

hi

Lecture 29, 04.25.2017

Particle Physics 4, Cosmology 5

housekeeping

Question about anything?

I'll make a movie for you:

Poster selection:

how you doin'?

Final: Thursday, May 4...in here...and yes, 0745h. I'll bring bagels.

1. Before Final day: second midterm available Friday midnight...closes midnight, Monday. **MasteringAstronomy**
2. Final day: first poster session...about 30 minutes or so
3. Final day: Feynman diagram part...random partner, sit anywhere in atrium or lecture room
4. Final day: return anonymous survey which will be available after Thursday's class

Homework #14...available last Saturday:

10 points-worth in MasteringPhysics + 20 points-worth on paper

walks you through some of the Feynman Diagram parts of the actual Finals-day FD part...a video is involved

http://www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/

Homework #15

will be assigned after Thursday's class and cover this week's subjects and content of a couple of movies...

MasteringAstronomy, closes midnight, Thursday, May 4



now hear this

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: 4/17/2017 - 5/17/2017
ISP 220 002: 4/17/2017 - 5/17/2017

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 5/17/2017 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).

also:

I'll have an optional anonymous course review with points

Honors Project

Data were due April 22. Paper due on May 4 (final day).

upload instructions:

http://www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/honors_project_2017/UploadInstructions

particle physics

where we are

Quarks

model confirmed

held in hadrons by the gluon field...which forms bulk of mass

masses of hadrons - insulting. masses of quarks - bizarre

Messenger particles

photon (electromagnetic), gluon (strong), W(weak), ?(gravity)

the modern picture

of the elementary particle patterns




circa 2000

and still current

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 2000

the quark families...quark “doublets”

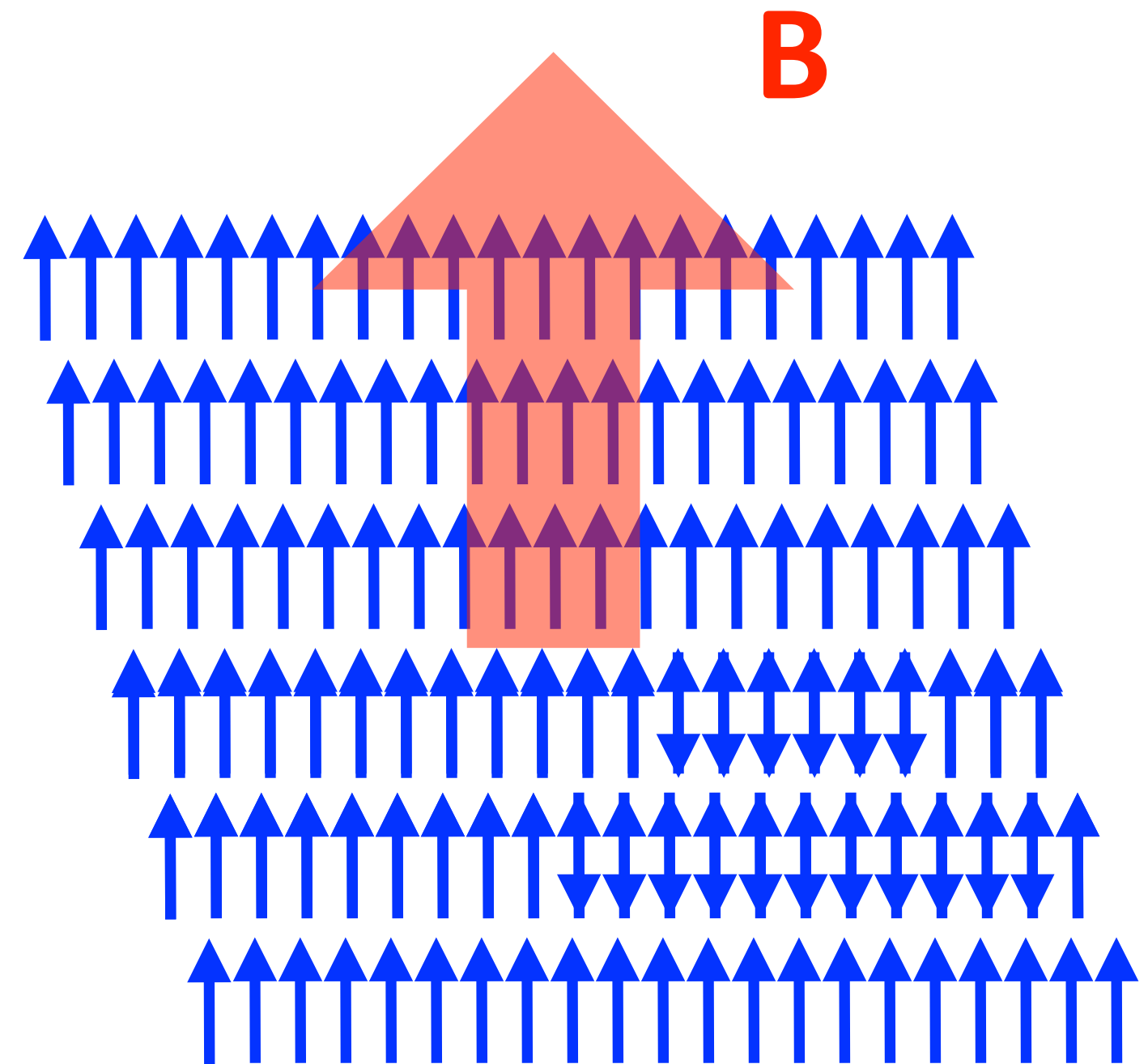
$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

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						

why

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



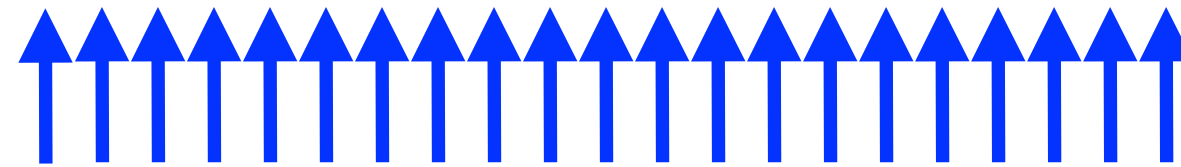
4.2 K - liquifies

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

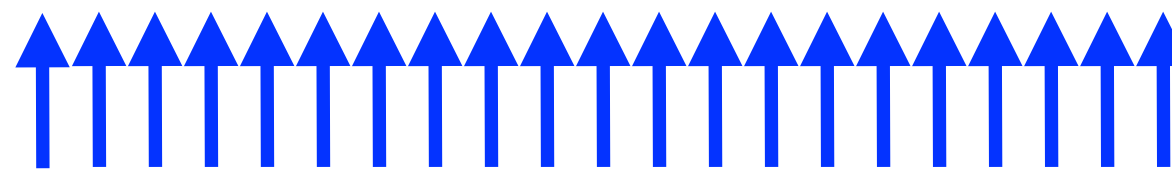
H



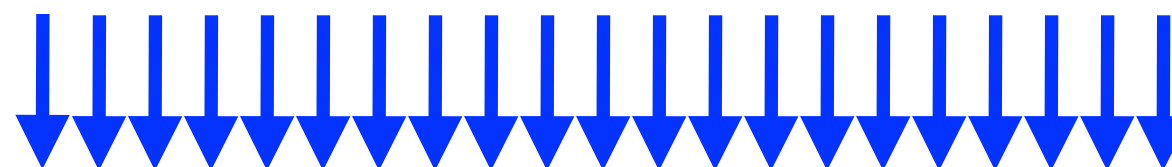
$M = 0$

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

C

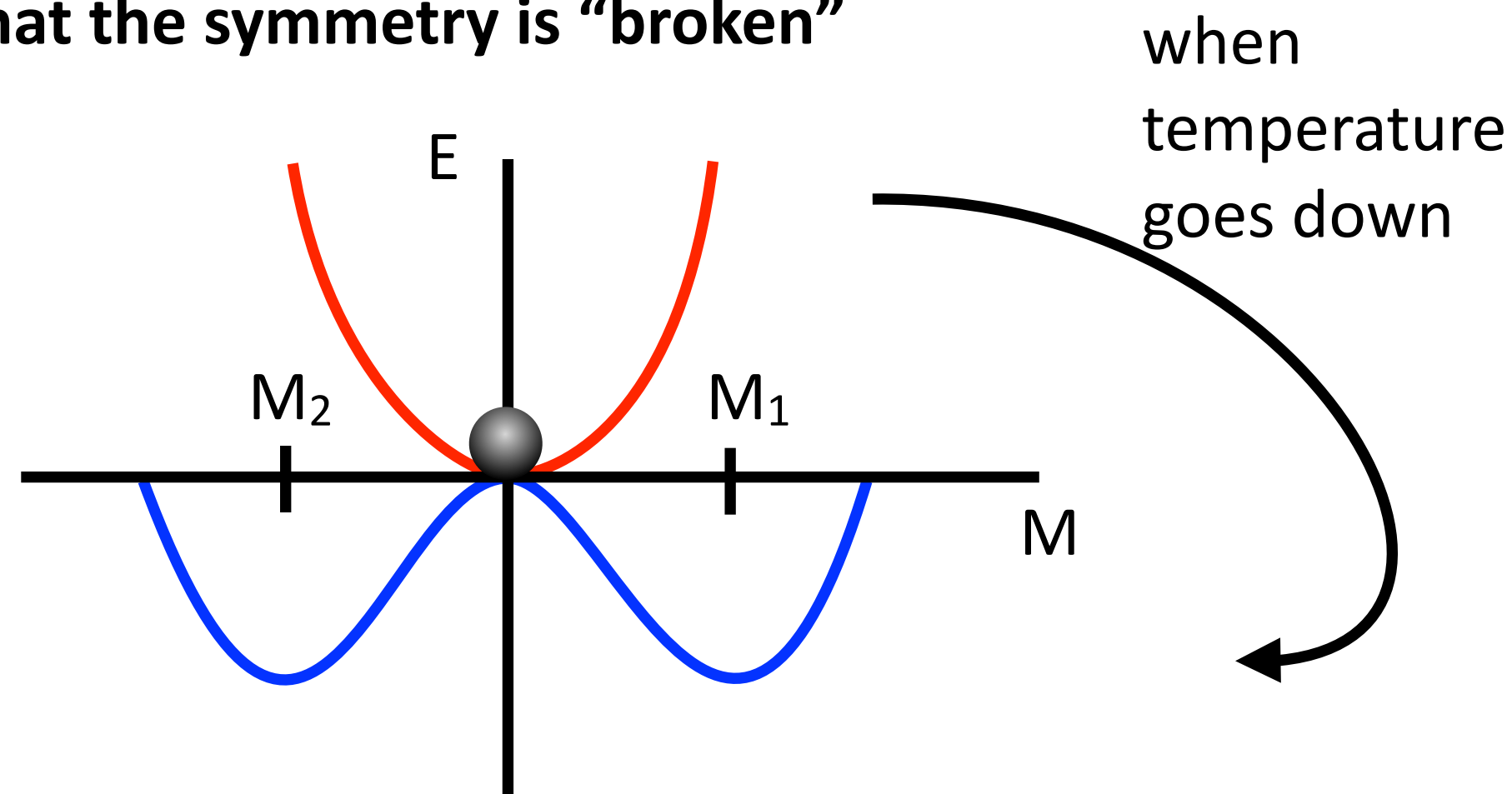


$M_1 \neq 0$



$M_2 \neq 0$

we say that the symmetry is "broken"



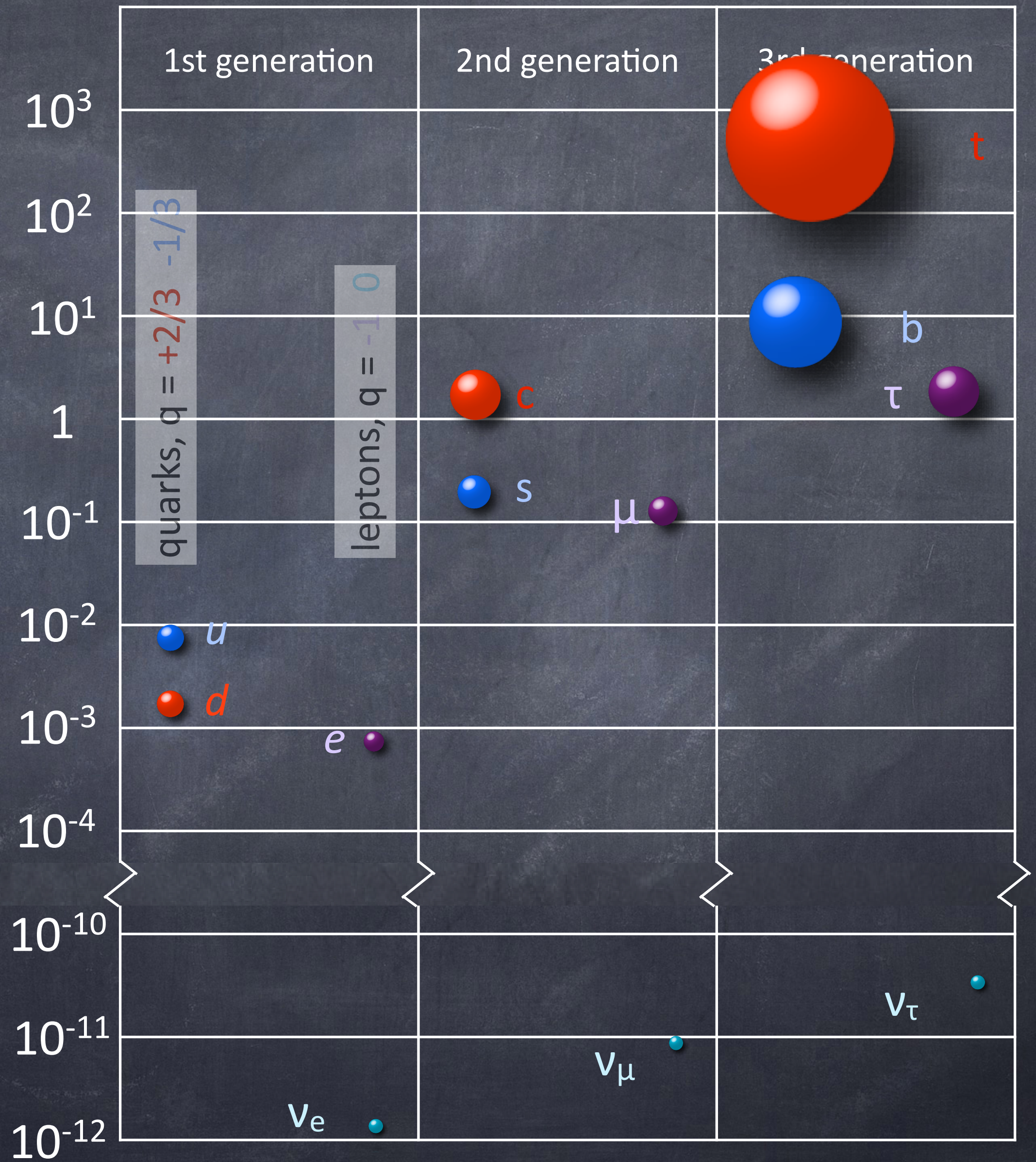
the energy level of the **hot ground state** is higher
than the energy level of the **cold ground state**

this often-told magnet story

evolves into the new story of MASS

quarks & leptons

proton masses



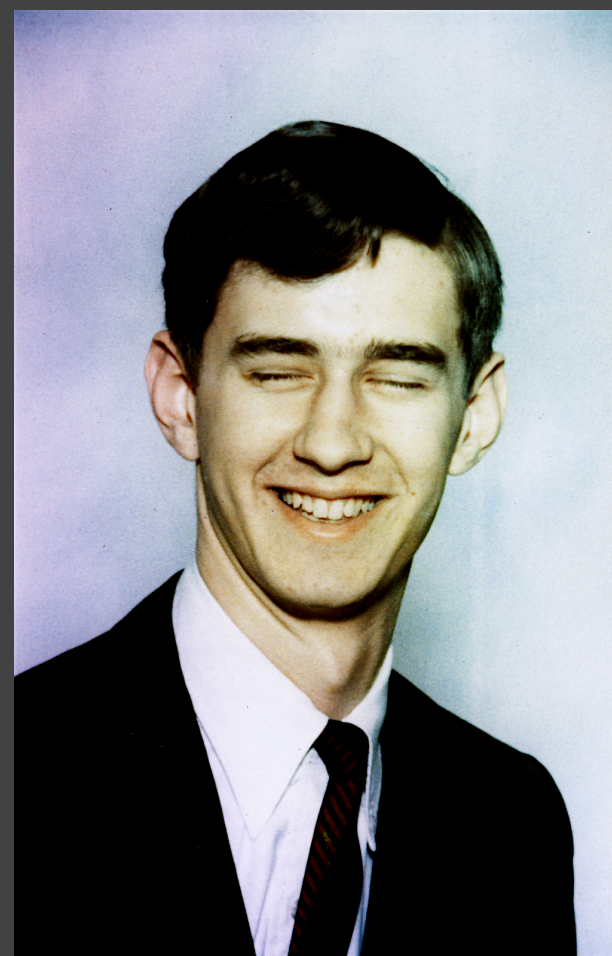
the only mathematical
solution that made sense:

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







A MODEL OF LEPTONS

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

Received 17 October 1967

[†]In obtaining the expression (11) the phase of the R field is chosen from between the charged and neutral Goldstone bosons to be $\pi/2$.
[‡]M. Ademollo and R. Gatto, *Nuovo Cimento* **48**, 1099 (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 more natural than to unite them into a multiplet of gauge fields. The way of this synthesis is through the differences in the masses of the intermediate meson, and in their couplings to the leptons. We might hope to understand these differences by imagining that the symmetries relating the weak and electromagnetic interactions are exact symmetries of the Lagrangian but are broken by the vacuum. However, this raises the specter of unwanted massless Goldstone bosons. This note will describe a model in which the symmetry between the electromagnetic and weak interactions is spontaneously broken, but in which the Goldstone bosons are avoided by introducing the photon and the intermediate-boson fields as gauge fields.³ The model may be renormalizable.

We will restrict our attention to symmetry groups that connect the observed electron-type leptons only with each other, i.e., not with muon-type leptons or other unobserved leptons or hadrons. The symmetries then act on a left-handed doublet

$$L = \begin{pmatrix} \nu_e \\ e \end{pmatrix} \quad (1)$$

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

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

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^\pm

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

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^0 and φ^- have no physical mass. The Lagrangian is gauge invariant under a combined isospin transformation which leaves invariant the kinetic energy without change. We see that G_e is very small, might be very large,⁷ and also be disregarded.

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

remain intact, while φ^- becomes

$$\langle \varphi^- \rangle = \lambda \frac{g'}{g} \quad (7)$$

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

$$g' = 1/2\lambda^2 \quad (15)$$

$$G_e = 2.07 \times 10^{-6} \quad (16)$$

coupling constant is very weak. Note also that G_e is larger than e , so G_e is $\sim 10^6$ BeV, while (12) gives $G_e \sim 10^3$ BeV. Our predictions made

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

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

and has mass

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

The neutral spin-1 fields of definite mass are

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

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

Their masses are

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

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

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 $\frac{1}{2}$. If $g \sim e$ then $g \ll g'$, and the vector interaction is multiplied by a factor $-\frac{1}{2}$ rather than $\frac{1}{2}$. 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 **17**, 592 (1966); 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**, 1554 (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**, 193 (1957).

