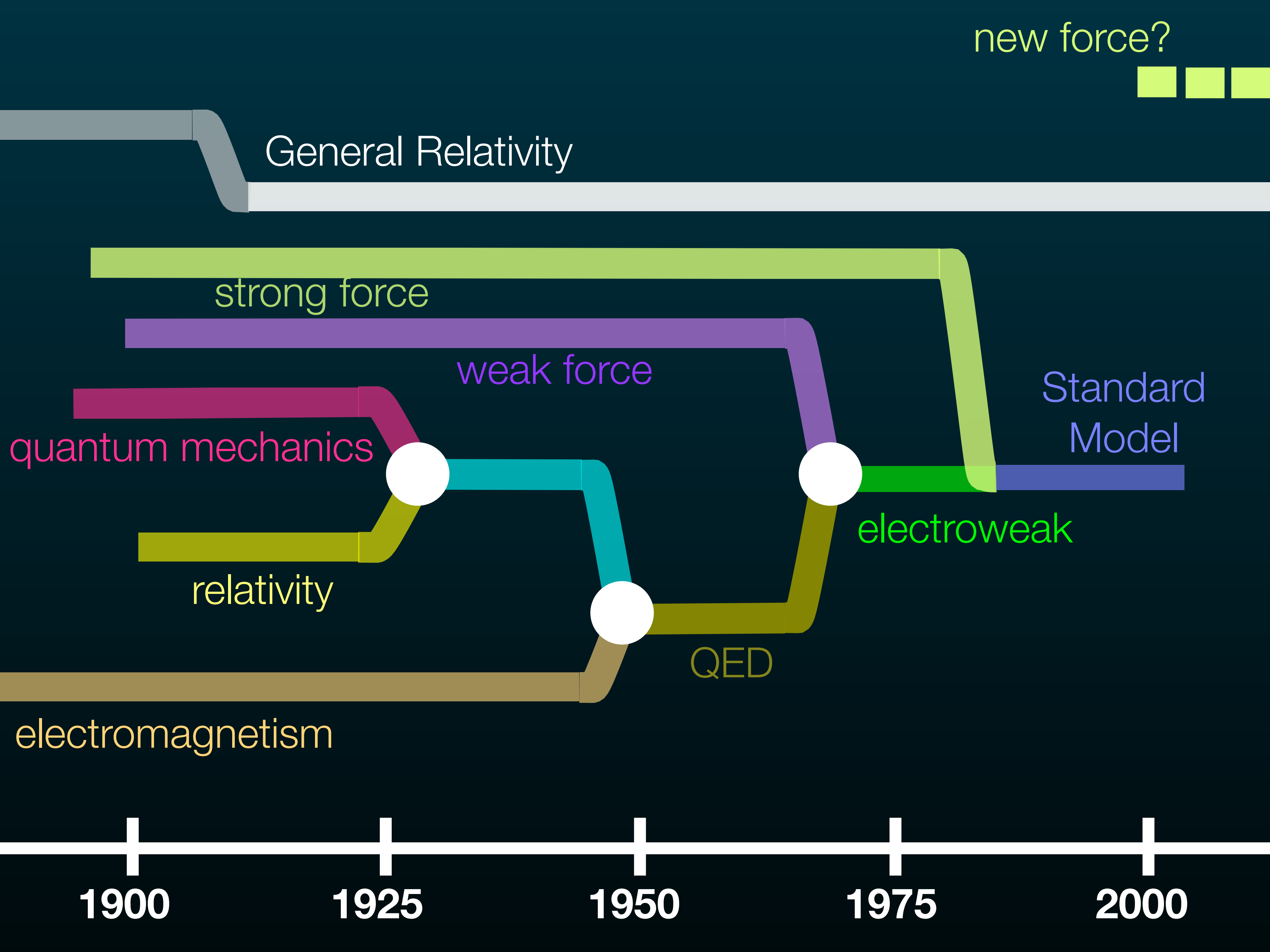
1			QED
2		3	
6		7	Strong Interactions
4		5	
8		9	



scalar Boson, spin 0, e.g., Higgs Boson







General Relativity

new force?

strong force

weak force

Standard Model

quantum mechanics

electroweak

relativity

QED

electromagnetism

1900

1925

1950

1975

2000

we now think in terms of
epochs in the stages of the early universe
distinguished by phase transitions - stay tuned

‘‘mass generation’’

the holy grail of physics since Newton

what is mass?

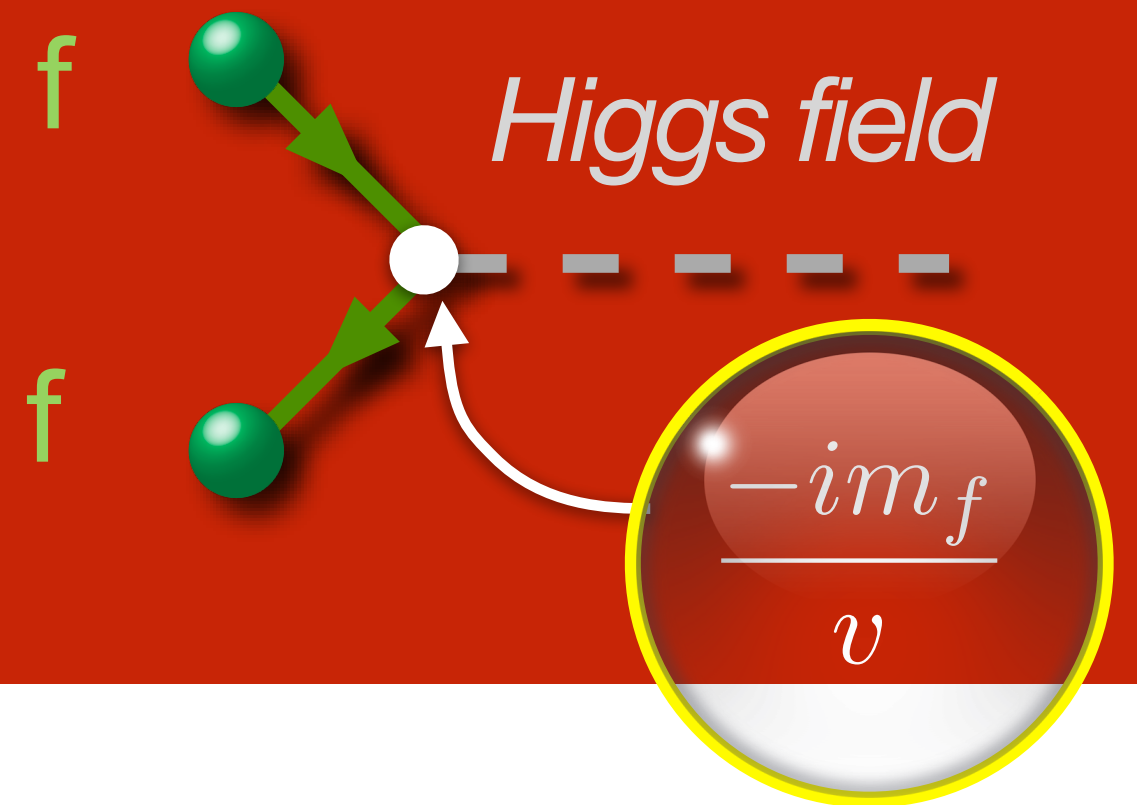
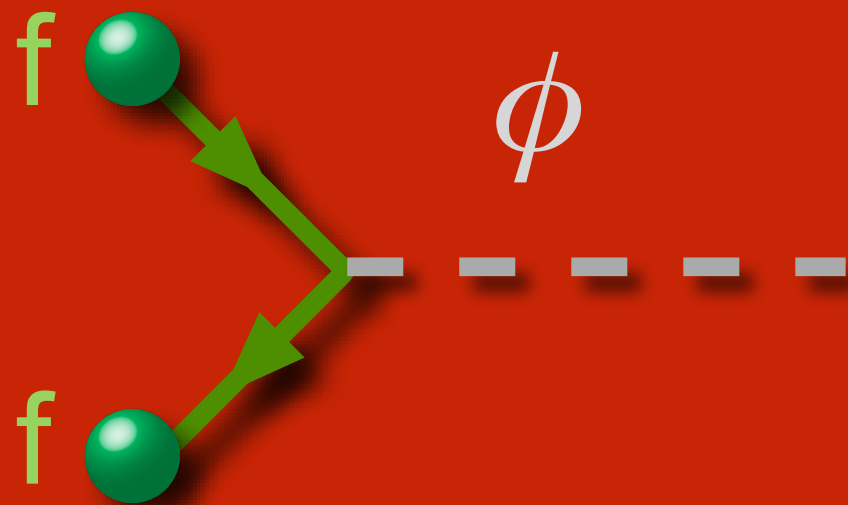
Is “mass” an intrinsic attribute? “nature”?