LEPTON-PAIR PRODUCTION 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





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**)

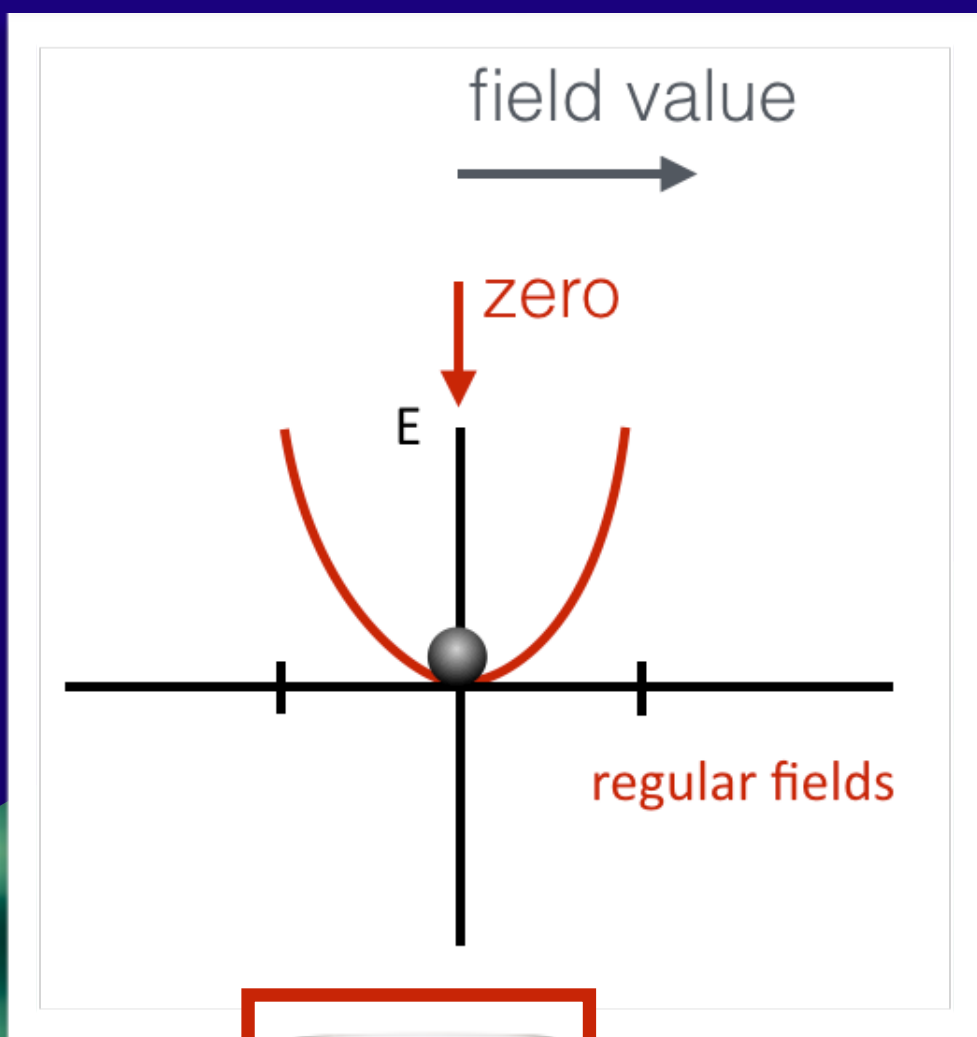
we live in the resulting "cold" universe

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

C  $M_1 \neq 0$
like a regular magnet

10⁻¹²s after the big bang

universe condensed: a phase change

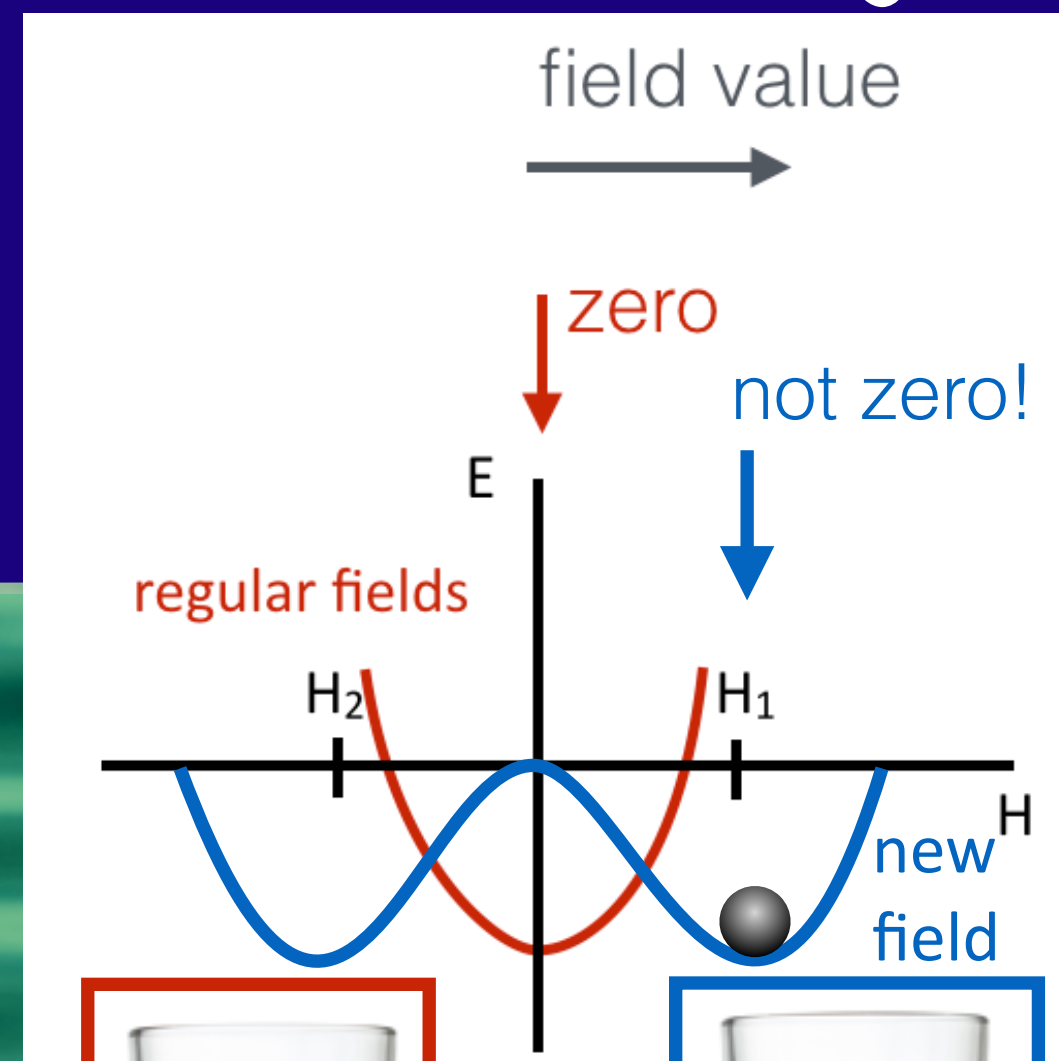


H



$M = 0$

like a hot, non-magnet



C



$M_1 \neq 0$

like a regular magnet

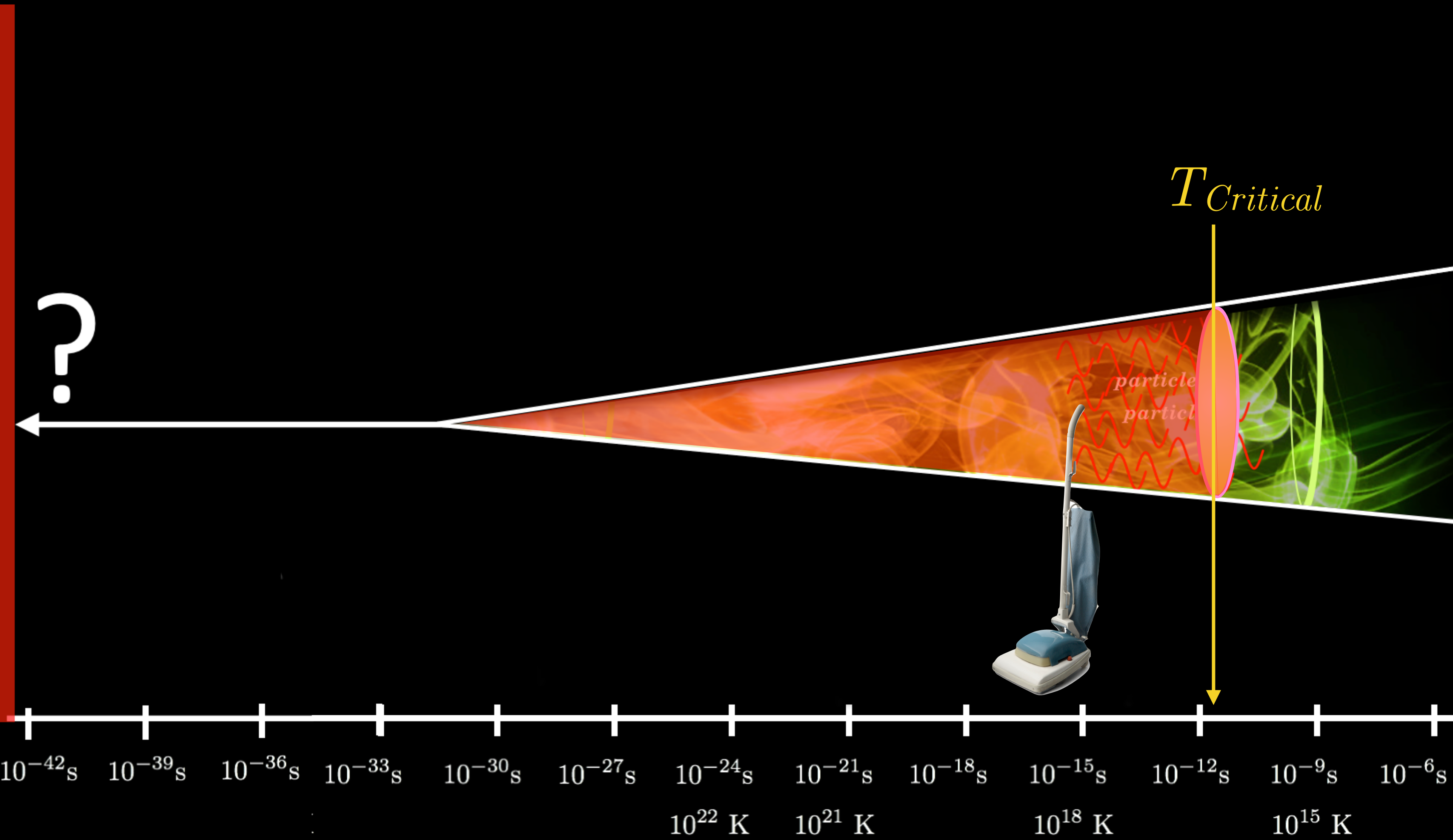


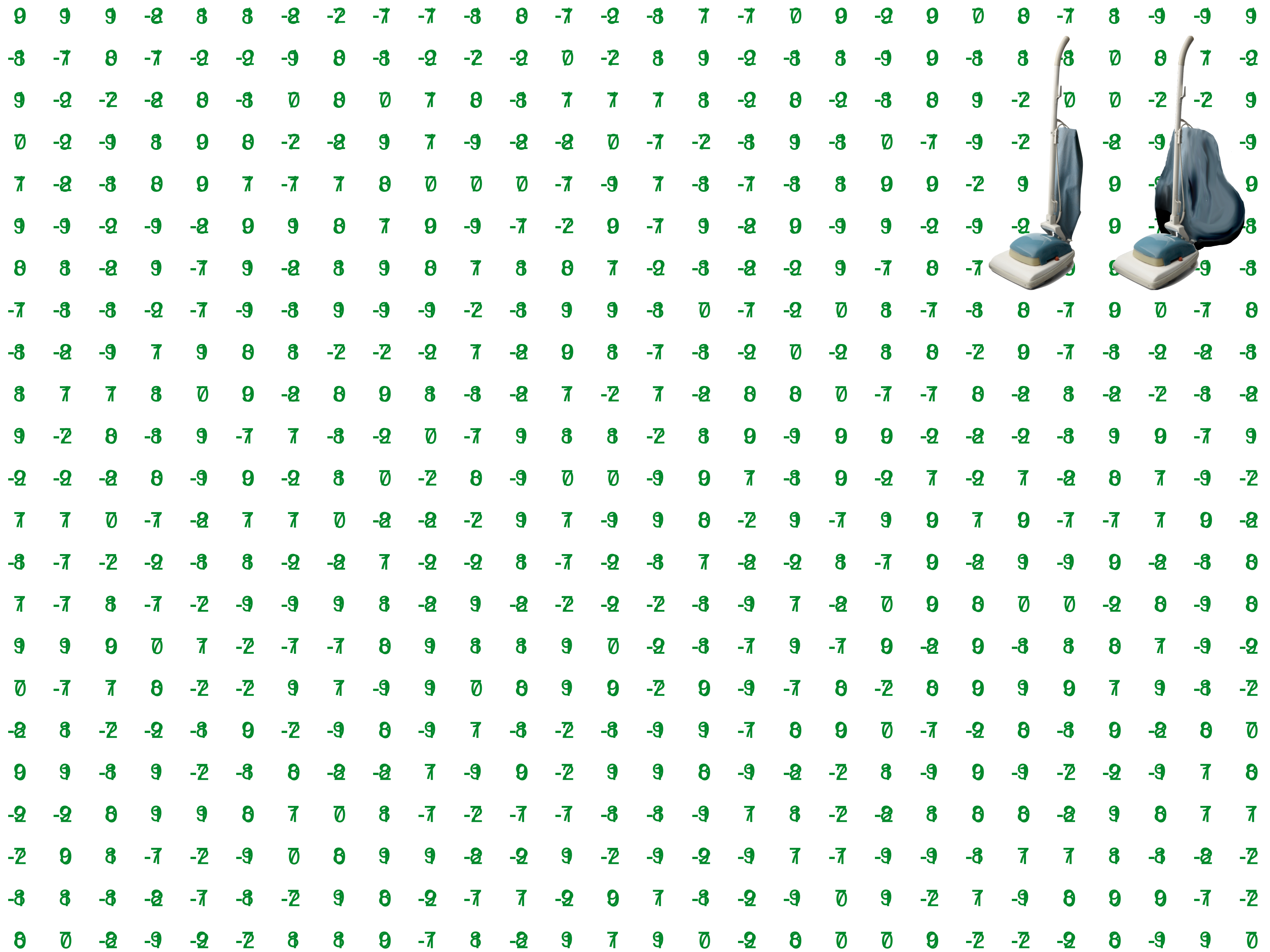
the big story of the
Standard Model

is the story of mass.

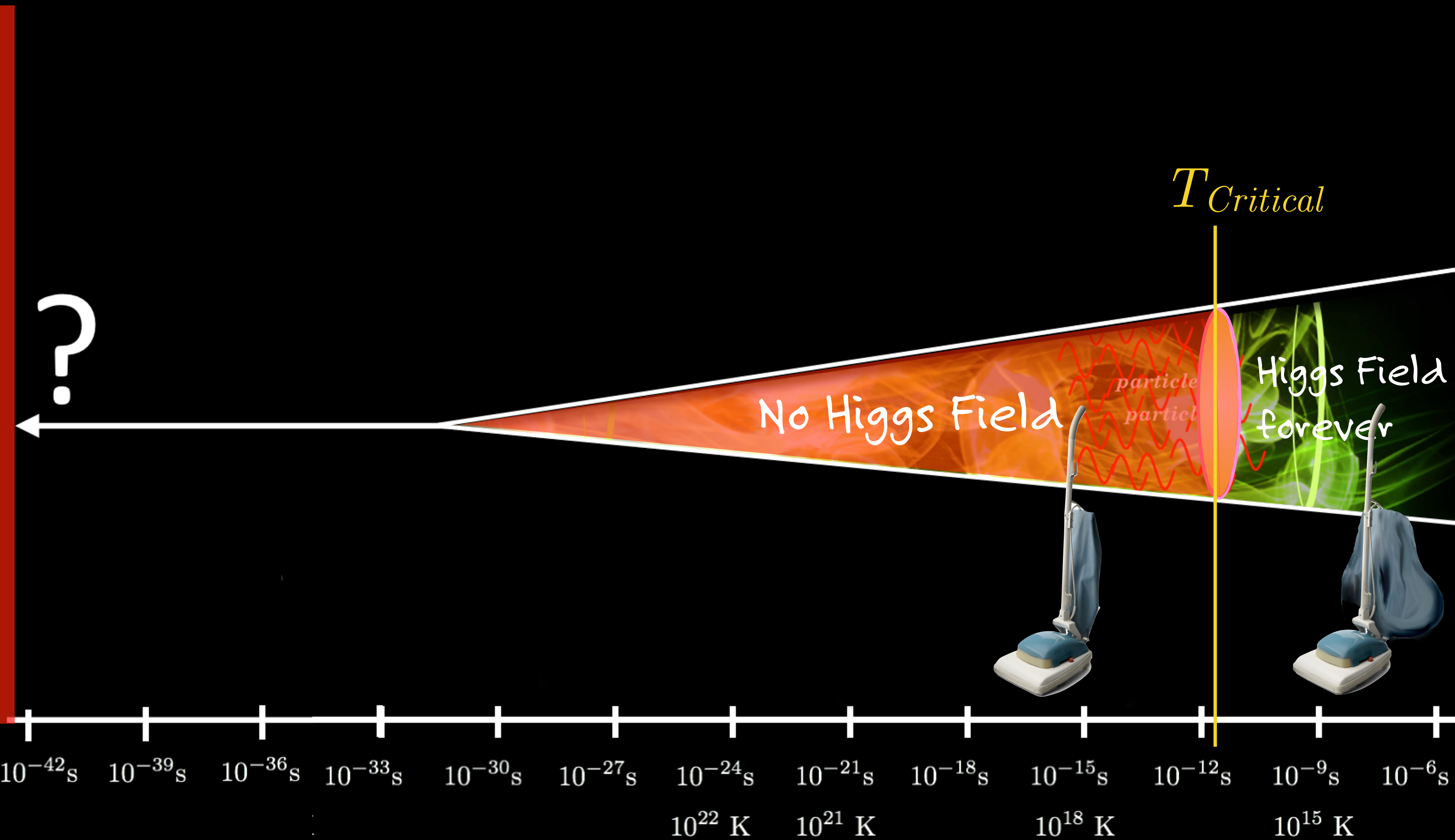


elementary particle epoch



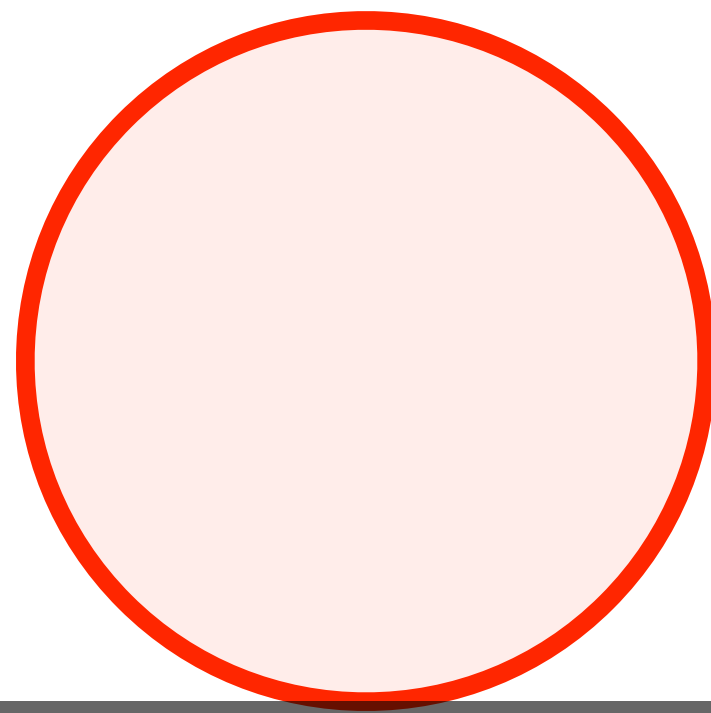


elementary particle epoch





a Higgs
metaphor

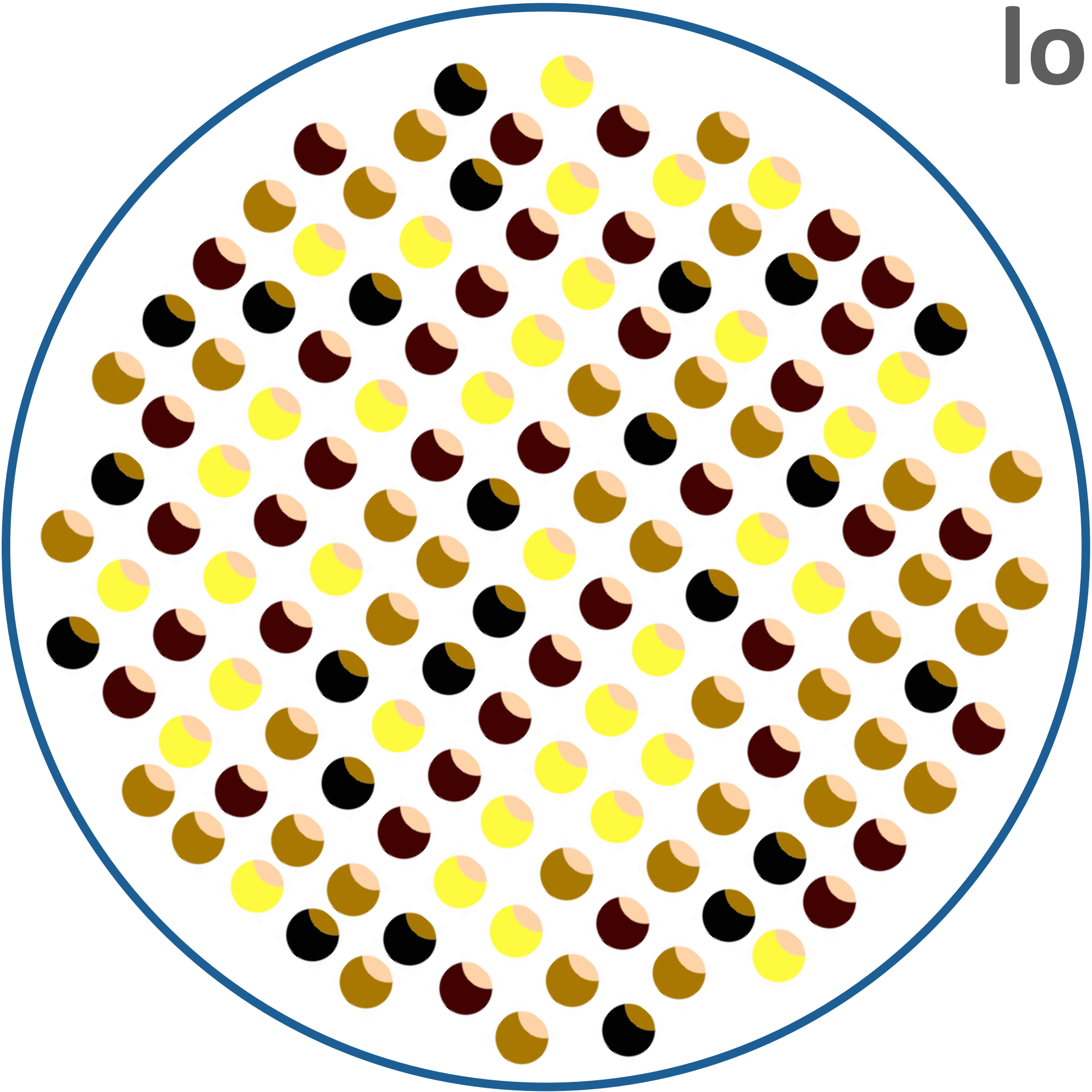


the hot universe: no Higgs Field

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 circle.