or

Is “mass” an acquired trait? “nurture”?

mass couplings? mass comes from the
Higgs FIELD

SM predicts from the hot phase:



find the Higgs
particle

confirmation of
the process

Big Discovery

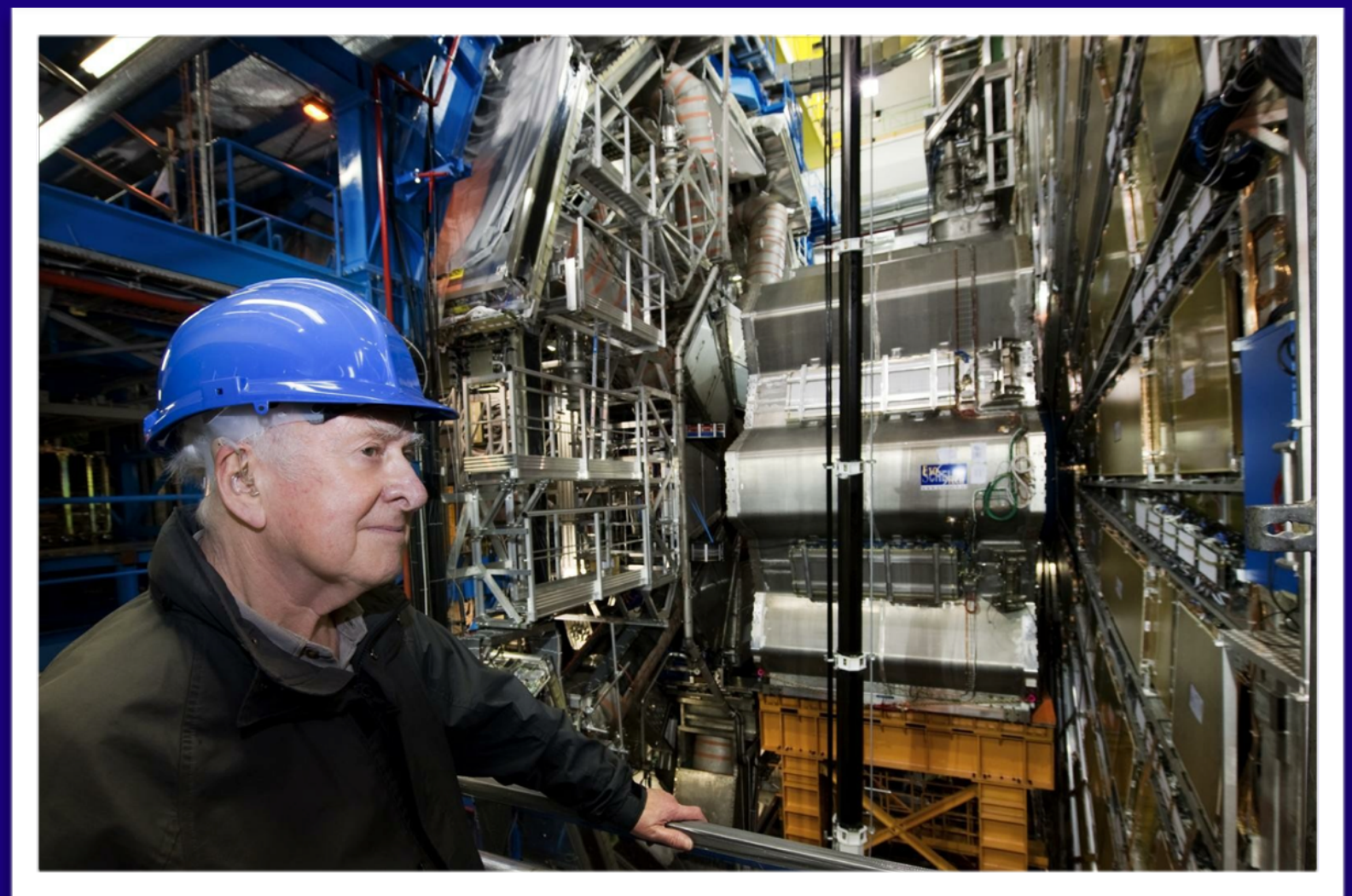
July 4, 2012

watch the off-line movie:

https://qstbb.pa.msu.edu/storage/Extras_2017/HiggsDiscovery/

how to find the
Higgs?

look for him!







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Rapid H.I.V. Home Test Wins Federal Approval
 By DONALD G. McNEIL Jr.
 The OraQuick test, which uses a cheek swab and gives results in 20 to 40 minutes, is the first chance for Americans to learn in the privacy of their own homes whether they are infected.

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Top Judge Helped Eject Millions



New Particle Could Be Physics' Holy Grail
 By DENNIS OVERBYE 4 minutes ago
 If confirmed to be the elusive Higgs boson, a newly discovered particle named for the physicist Peter Higgs, above in Geneva, could explain the universe's origin.