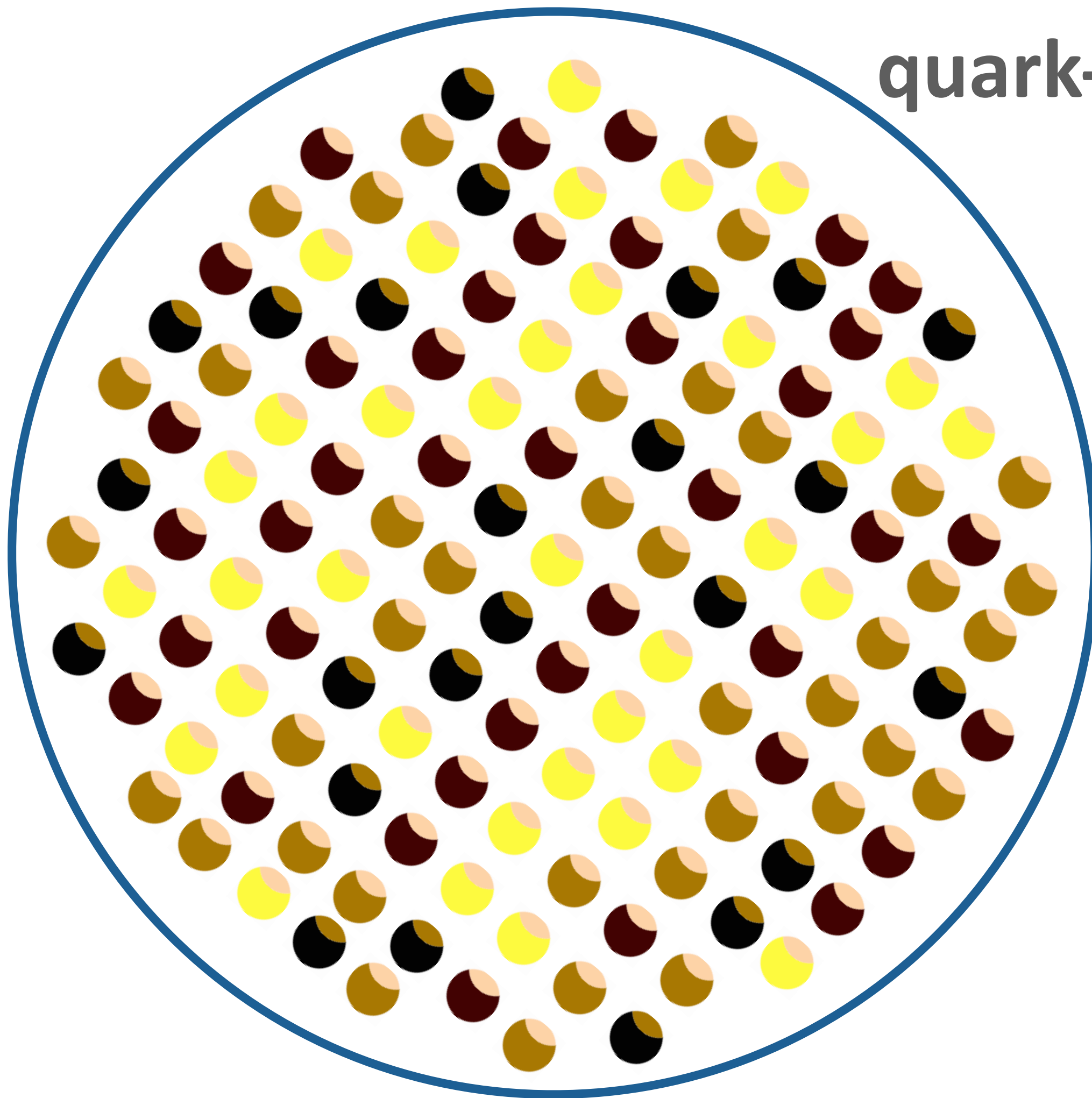
a cooled universe: Higgs Field

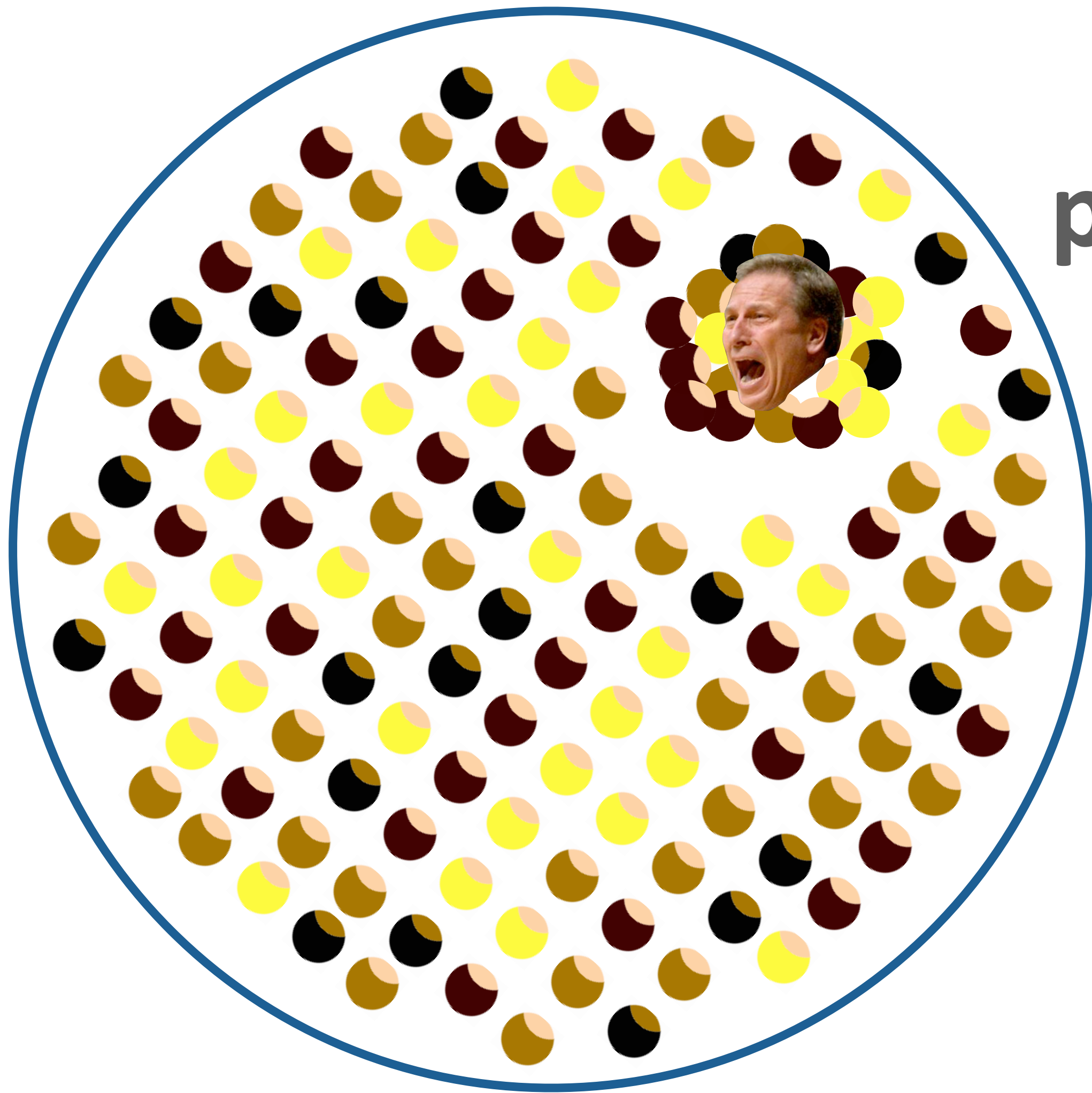
loud





quark-Tom-Izzo

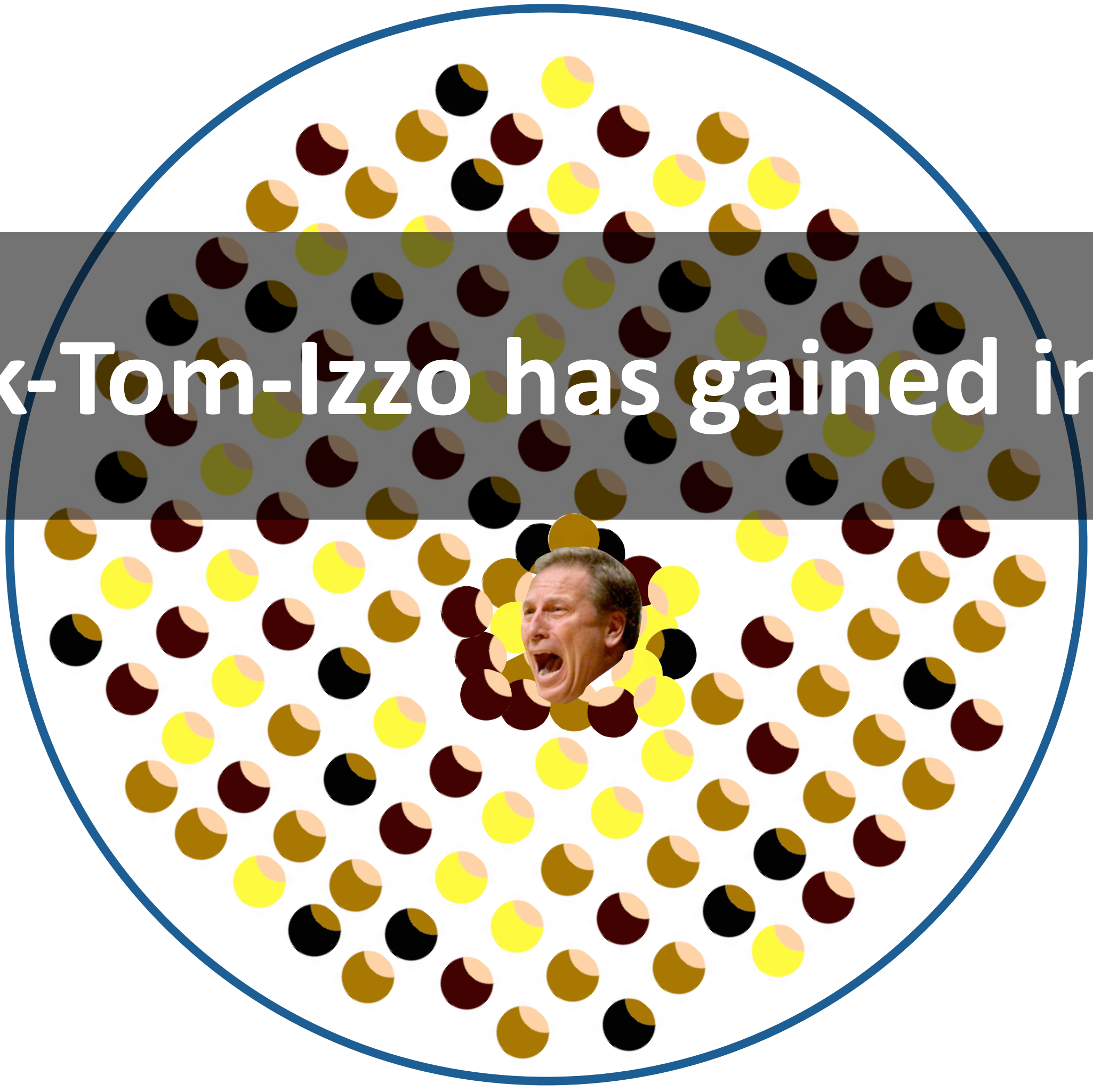




popular



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

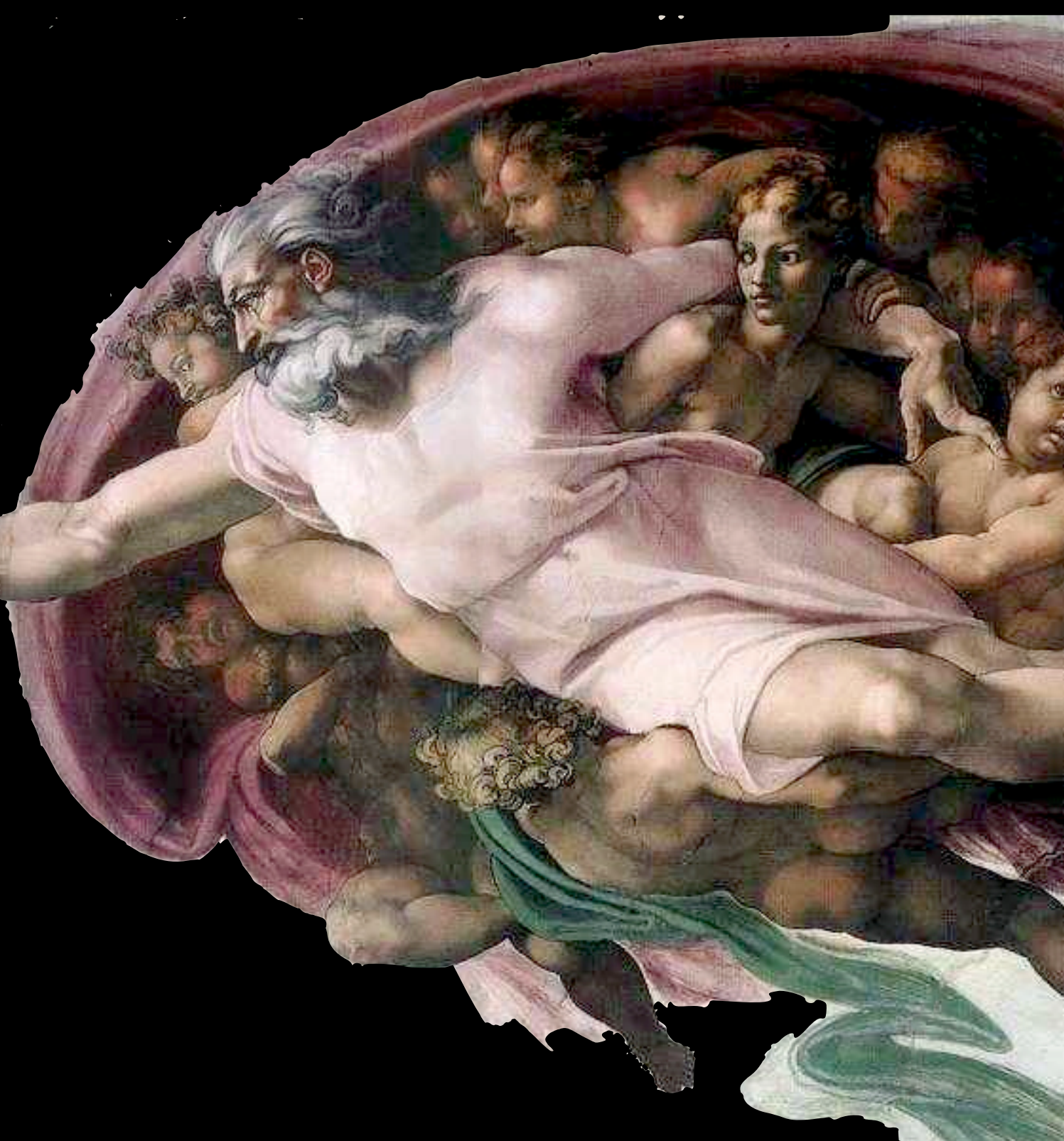
the unification of forces



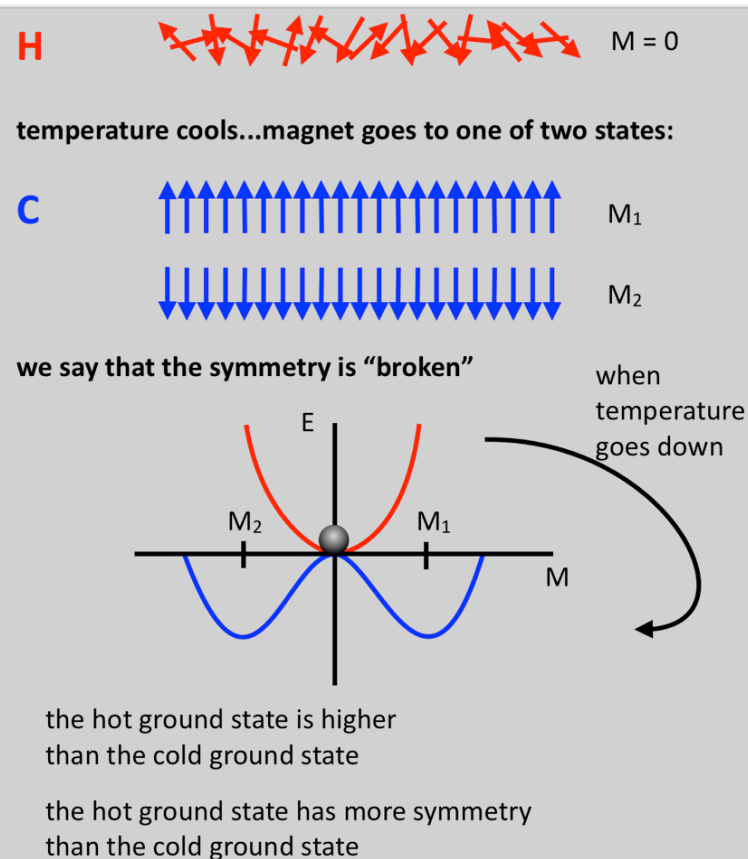
from a hot phase in the universe

cool it all at once

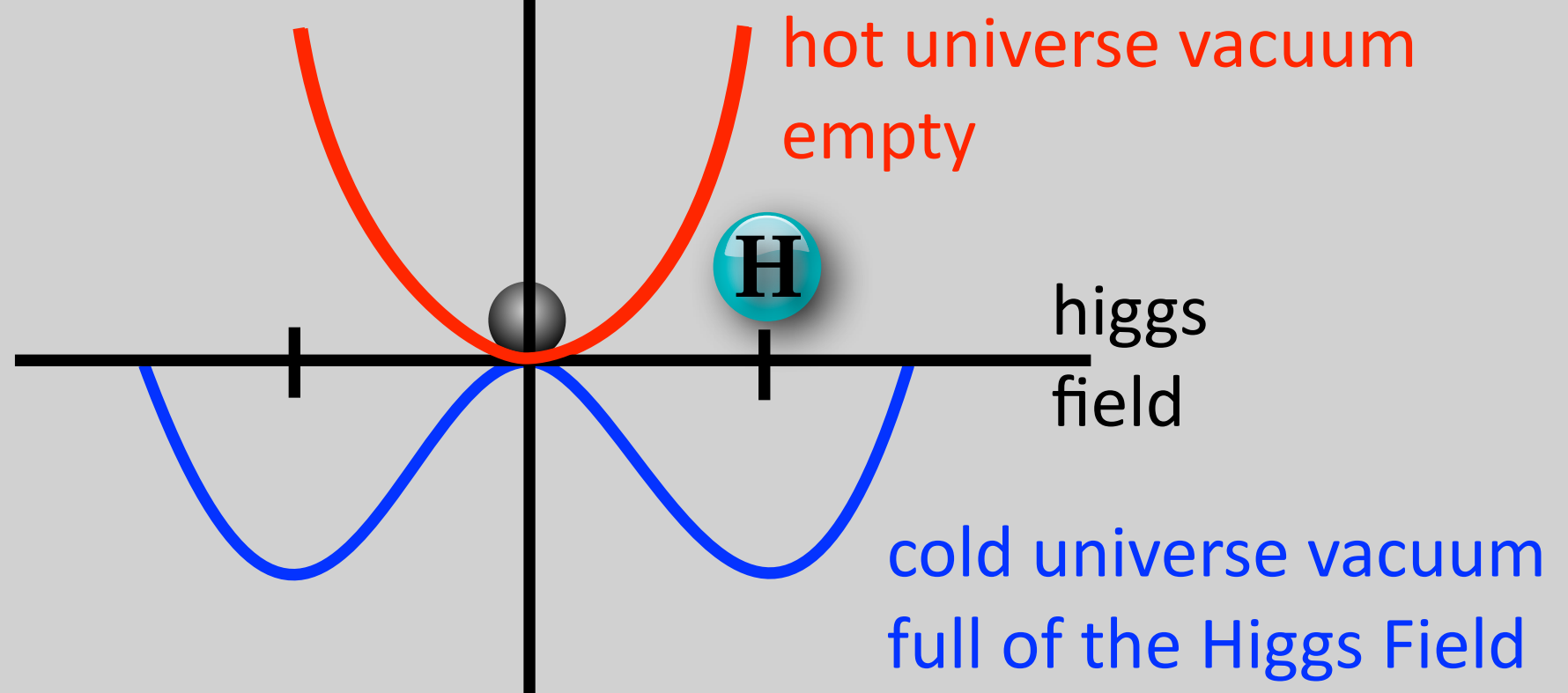
@ 10^{-12} seconds after the BB



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

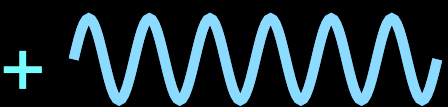
a^0



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

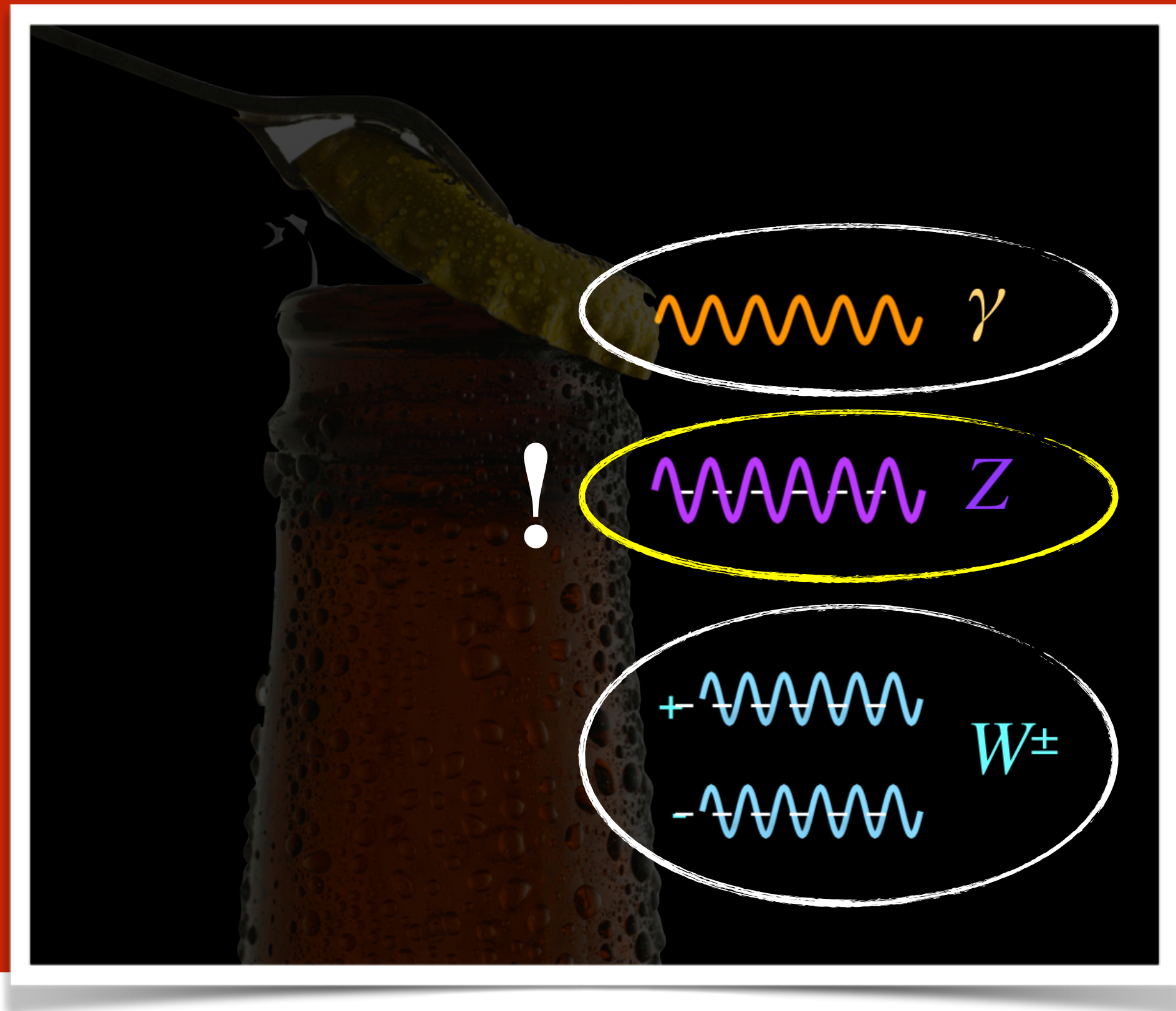
t = 10⁺¹⁸ s



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

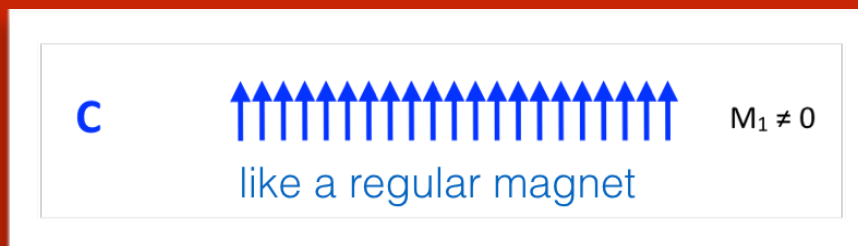


this is quite remarkable

If the idea is right:

the electromagnetic and weak forces

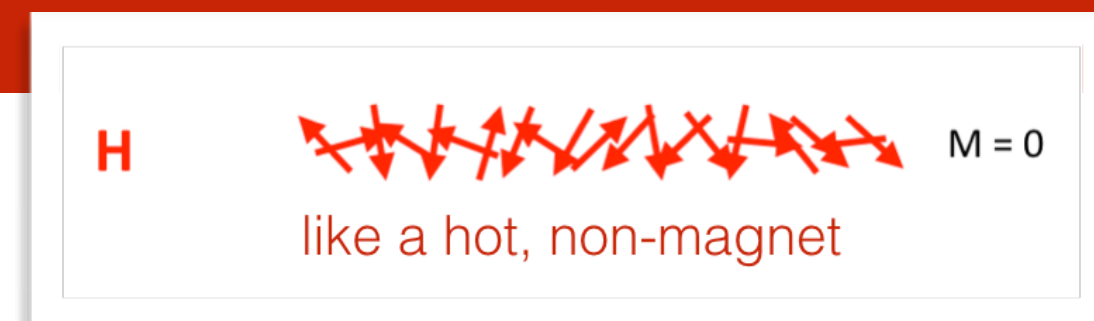
that are so different today



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:

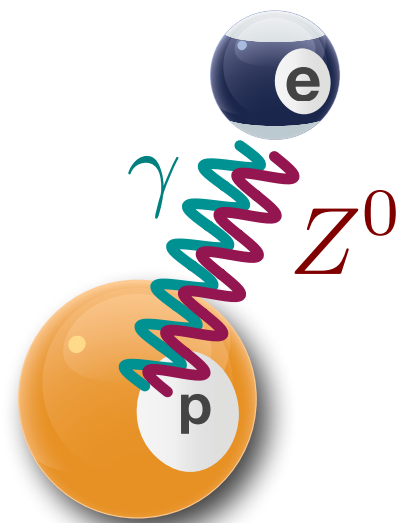
weak Vector Boson

Photon and Z always mix

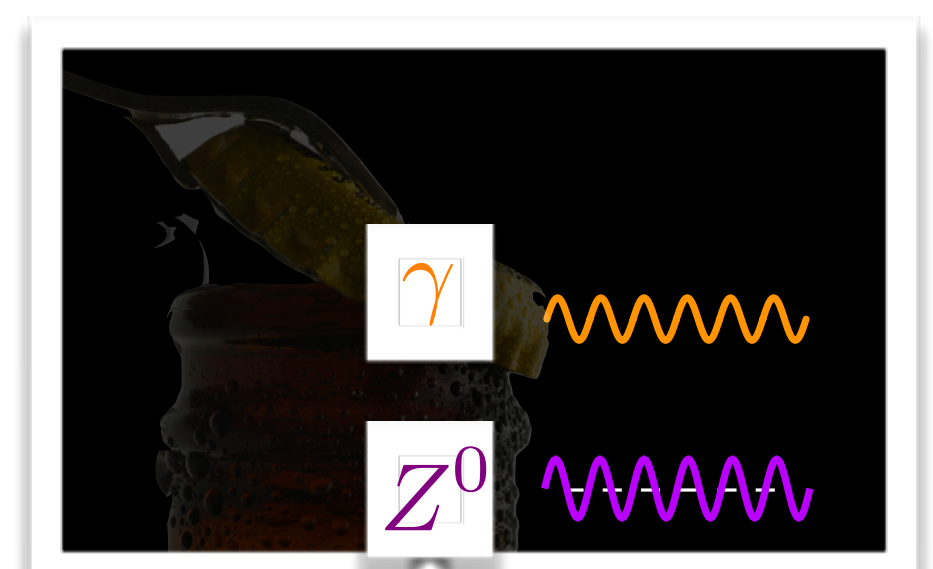
Z, very weakly

3. The Z Boson and the γ are intimately related


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

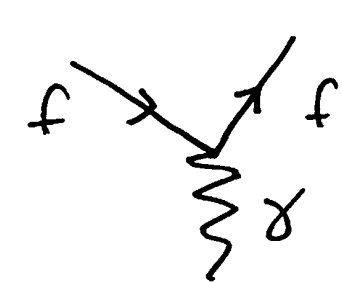
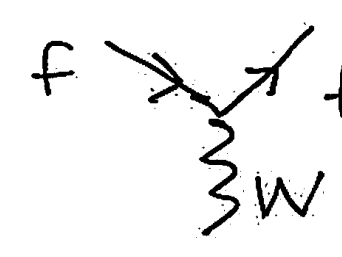
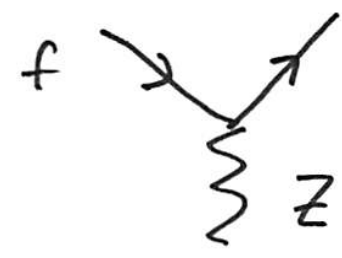
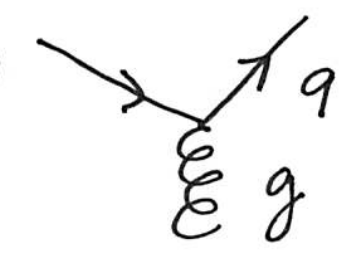
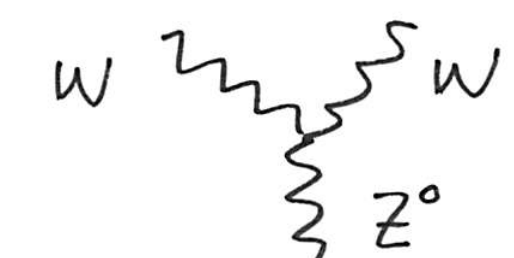
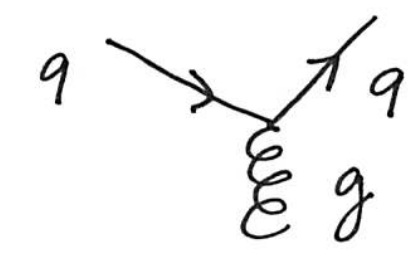
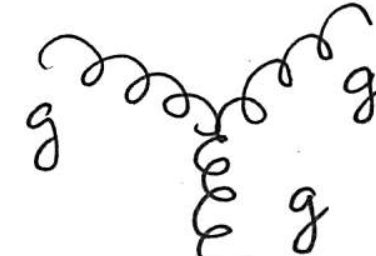


very delicate effects
observed in atomic systems
due to the Z Boson



sixth and seventh entries into your table of primitive diagrams

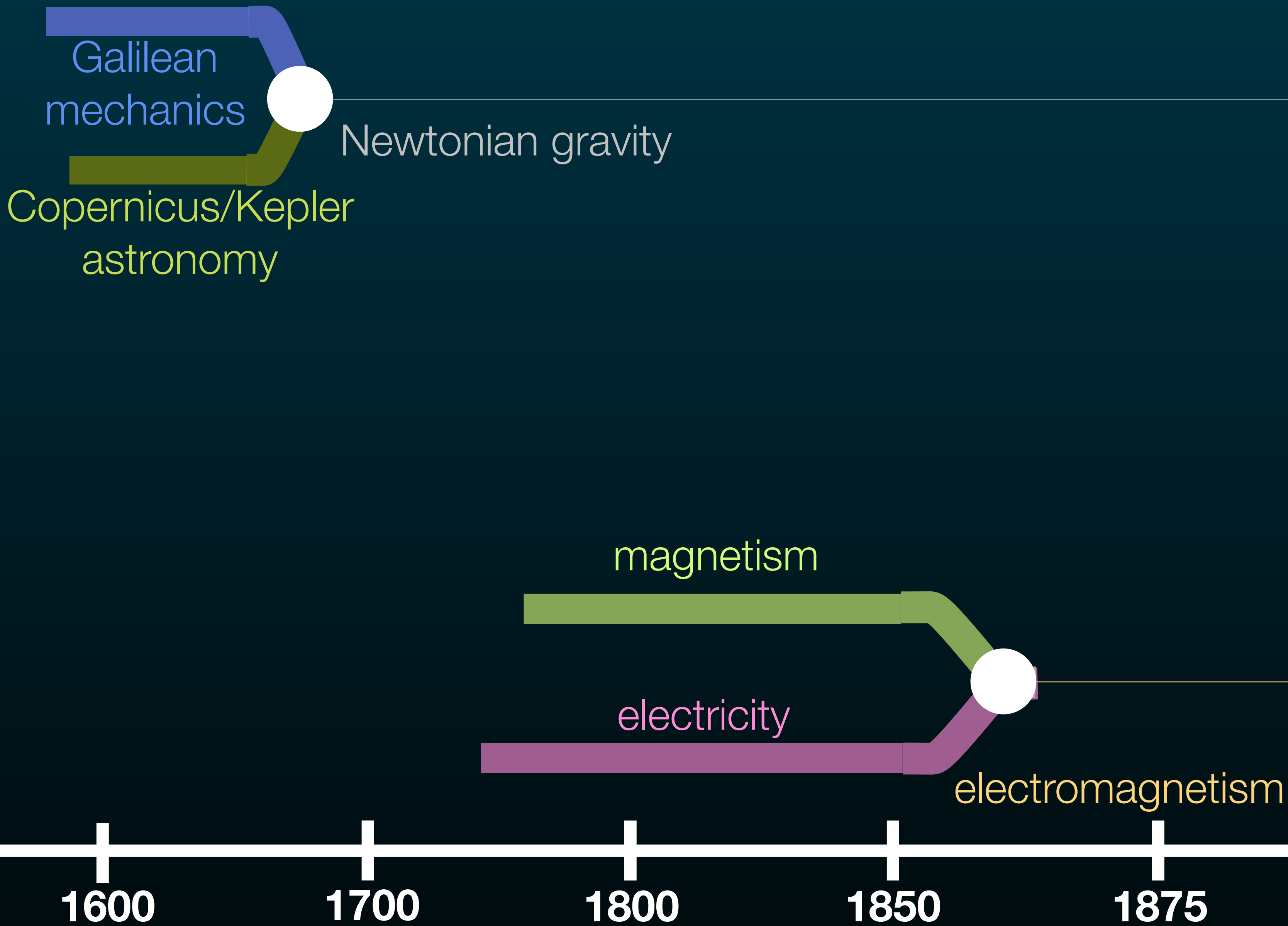
Primitive Diagrams TIME always: 

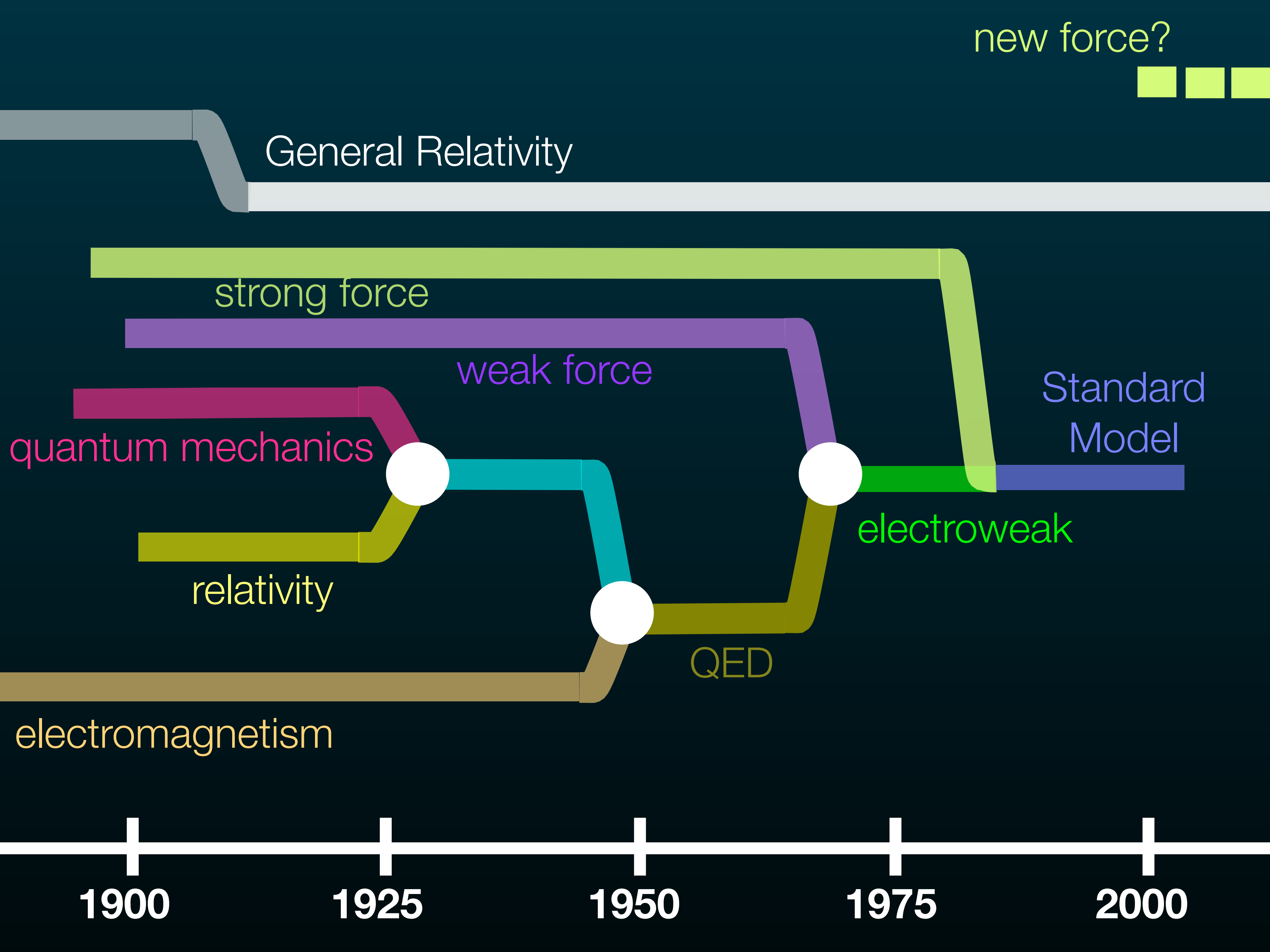
1			QED	
2		3		Weak Interactions
6		7		
4		5		Strong Interactions
8		9		Higgs Interactions



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?

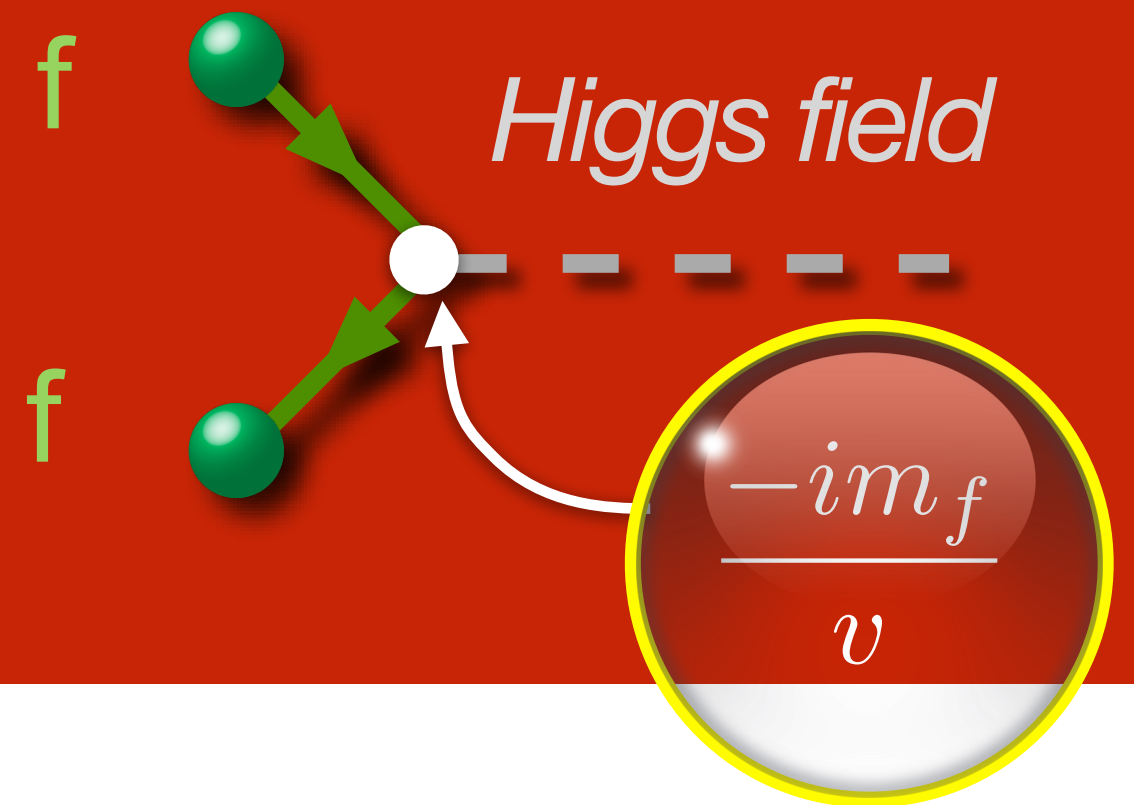
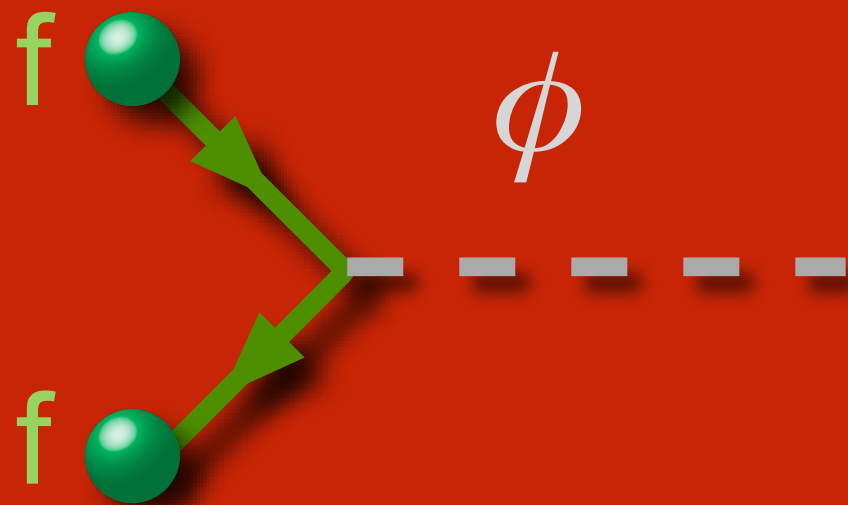
Is “mass” an intrinsic attribute? “nature”?

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!







MARCJACOBS.COM

The New York Times

Wednesday, July 4, 2012 Last Update: 4:00 AM ET



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- Education
- Event Guide
- Fashion & Style
- Home & Garden
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- Obituaries

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.

As Bank Frames a Defense, Barclays' C.E.O. Resigns

By BEN PROTTESS and MARK SCOTT
Ahead of a British parliamentary hearing, senior Barclays executives said they thought they had implicit approval from regulators to manipulate interest rates.

Top Judge Helped



Pool photo by Denis Balibouse

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
The Fire Department in Narrowsburg, N.Y., canceled its annual display after planned fireworks were said to

OPINION

EDITORIAL

Too Quiet, Again, on Health Care

The Obama campaign has not forcefully countered Republican misinformation on the reform law.

- 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

Britain	Germany	France
FTSE 100	DAX	CAC 40
5,673.04	6,553.19	3,248.93
-14.69	-25.02	-22.27
-0.26%	-0.38%	-0.68%

Data delayed at least 15 minutes

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From insight comes inspiration.



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 breadcrumb trail reads "Home / Nobel Prizes / Nobel Prize in Physics / The Nobel Prize in Physics 1979".

On the left, a sidebar menu lists various categories, with "Nobel Prize in Physics" selected. Below it, there are links for "All Nobel Prizes in Physics", "Facts on the Nobel Prize in Physics", "Prize Awarder for the Nobel Prize in Physics", "Nomination and Selection of Physics Laureates", "Nobel Medal for Physics", "Articles in Physics", "Video Interviews", and "Video Nobel Lectures".

The main content area features a timeline from 1901 to 2012, with 1979 selected. Below the timeline, there are options for "Sort and list Nobel Prizes and Nobel Laur" and "Prize category: Physics".

The central focus is the "The Nobel Prize in Physics 1979" section, which lists the laureates: Sheldon Glashow, Abdus Salam, and Steven Weinberg. Below their names are three black and white portrait photographs of each laureate.

At the bottom of the page, the award description is partially visible: "The Nobel Prize in Physics 1979 was awarded jointly to Sheldon Lee Glashow, Abdus Salam, and Steven Weinberg for their contributions to the theory of the weak interaction between elementary particles, and the prediction of the neutral current".

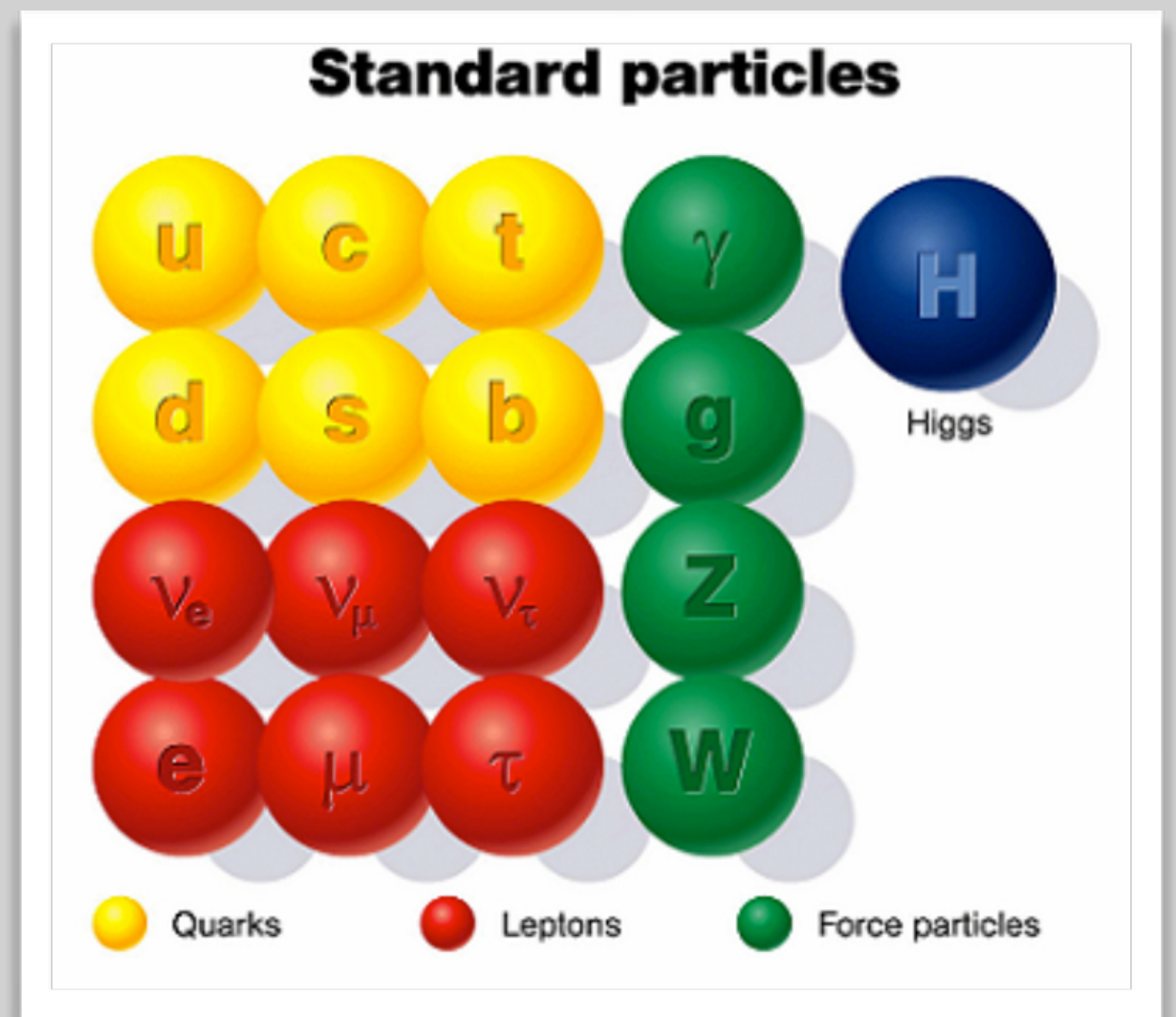


the
particle
players

and

the "substrate"

Our "Periodic Table"


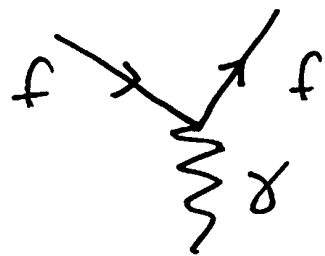


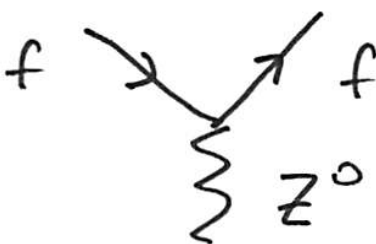
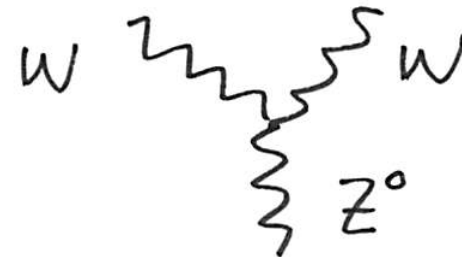
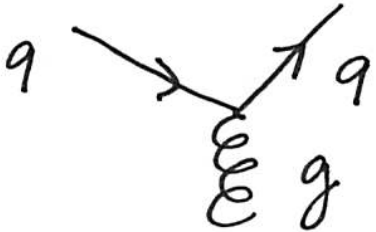

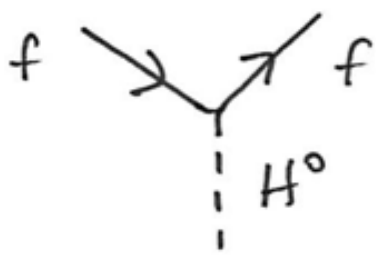

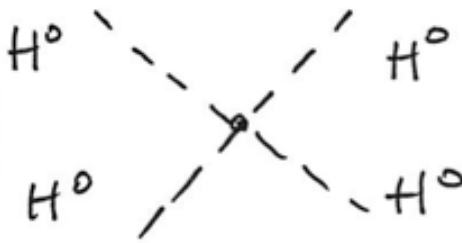
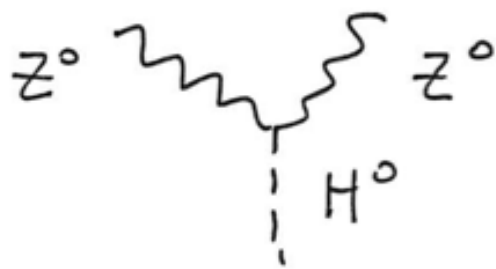


like any
particle,

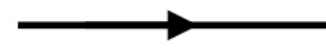
we predict and
then search for its
manifestation

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		Higgs Interactions
5		
8		Higgs Interactions
9		
10		Higgs Interactions
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

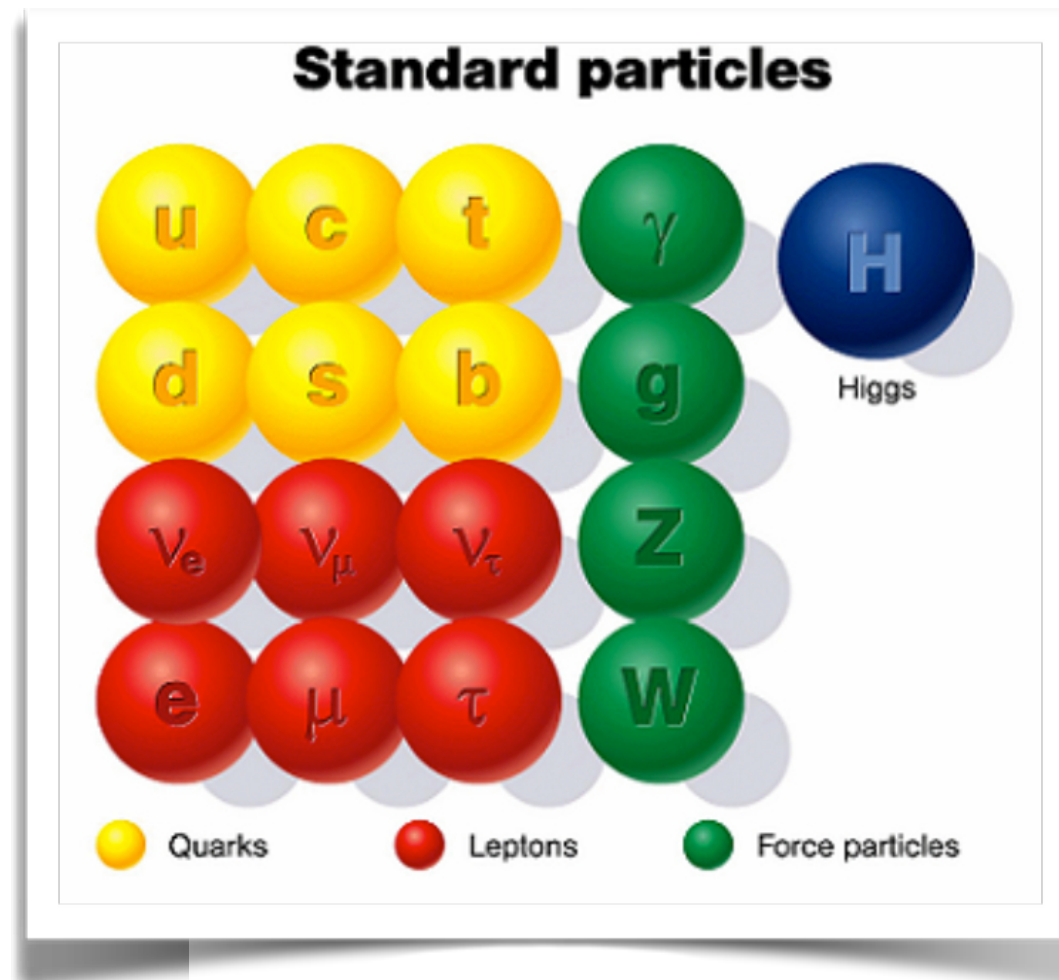
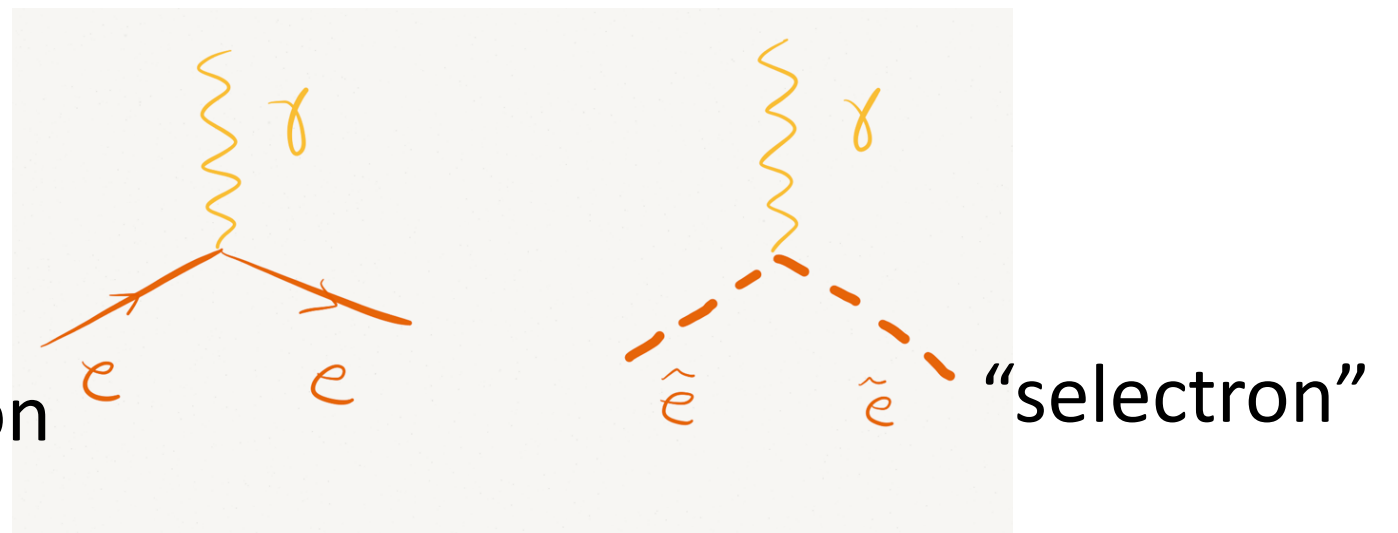
"supersymmetry"