Fears of Fires Take Fireworks Out of July 4th Celebrations
 By DAN FROSCH
 Many U.S. cities and towns across the country have decided to scrap their displays, driven by narked

As Symbols Clash, Fireworks Lose Out to a Hamlet's Bald Eagles
 By AARON EDWARDS
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OPINION
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- Dowd: Gaelic Guerrilla
- Friedman: Morsi, Israel
- Douthat: Books for Obama
- Fixes: Rwanda's Miracle
- Kurt Andersen: The Downside of Liberty
- Op-Ed: Anderson Cooper

MARKETS At 4:02 AM ET

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-14.69	-25.02	-22.27
-0.26%	-0.38%	-0.68%

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The Nobel Prize in Physics 2013
 François Englert, Peter Higgs

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The Nobel Prize in Physics 2013



Photo: A. Mahmoud
François Englert
 Prize share: 1/2



Photo: A. Mahmoud
Peter W. Higgs
 Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

Photos: Copyright © The Nobel Foundation





of particle physics

definite predictions

of Weinberg's
model

- ✓ 0. The weak and electromagnetic interactions are two aspects of the same force
- ✓ 1. The W Boson should exist
- ✓ 2. An additional “Z Boson” should exist

Many physics reactions relate M_w to M_z
- ✓ 3. This Z Boson and the γ are intimately related

any reaction with a photon, must also happen with a Z^0
- ✓ 4. The Higgs Boson should exist

Weinberg, Salam, and Glashow 1979

The screenshot shows the Nobelprize.org website. At the top, the logo and name "Nobelprize.org" are displayed, along with the tagline "The Official Web Site of the Nobel Prize". A navigation bar includes "Nobel Prizes", "Alfred Nobel", "Educational", "Video Player", and "Nobel Organizations". The main content area is titled "The Nobel Prize in Physics 1979" and lists the laureates: Sheldon Glashow, Abdus Salam, and Steven Weinberg. Below the names are three black and white portrait photographs of each laureate. A sidebar on the left provides navigation options for various Nobel Prizes and related information. At the bottom of the screenshot, three gold Nobel medals are shown, each featuring a profile of Alfred Nobel. The text below the medals is partially obscured but mentions the laureates' contributions to the theory of elementary particles and the neutral current.

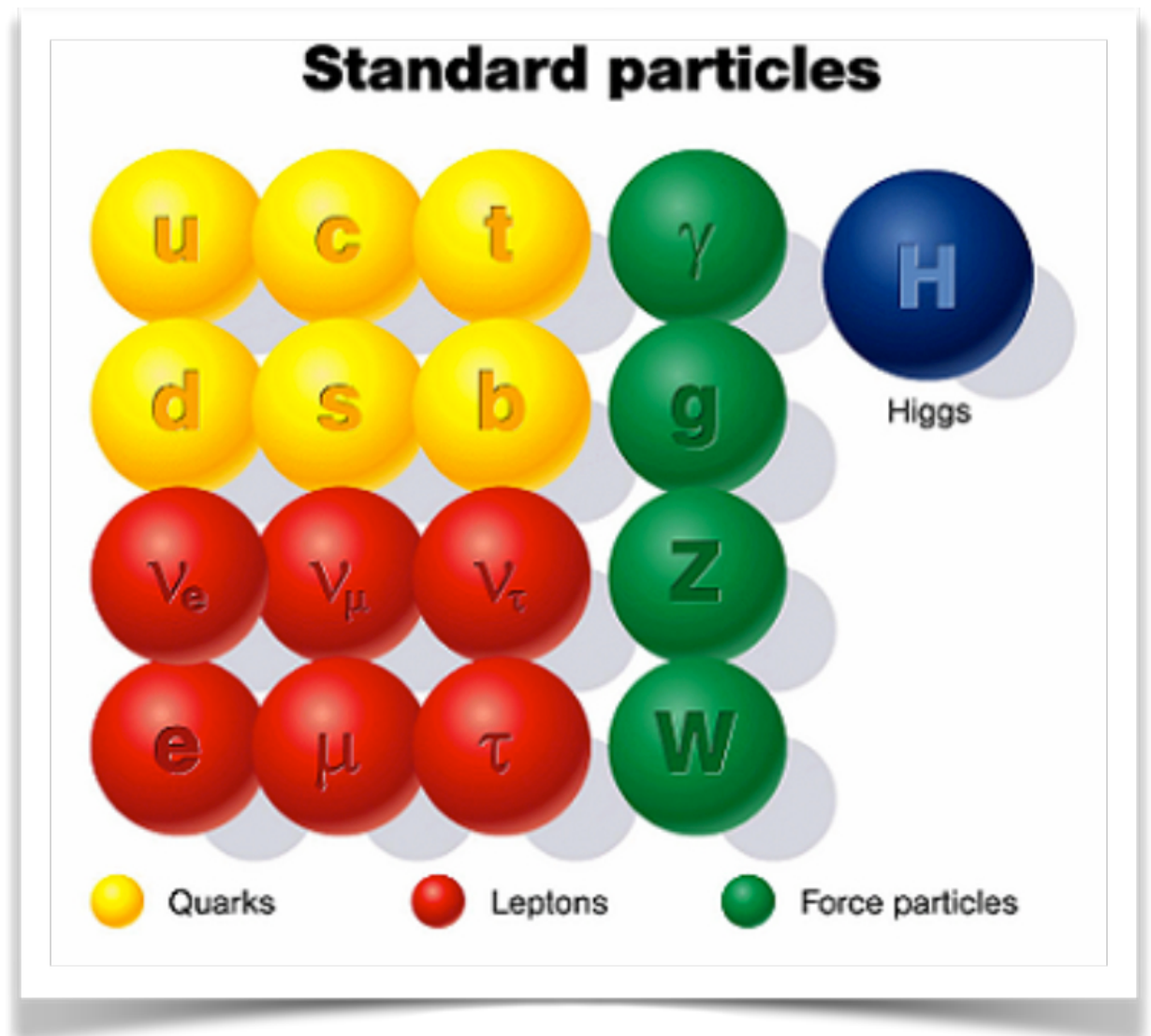


the
particle
players

and

the "substrate"

Our "Periodic Table"


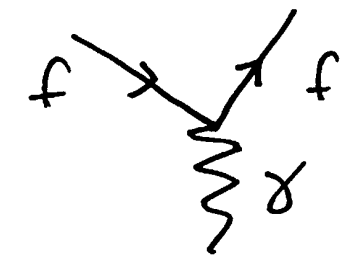
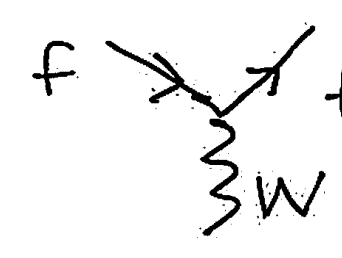
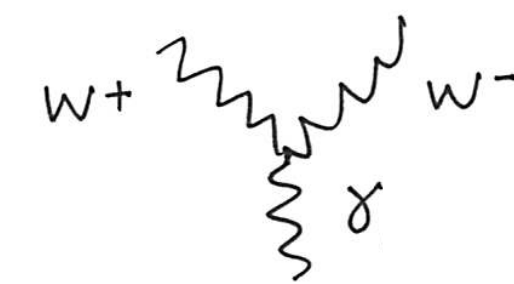
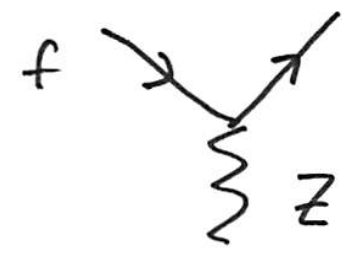
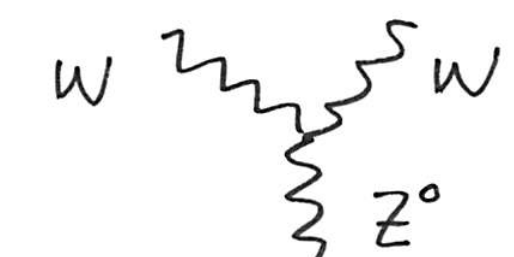
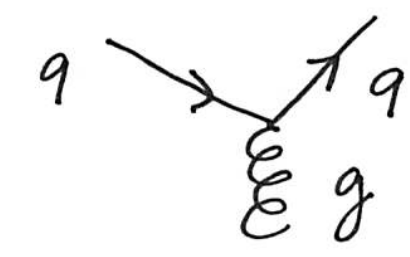
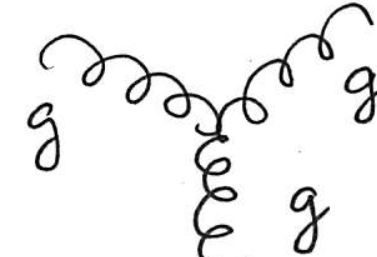
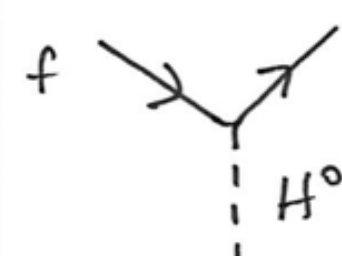
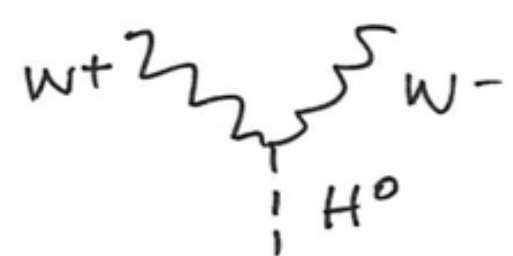