every "Standard
Model Particle"

has a super-partner

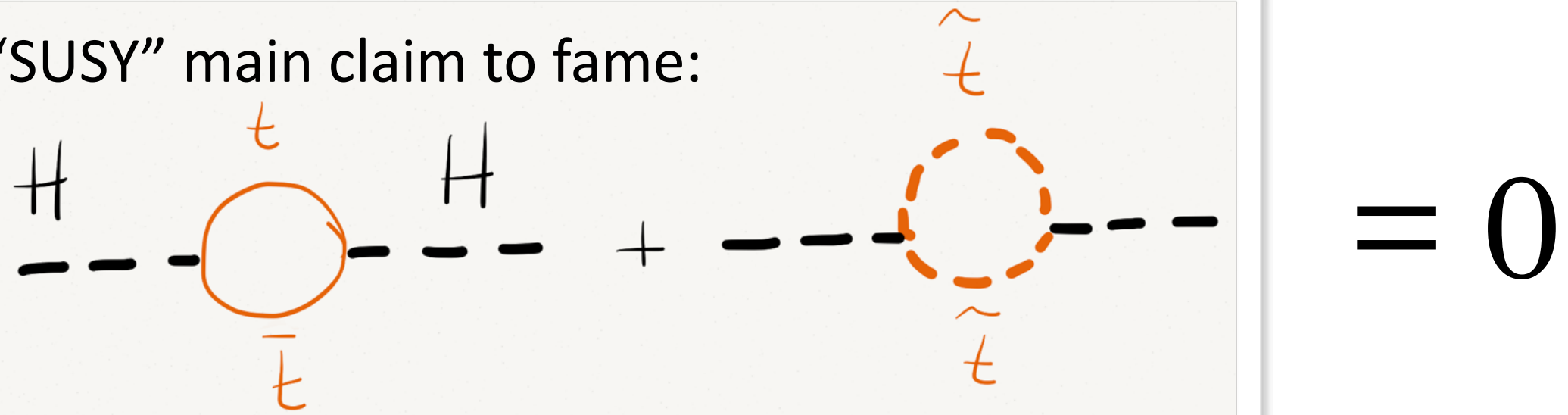
*presumably
much heavier*

electron



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

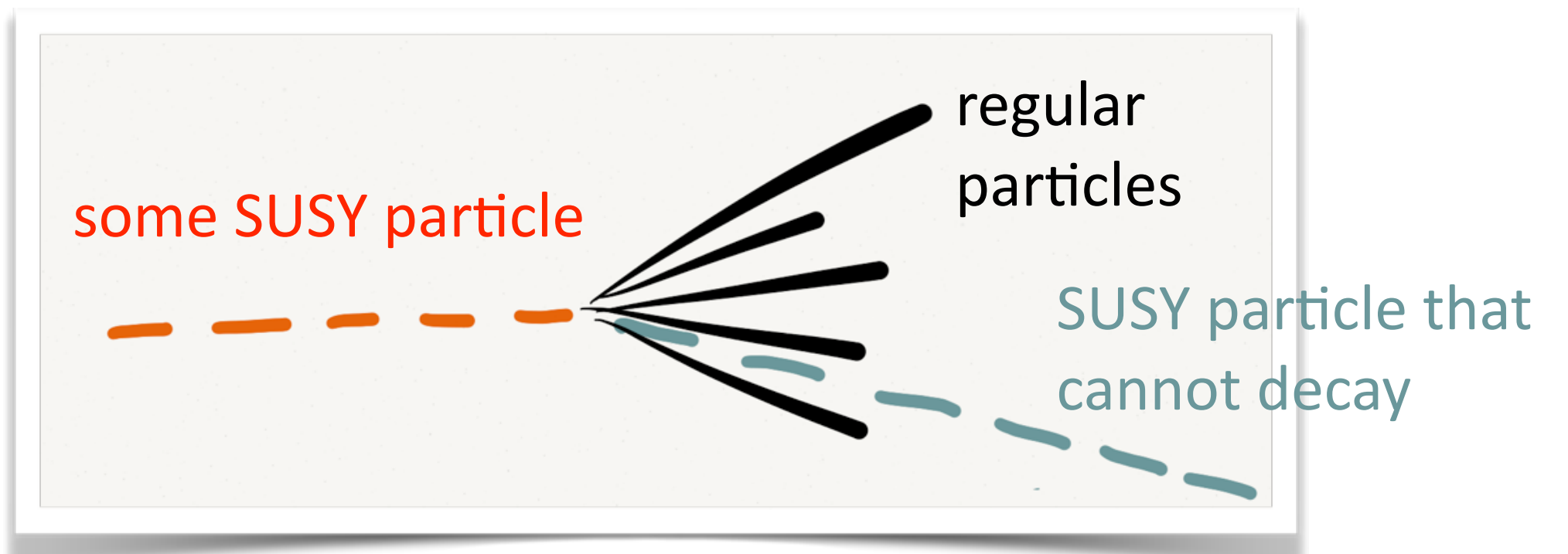
“SUSY” main claim to fame:



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

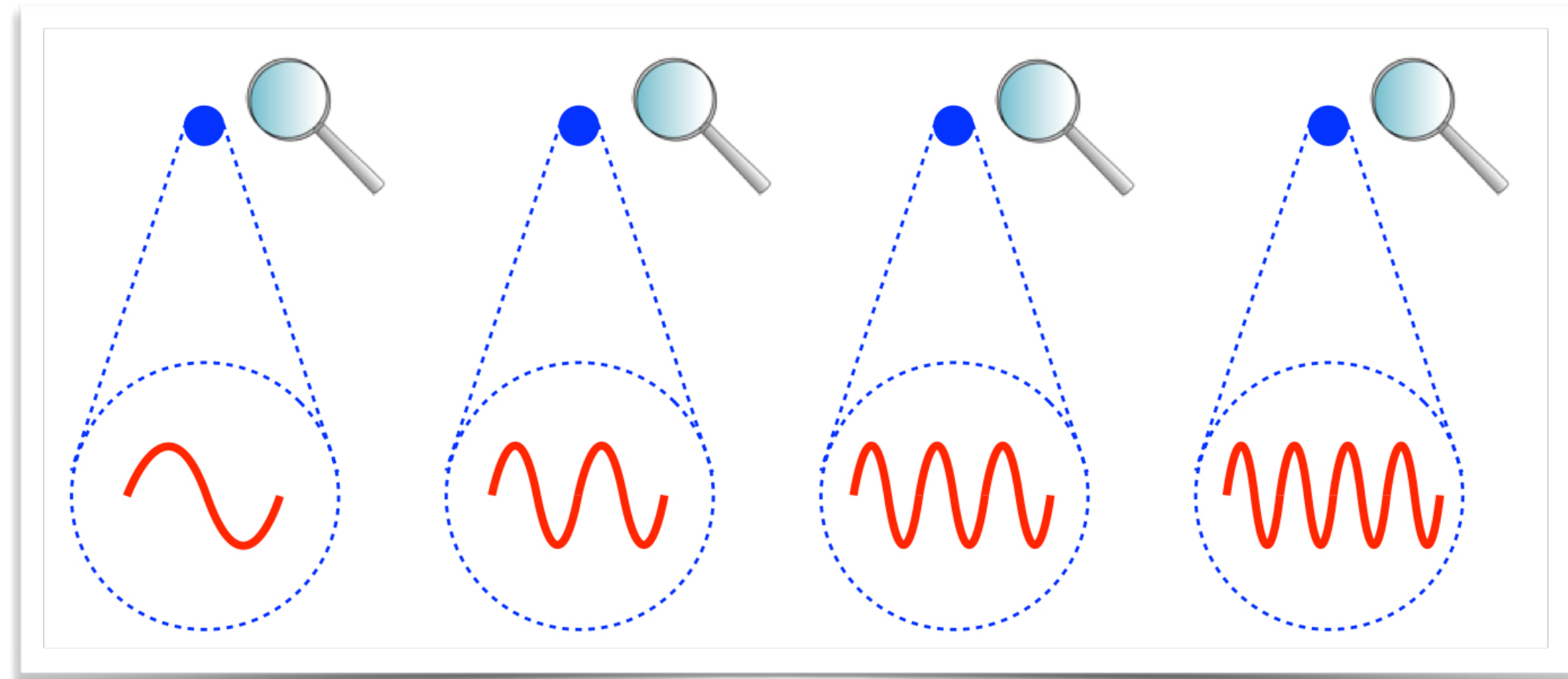
composite Higgs

composite quarks and leptons

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

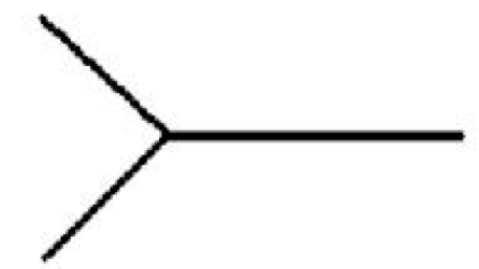
The “infinities” in Relativistic Quantum Field Theory are related to extrapolation in spacetime to zero, $x, y, z, = 0$

Suppose there is a minimum length in Nature?

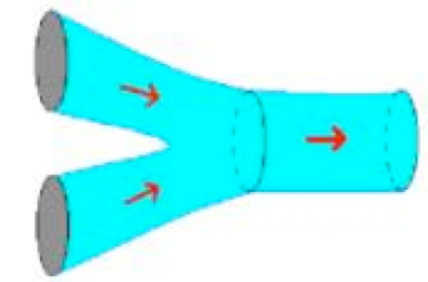


each wavelength...a different – e x t e n d e d – particle.

Plus: get a gravity and the graviton for free!



Point particle interaction

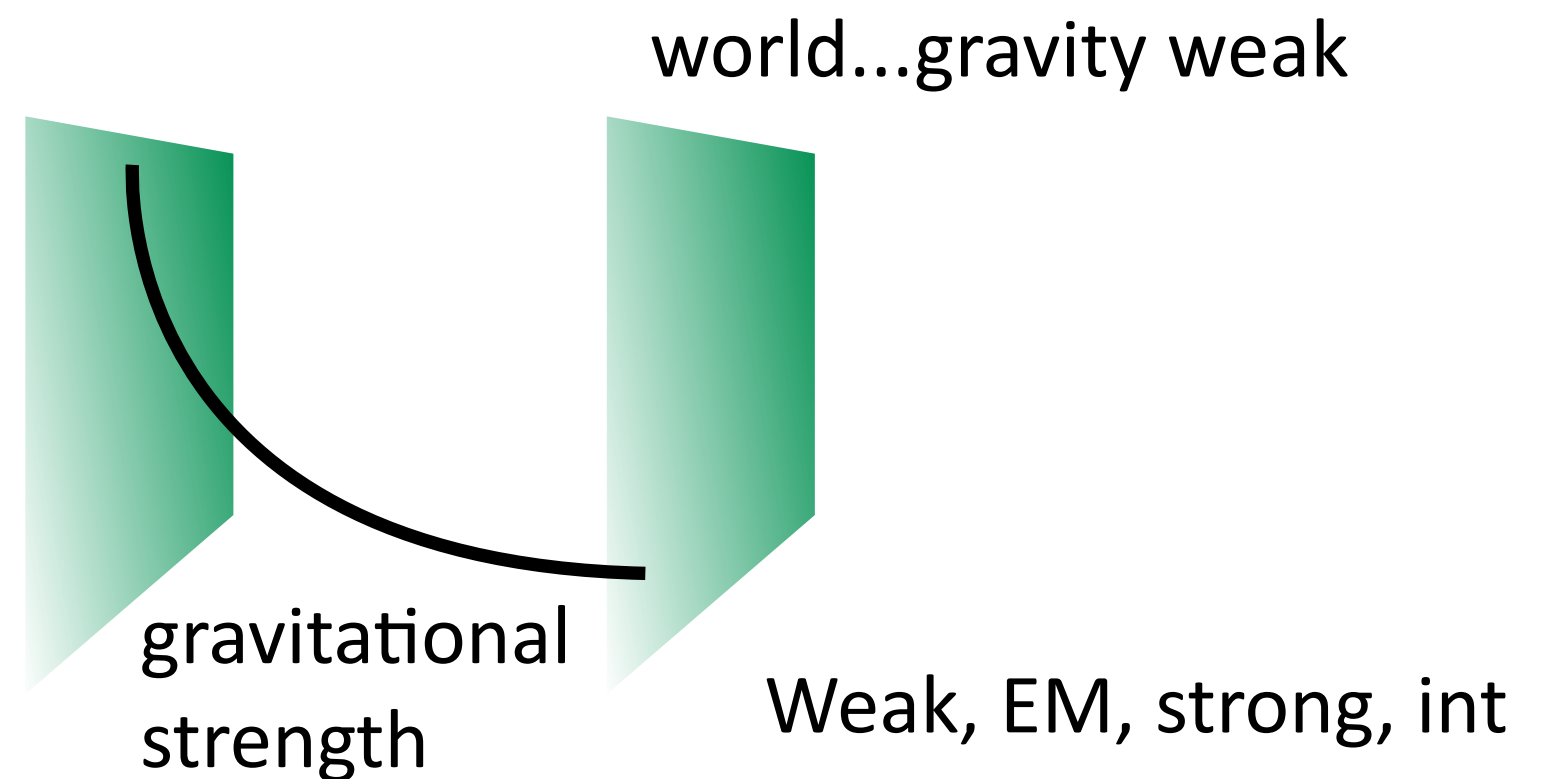


String interaction

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



high energy
scale
dimension(s)



pretty:



Cosmology 5

FLRW catalogue of Universes

$$\Lambda > 0$$

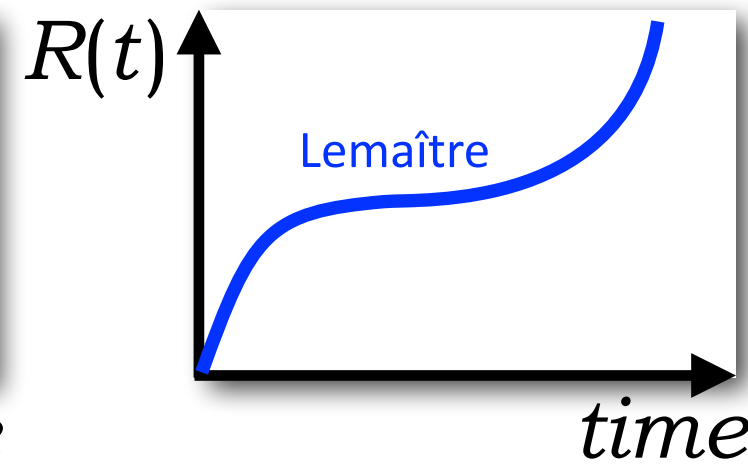
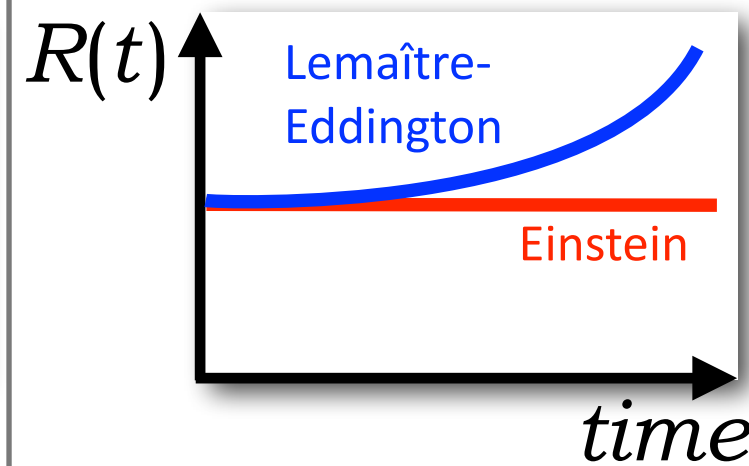
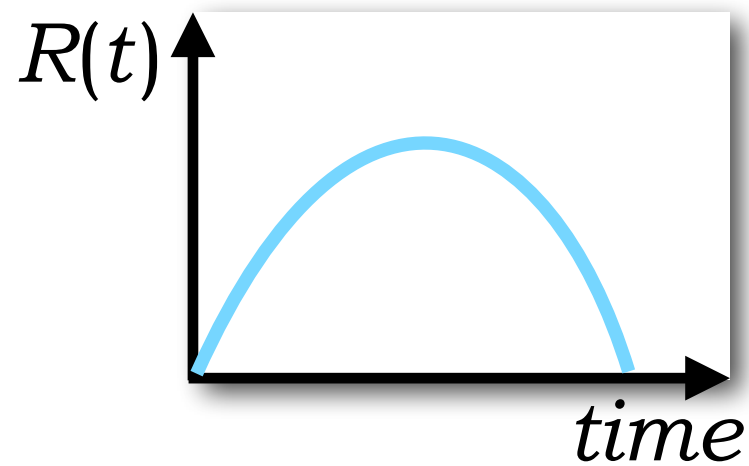
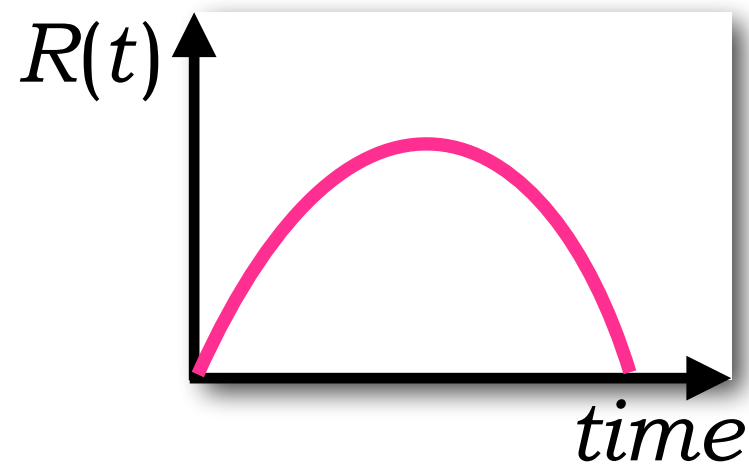
$$\Lambda < 0$$

$$\Lambda = 0$$

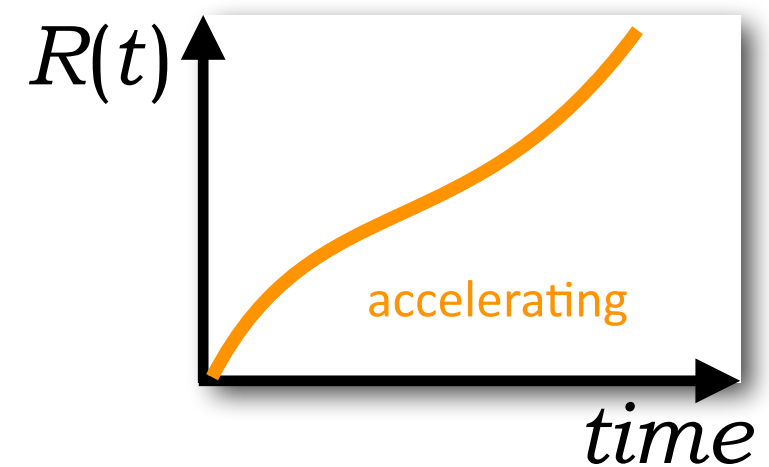
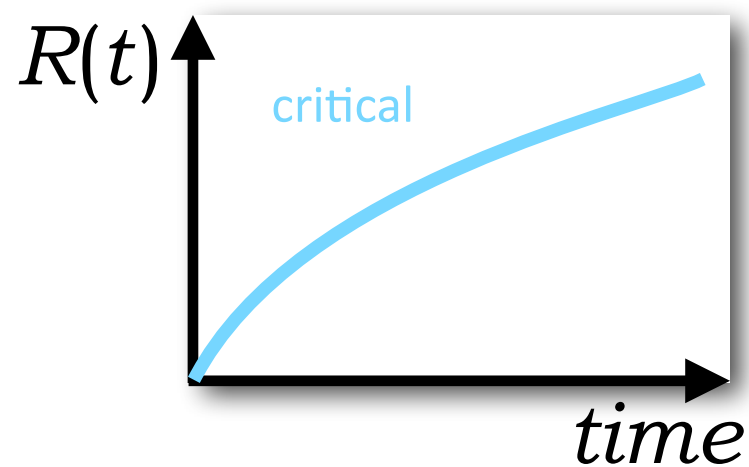
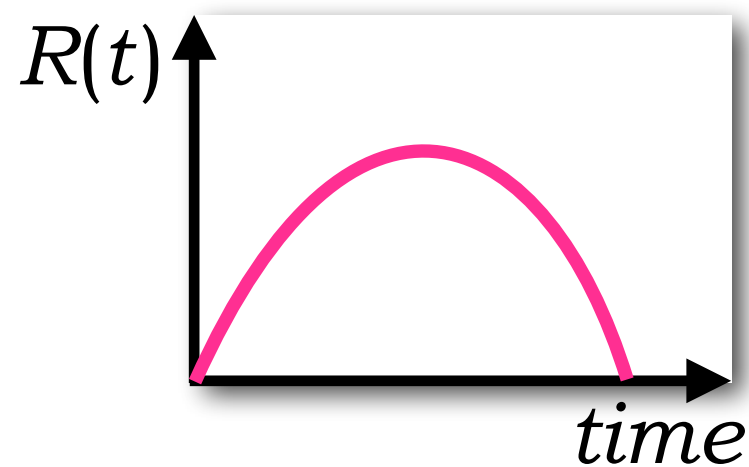
$$\Lambda = \Lambda_E$$

$$\Lambda > \Lambda_E$$

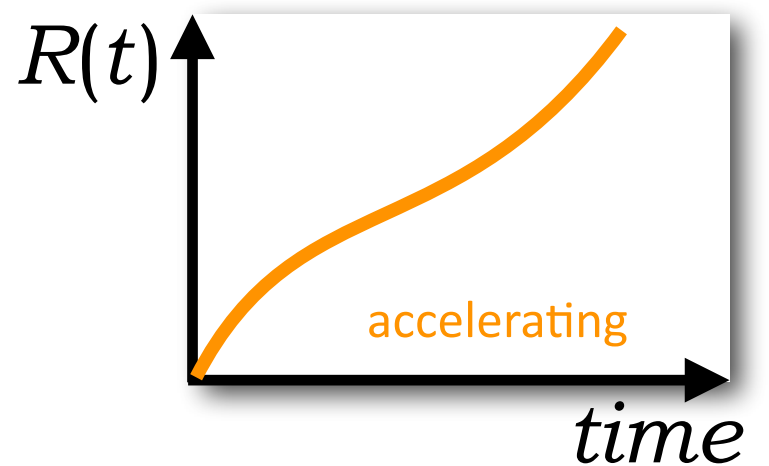
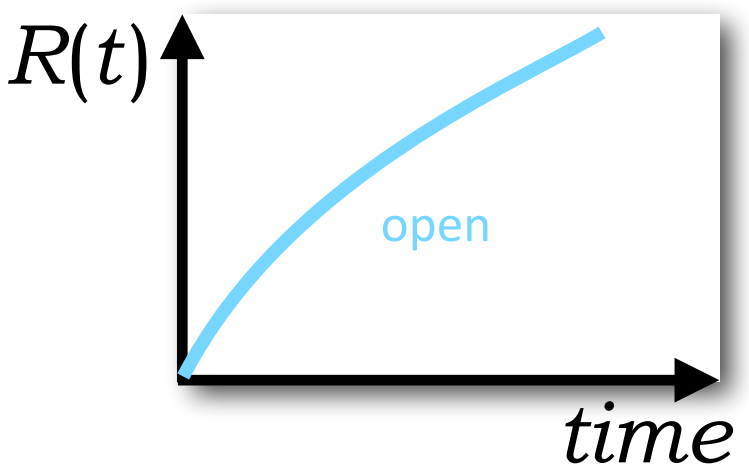
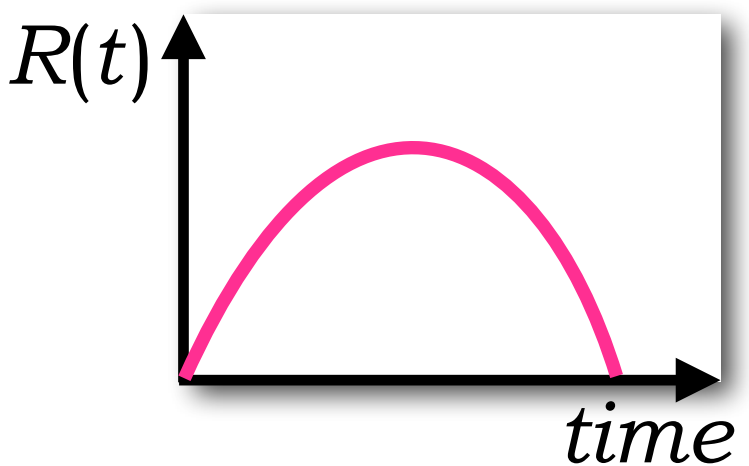
$$k = +1$$



$$k = 0$$



$$k = -1$$



~~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

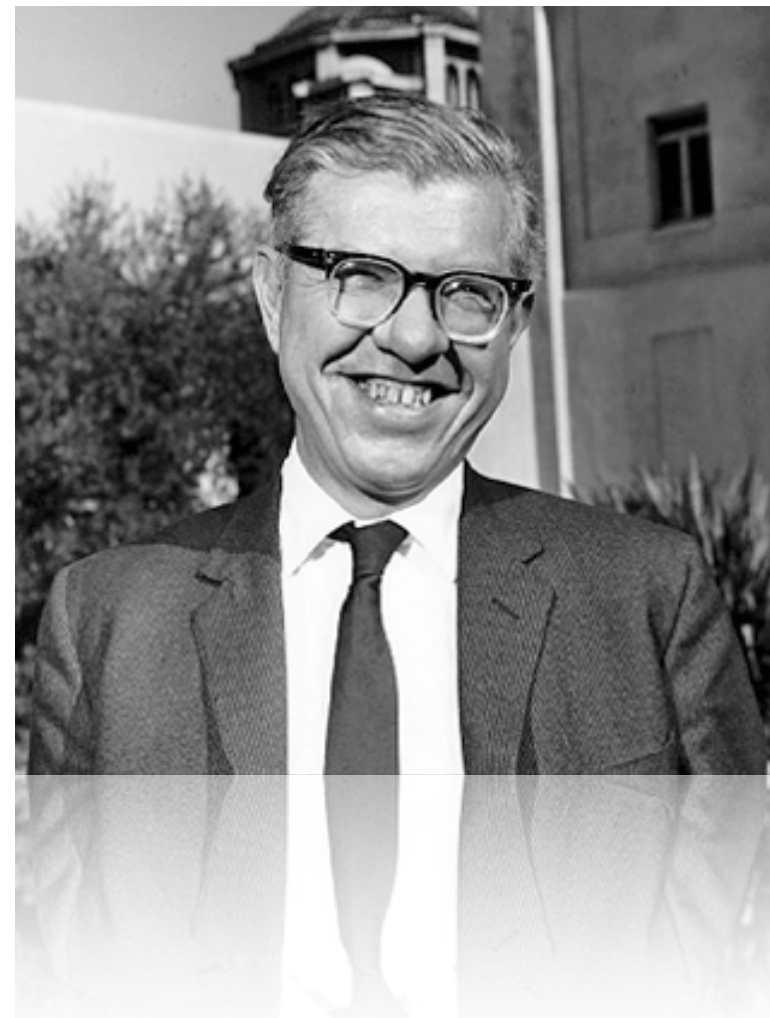
George Gamow

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

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

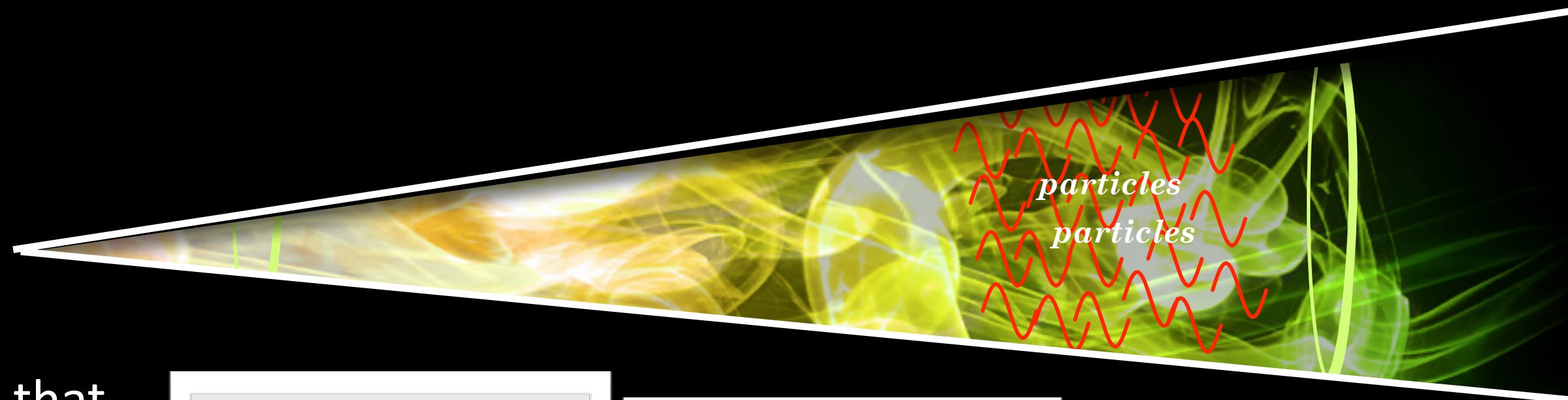
Home is Where the Wind Blows 1994.

Sorry, Fred.

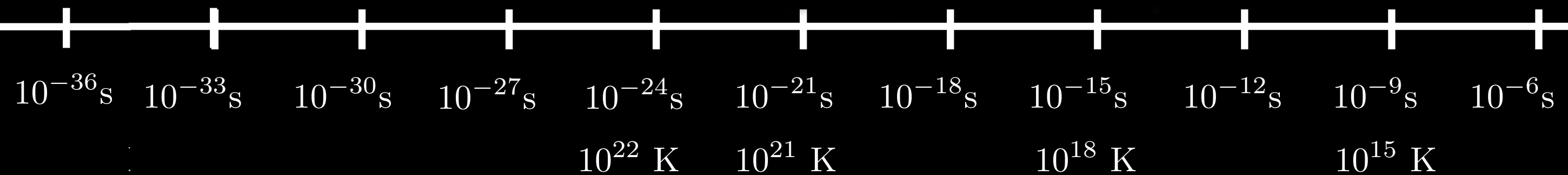
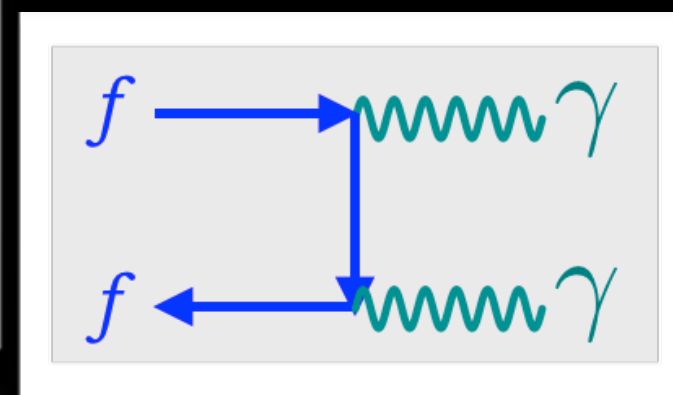
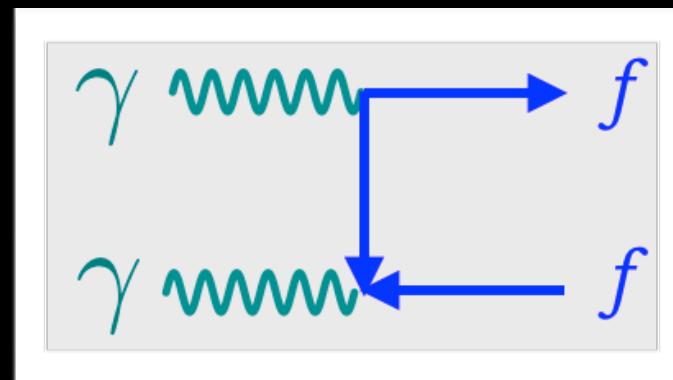
Here's the current understanding of the life of a
Universe:

evolving in time and temperature.

elementary particle epoch



presumed that
processes are in
equilibrium



There is a limit

Beyond which
there is no
physics

at the current time

Planck Time = 5.4×10^{-44} s

Planck Length = 1.6×10^{-35} m

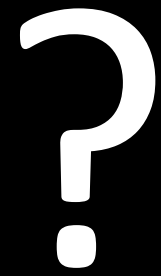


need a quantum
theory of gravity

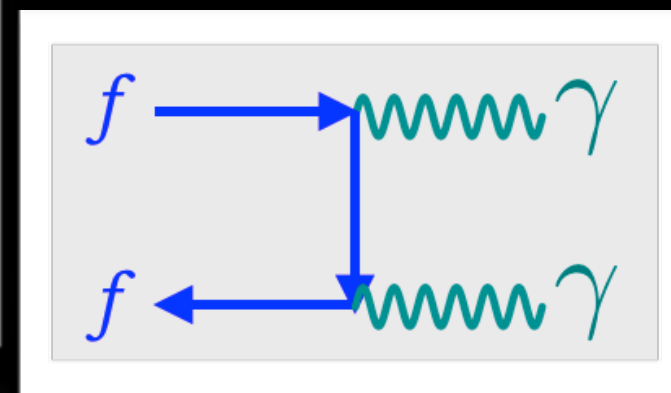
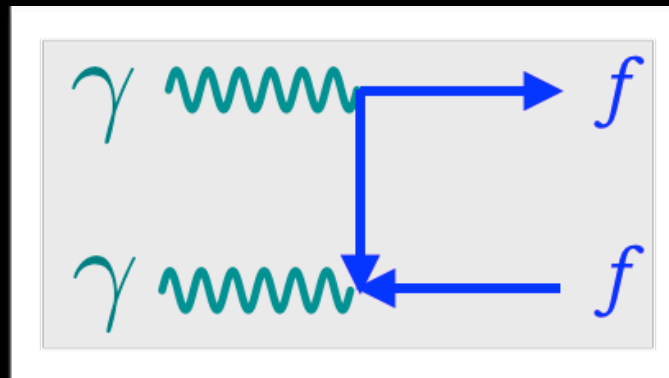
Or a physics with a built-in minimum length in
Nature...String Theory.

elementary particle epoch

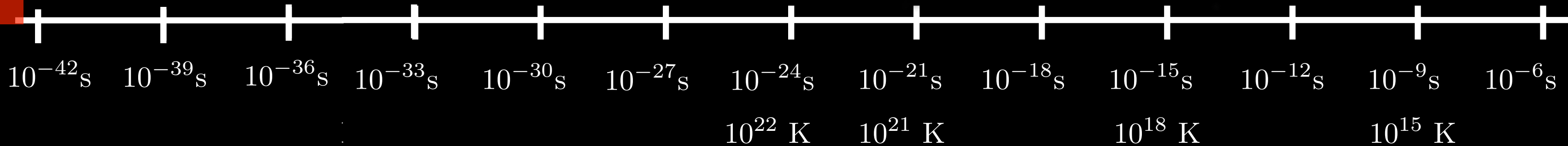
“Quantum Foam”



presumed that
processes are in
equilibrium



particles
particles

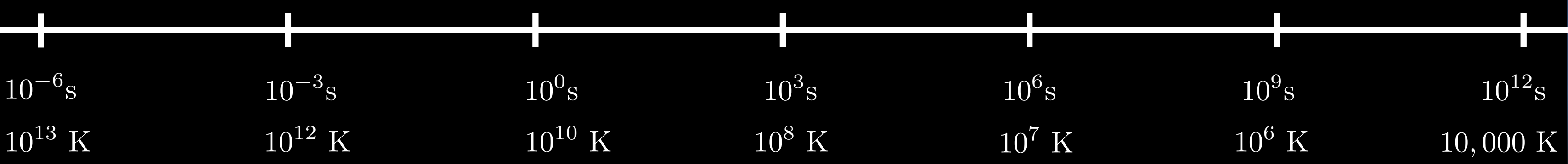
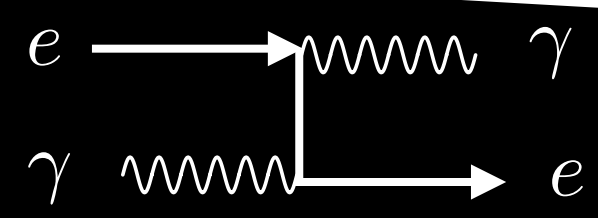
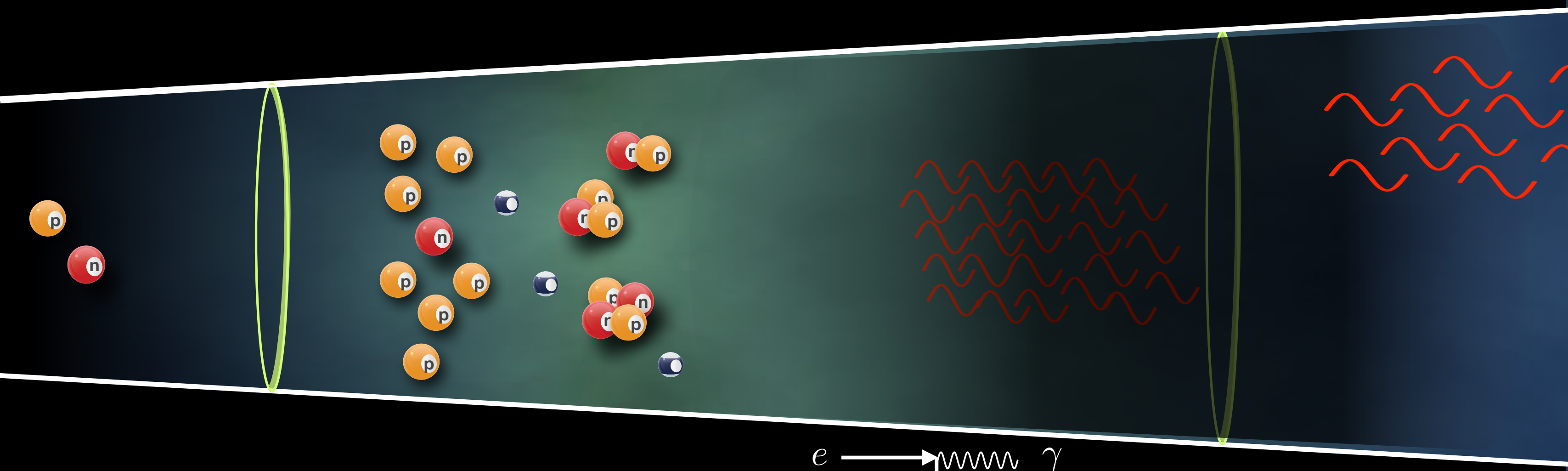