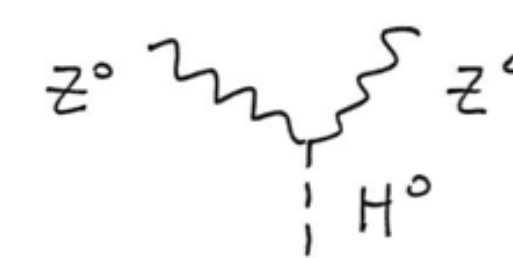






like any
particle,

we predict and
then search for its
manifestation

through its decays

Your final entries
into the Primitive
Diagram
collection

Primitive Diagrams		TIME always: 
1		QED
2		Weak Interactions
3		
6		Strong Interactions
7		
4		Strong Interactions
5		
8		Higgs Interactions
9		
10		
11		
fermion, spin 1/2, e.g., electron  Vector Boson, spin 1, e.g., photon  gluon, spin 1  scalar Boson, spin 0, e.g., Higgs Boson 		



there are two other "issues"

where's

the antimatter?



what the heck

is dark matter?

watch the off-line movie:

https://qstbb.pa.msu.edu/storage/Extras_2017/DarkMatter/



the more
pleasing

extension of the
Standard Model

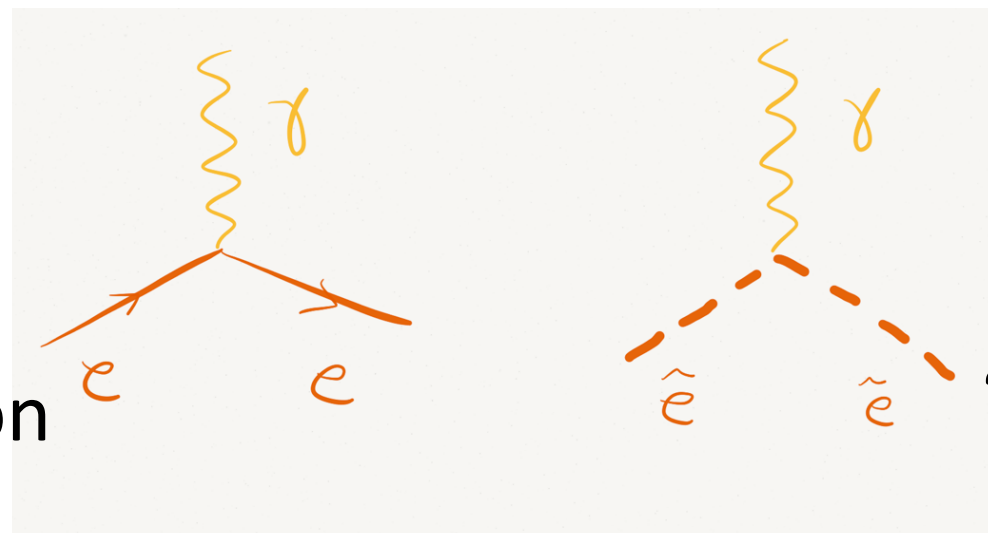
"supersymmetry"

every "Standard
Model Particle"

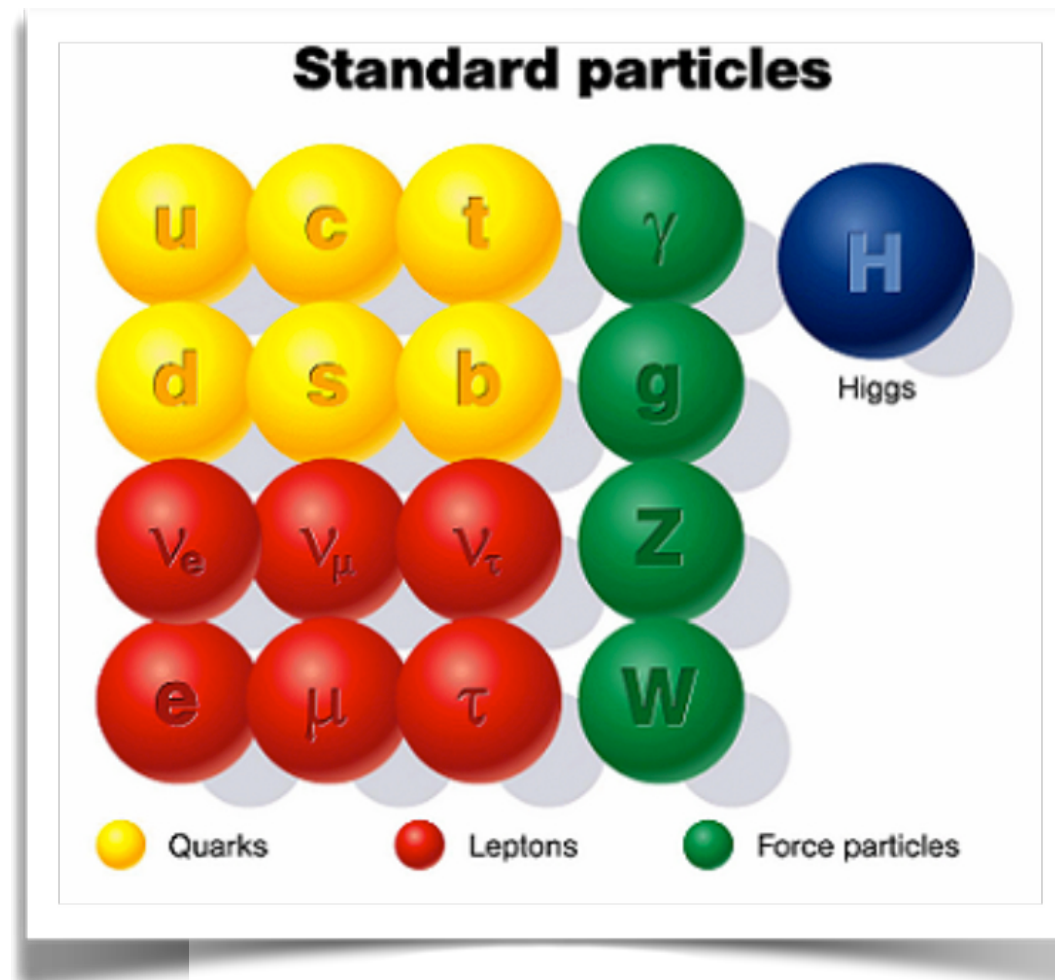
has a super-partner

*presumably
much heavier*

electron

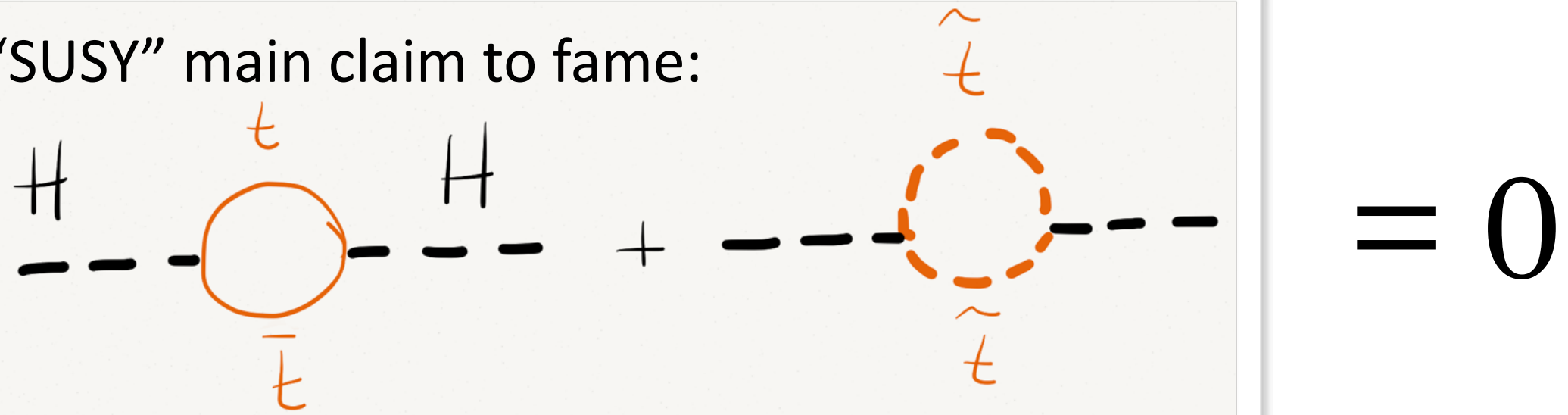


"selectron"



Searching for decades with every incremental increase in energy and luminosity. No evidence so far.

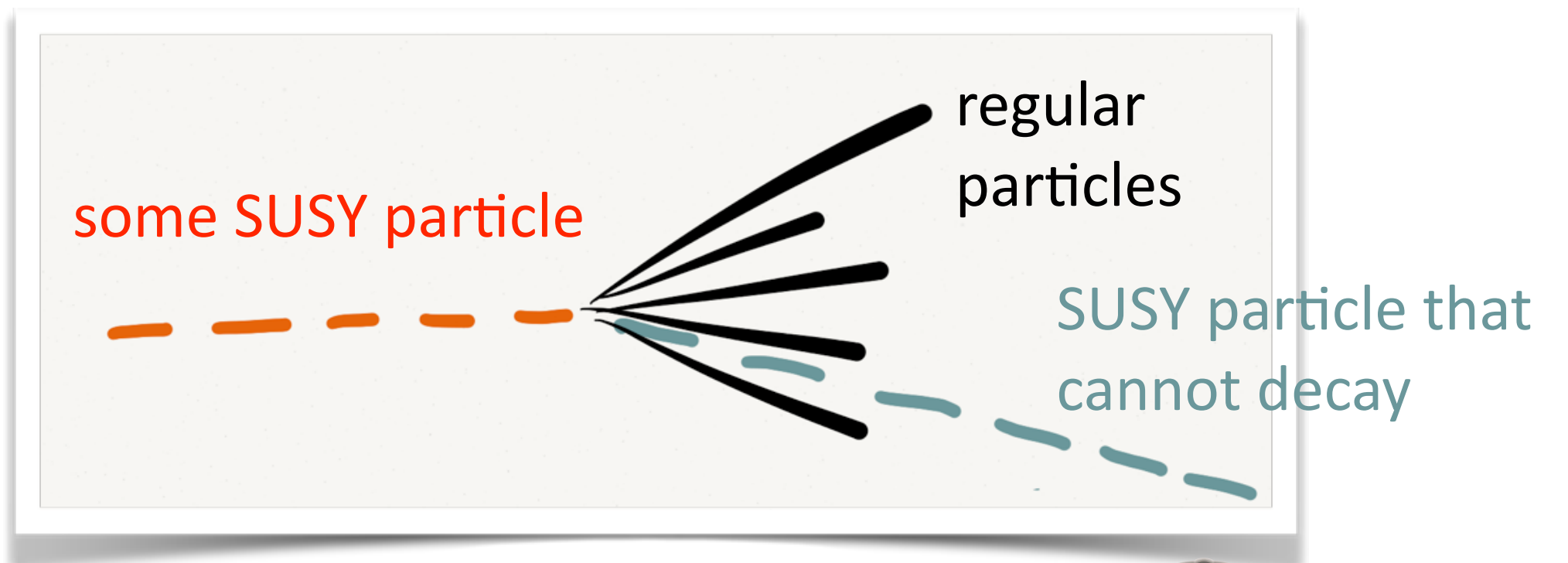
“SUSY” main claim to fame:



intriguing

for two big reasons

tames a SM Higgs mass problem*, “naturally”



???

*mass should be much higher

many other extensions

which unify forces and fix the infinities

add messenger particles

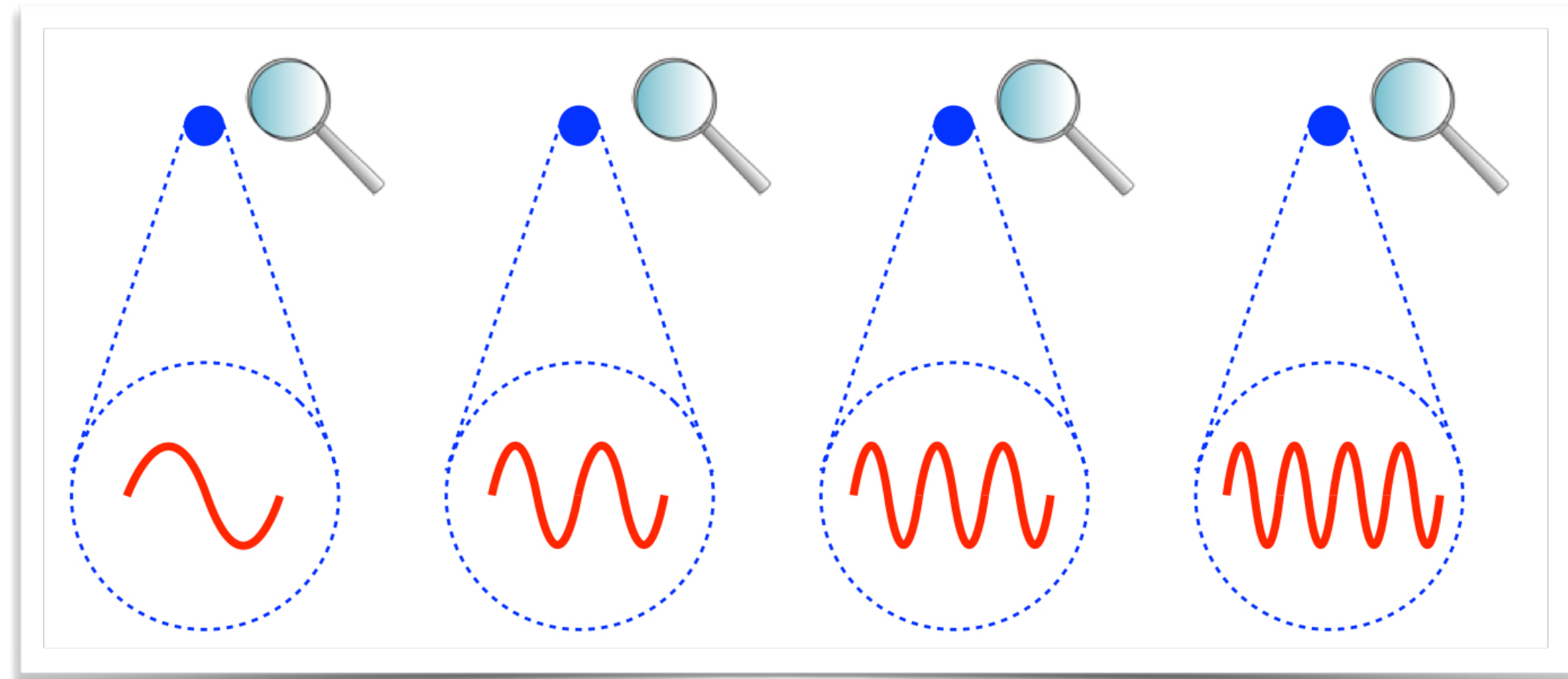
composite Higgs

composite quarks and leptons

“String Theory”...stop and start history in mathematics

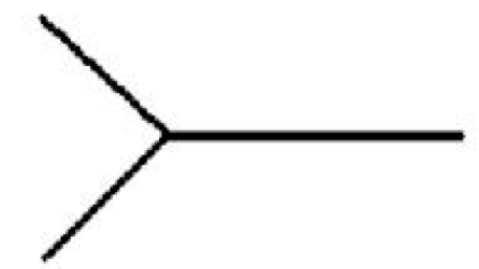
The “infinities” in Relativistic Quantum Field Theory are related to extrapolation in spacetime to zero, $x, y, z, = 0$

Suppose there is a minimum length in Nature?

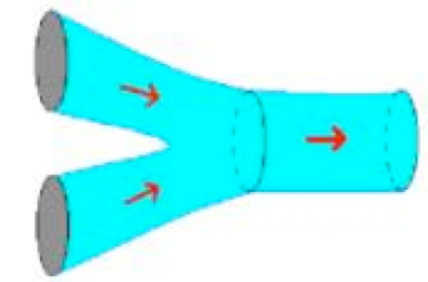


each wavelength...a different – e x t e n d e d – particle.

Plus: get a gravity and the graviton for free!



Point particle interaction

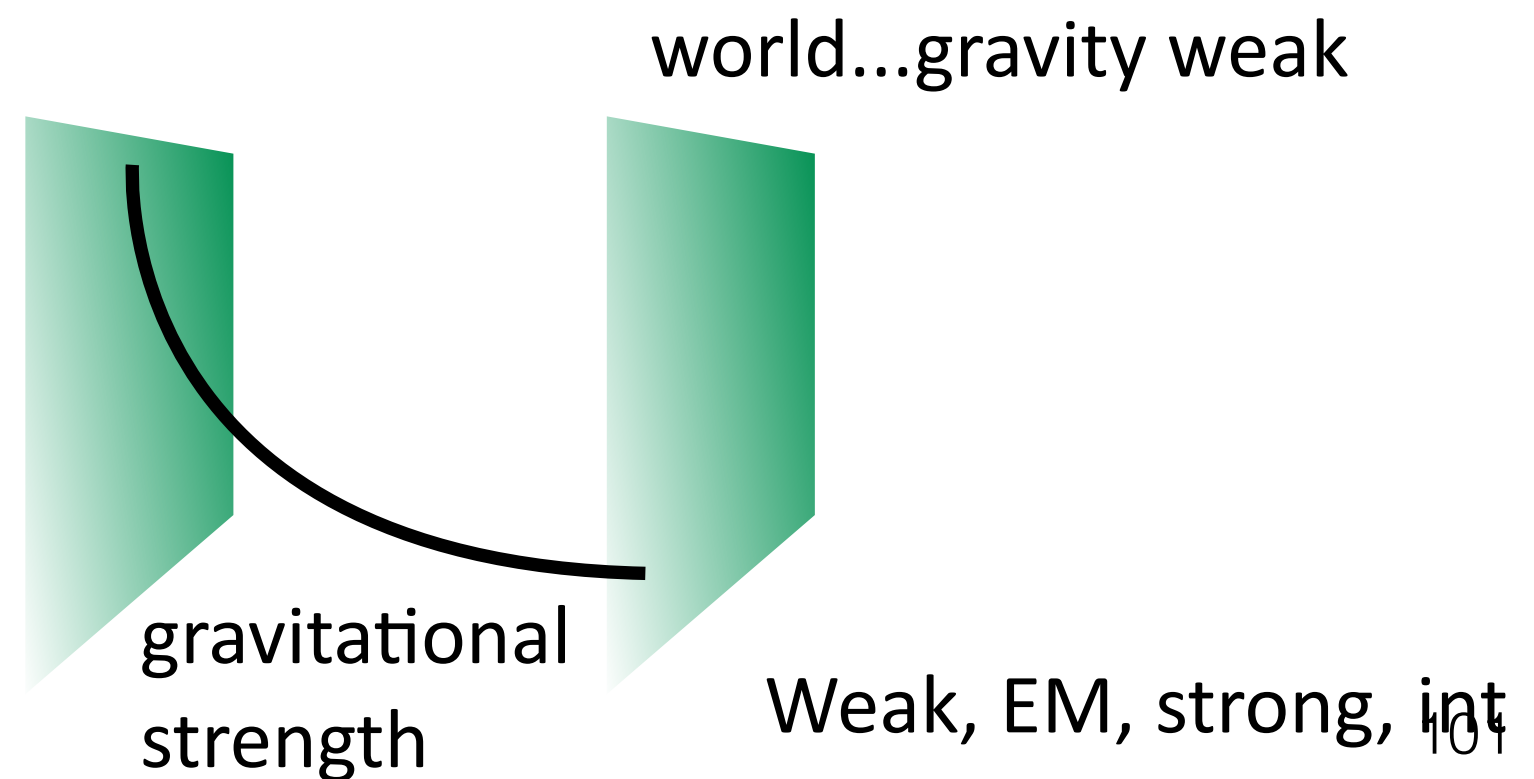


String interaction

....up to 10 space and 1 time dimensions.



high energy
scale
dimension(s)



pretty:



Cosmology 5

FLRW catalogue of Universes

$$\Lambda > 0$$

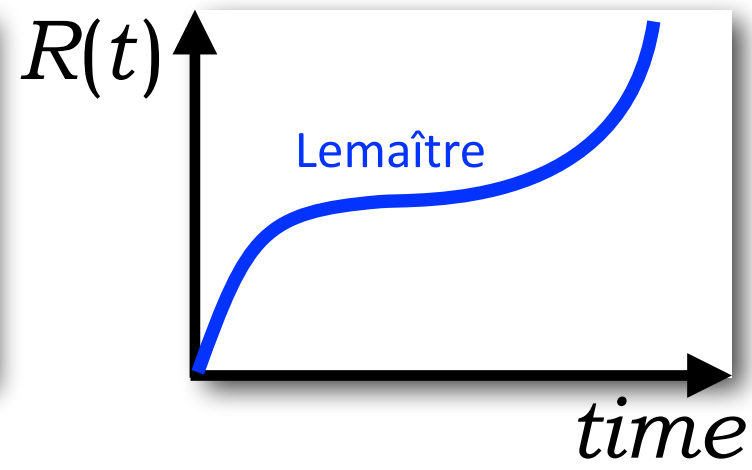
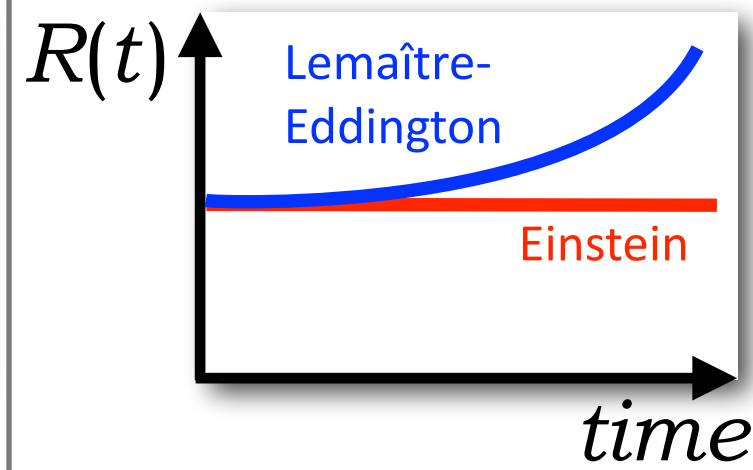
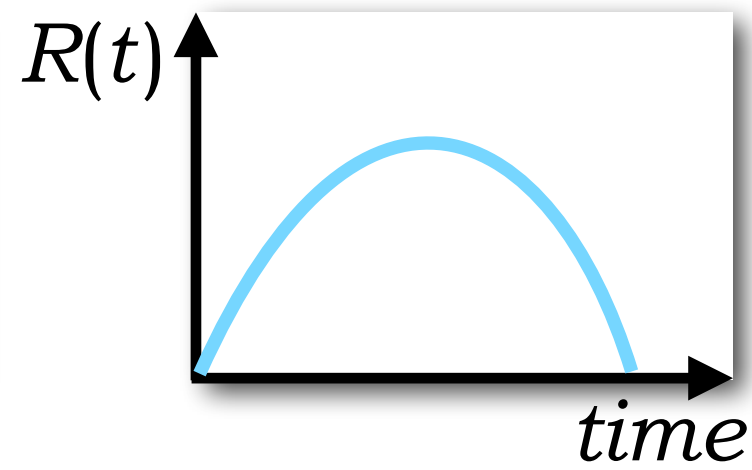
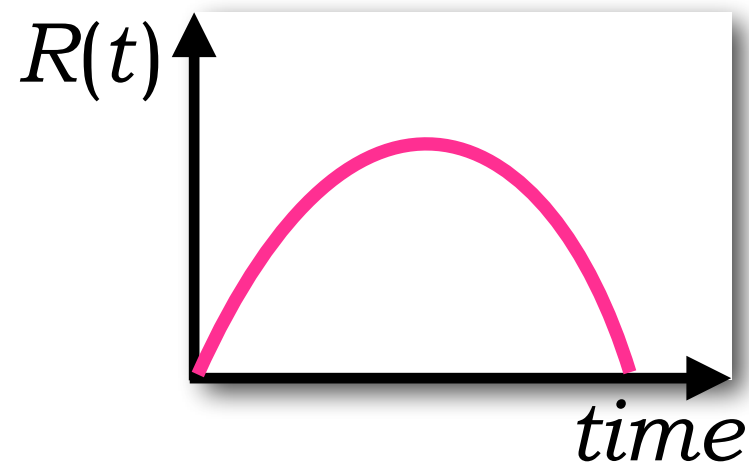
$$\Lambda < 0$$

$$\Lambda = 0$$

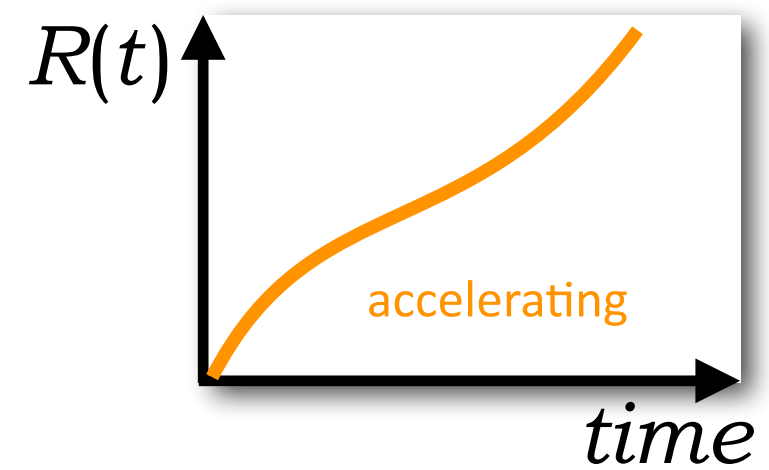
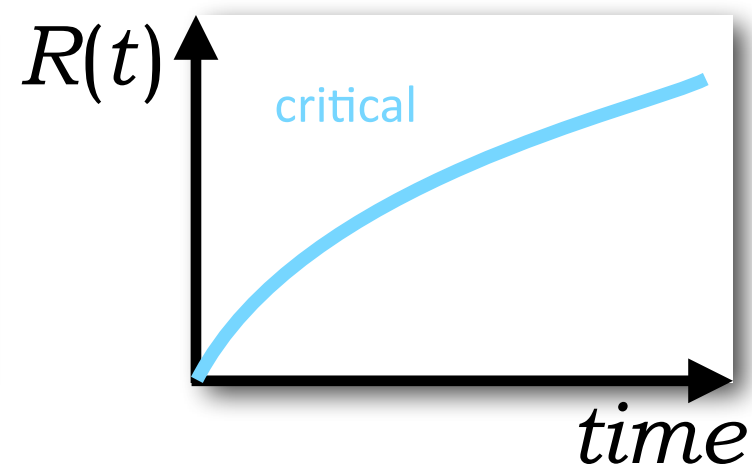
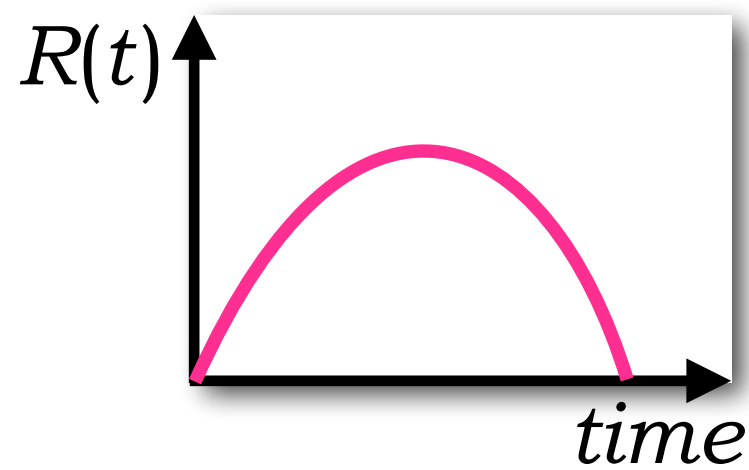
$$\Lambda = \Lambda_E$$

$$\Lambda > \Lambda_E$$

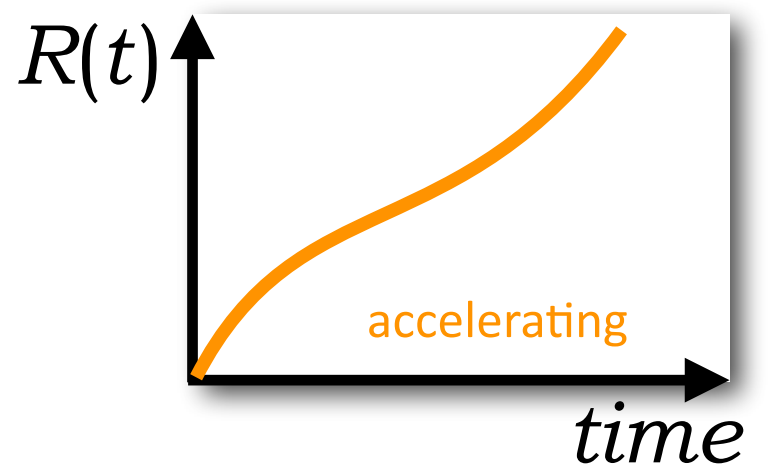
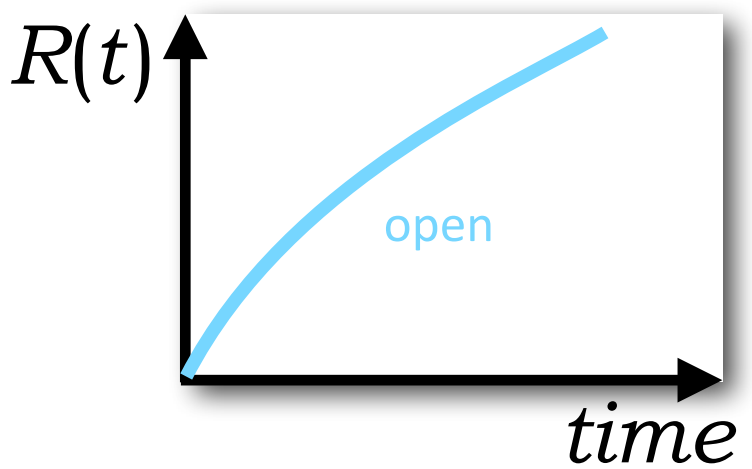
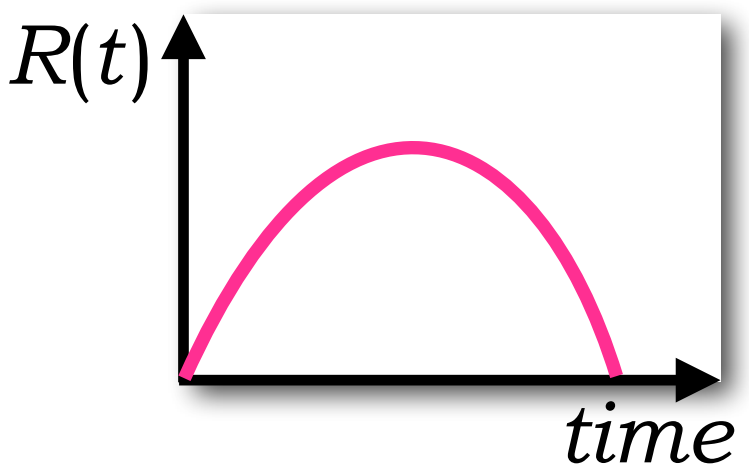
$$k = +1$$



$$k = 0$$



$$k = -1$$



~~two~~ ^{three} opposing views

"Steady State Universe"

eternal, matter created out of vacuum to maintain constant energy density..

"Big Bang Universe"

universe began at an instant

I lied: cyclic universe

over and over...bang and collapse - so eternal and a beginning

George Gamow

universe born

hot primordial soup

Fred Hoyle

steady state model,
continuous creation
of matter.



To Hoyle: the Big Bang implied a creator.

“Big Bang” was coined by Fred Hoyle in a

BBC radio
broadcast for the
general public in
1948

-4-

The recession of the galaxies does not give the only observational test that a theory of the expanding universe must satisfy. During the past few years astronomers have developed a number of further requirements. Although I don't wish to go into these in detail, I might mention that it is now possible to determine the ages of our own Galaxy and of several neighbouring galaxies with a substantial degree of accuracy. The result is about five thousand million years. A satisfactory theory must provide for this age, neither more nor less.

We now come to the question of applying the observational tests to earlier theories. These theories were based on the hypothesis that all the matter in the universe was created in one big bang at a particular time in the remote past. It now turns out that in some respect or other all such theories are in conflict with the observational requirements. And to a degree that can hardly be ignored. Investigators of this problem are like a party of mountaineers attempting an unclimbed peak. Previously it had seemed as if the main difficulty was to decide between a number of routes, all of which seemed promising lines of ascent. But now we find that each of these routes peters out in seemingly hopeless precipices. A new way must be found. The new ~~new~~ way I am now going to discuss involves the hypothesis that matter is created continuously.

How are the difficulties facing former theories overcome by introducing continuous creation of matter?

I cannot deal fully with this question, but perhaps you may like to hear one of many possible examples. According to the majority of the earlier theories the density of the matter which composes the background, the background which I've already described, must in the distant past, have been vastly greater than it is at present. This is an effect arising from the expansion, which in these theories produces a decrease of background density as we go forwards into the future but an

Big Bang cosmology is a form of religious fundamentalism ...and this is why these peculiar states of mind have flourished so strongly over the past quarter century. It is the nature of fundamentalism that it should contain a powerful streak of irrationality and that it should not relate, in a verifiable, practical way, to the everyday world. ...it would take an eternity of time to distill even one drop of sense...Big bang cosmology refers to an epoch that cannot be reached from any form of astronomy...

Fred Hoyle

Home is Where the Wind Blows 1994.

Sorry, Fred.

Here's the current understanding of the life of a
Universe:

evolving in time and temperature.