n u c l e o n e p o c h

hadron era

nucleosynthesis era

opaque era

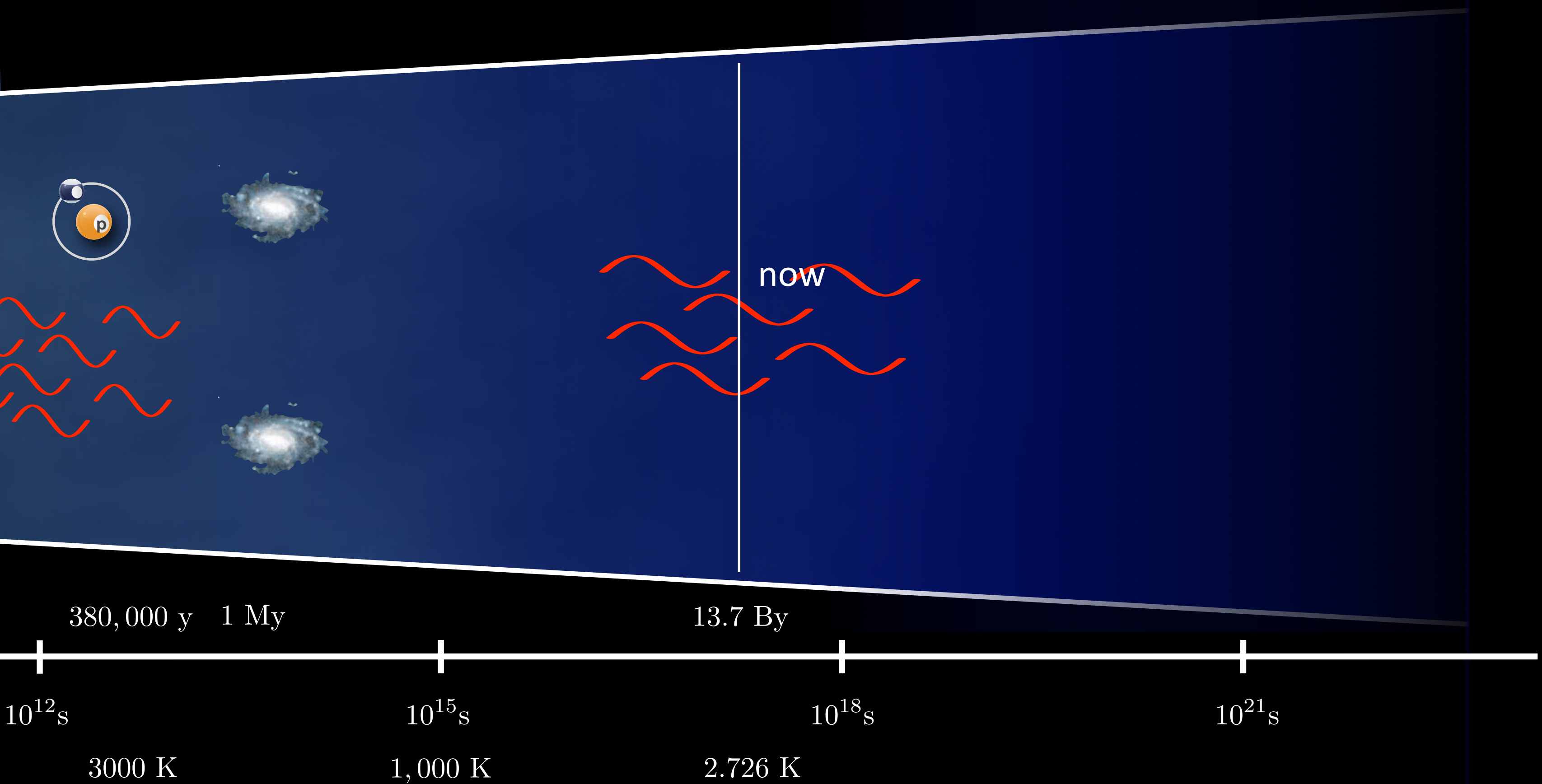


galactic epoch

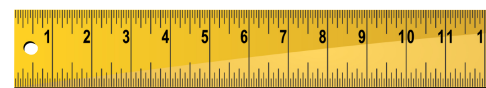
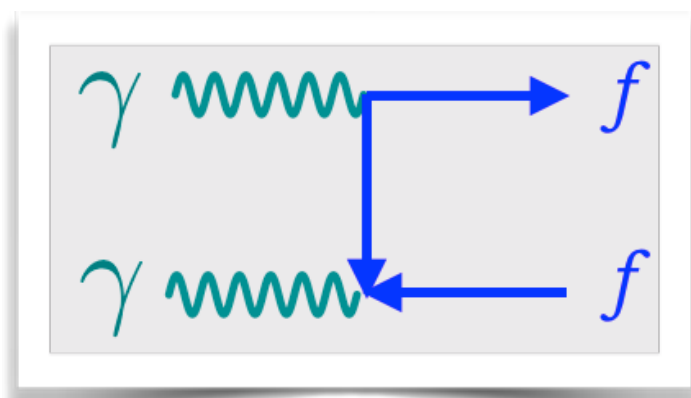
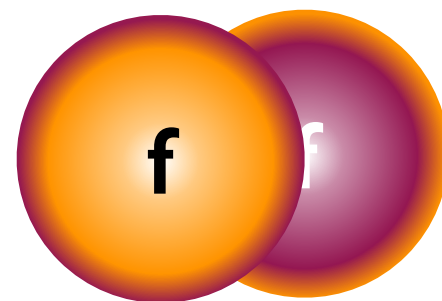
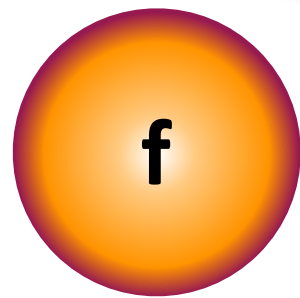
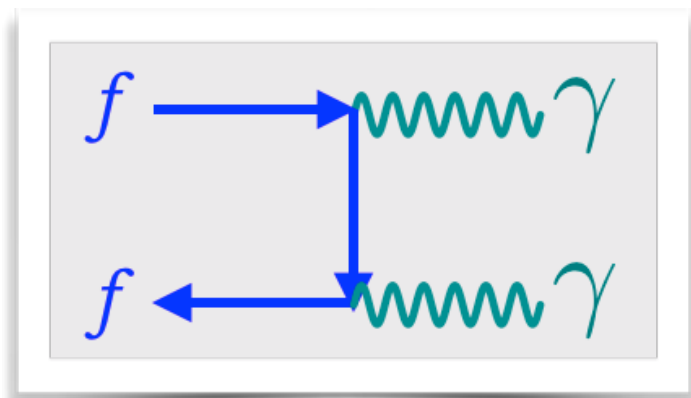
light era

our era

dark era



prior to 3 minutes: balance between radiation and particles.



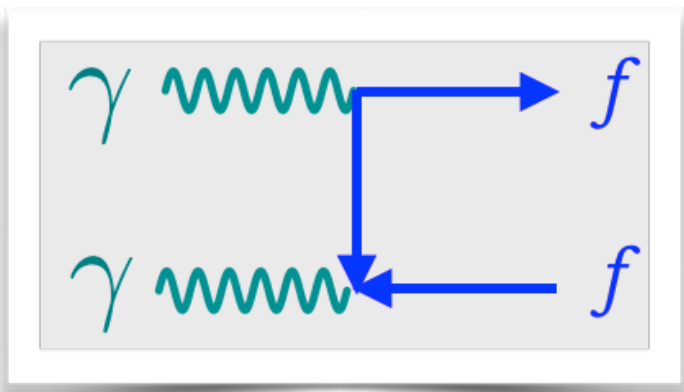
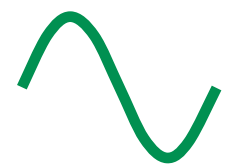
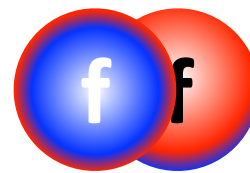
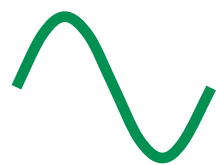
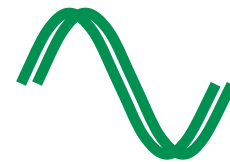
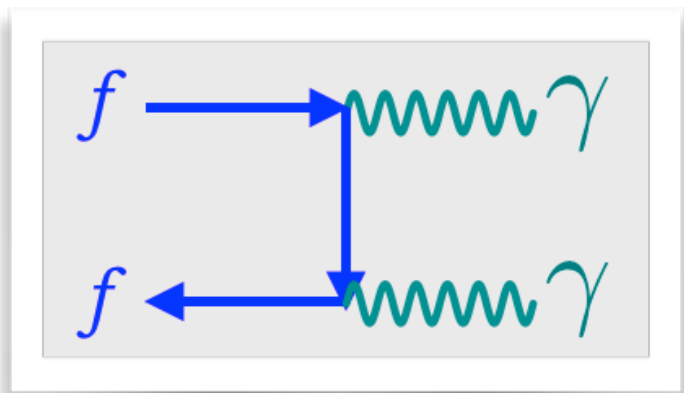
Early moments: short wavelength photons = high frequency photons = high energy photons
lots of mc^2 available—can make heavy particles

prior to 3 minutes: balance between radiation and particles.

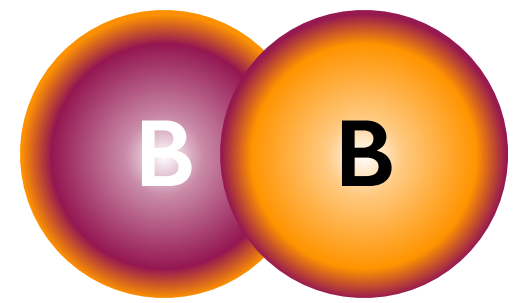
spacetime has stretched!

longer wavelength, lower frequency = less high energy photons
less mc^2 available—can't make heaviest particles

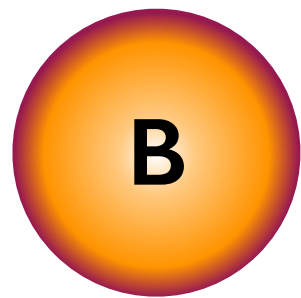
Later moments:



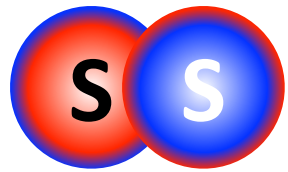
heavy species “freeze out”: pairs cannot be created any more



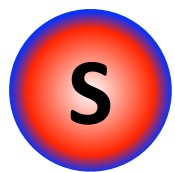
$$2m_{\text{really heavy}}c^2$$



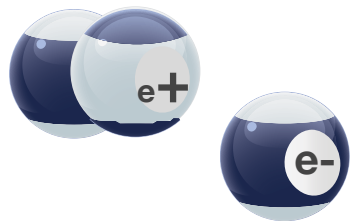
$$m_{\text{really heavy}}c^2$$



$$2m_{\text{heavy}}c^2$$

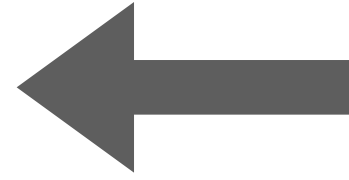
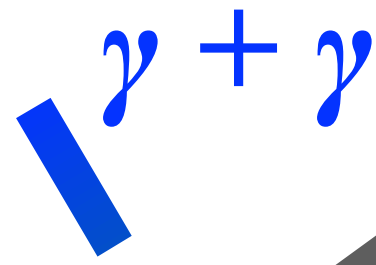


$$m_{\text{heavy}}c^2$$



$$2m_{\text{electron}}c^2$$

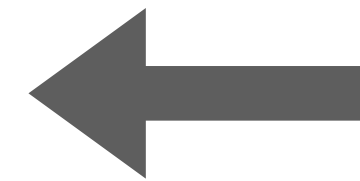
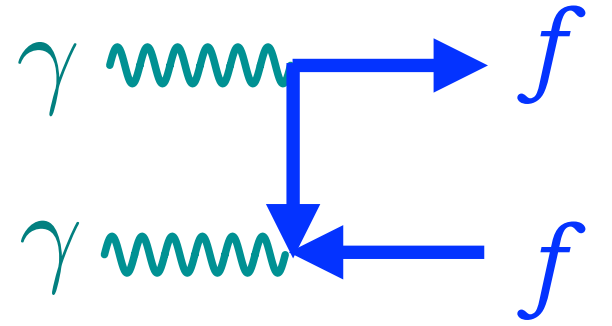
$$m_{\text{electron}}c^2$$



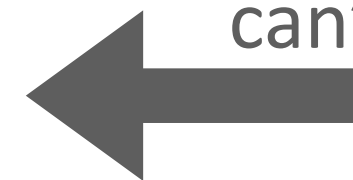
below this point:
can't make BB

wavelength stretching...
energy shrinking

from:



below this point:
can't make SS



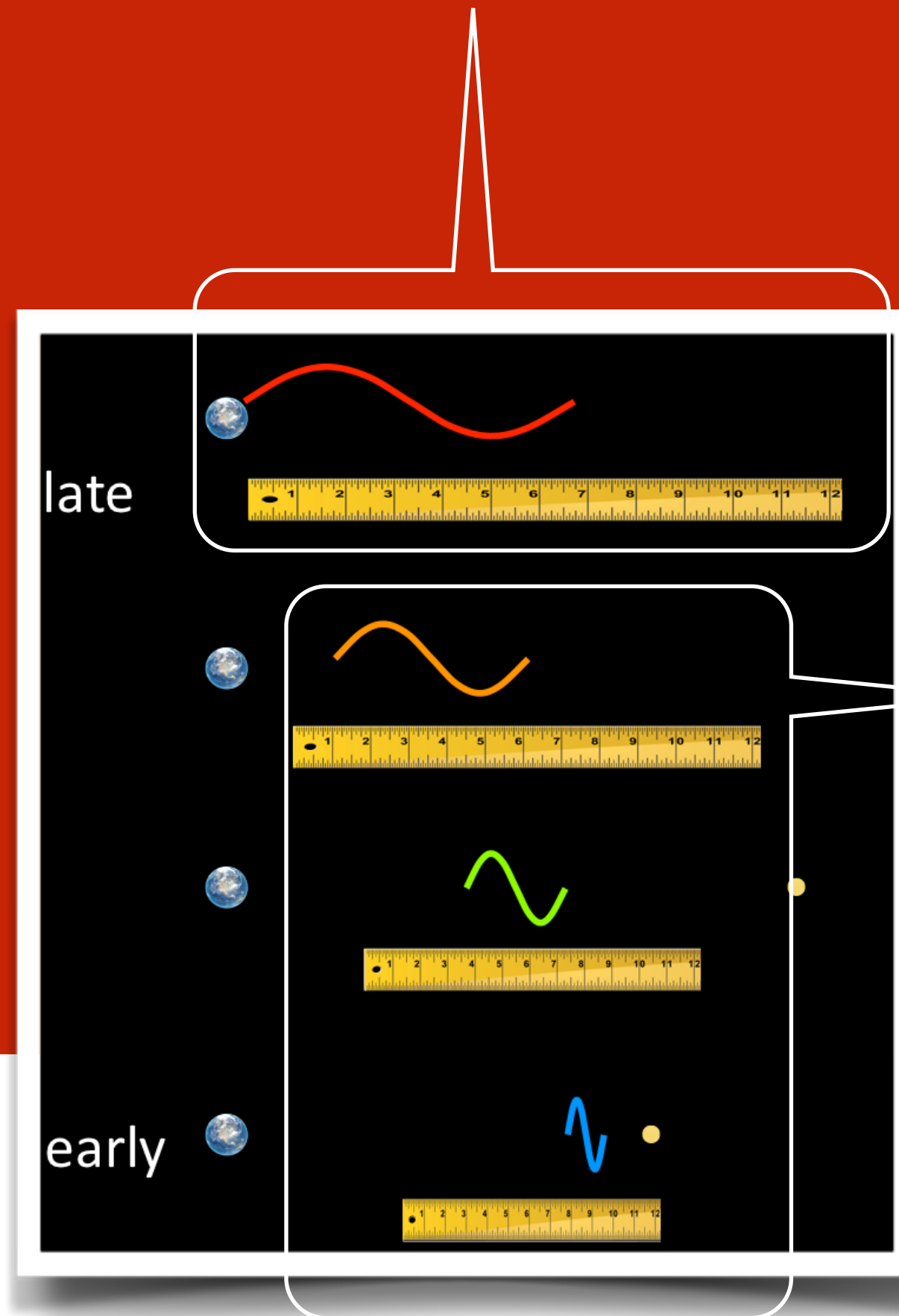
below this point:
can't make anything!

time →

space stretching →

at some point, they are too low in energy to do anything...they just hang around.
about 70,000 years after BB

remember



many high energy photons:
create new particles, ionize atoms, disintegrate nuclei

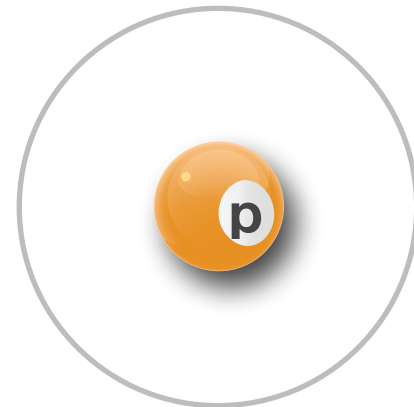
there is
a magic
point

at which atoms
can start to form

"recombination"

*which is an odd
name, since
there wasn't a
"combination"
yet!*

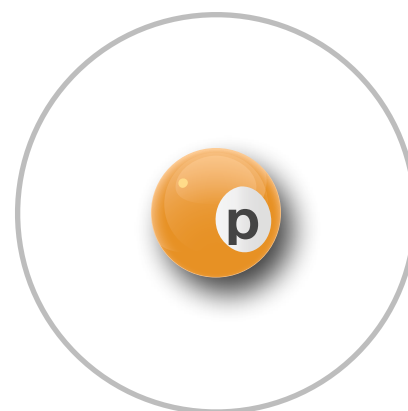
After protons, neutrons, and electrons are stable...



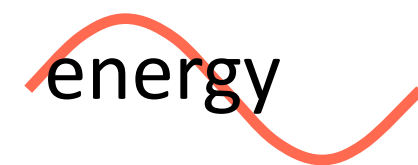
left-over photons ionize the
baby Hydrogen atoms

The Universe consists of: a **plasma**...charged particles,
unbound...freely moving around. Opaque.

At one point...about 10^{12-13} s - 370,000 y:



the photons don't
have 13.6 eV of
energy



Bingo.
We have H atoms
(and He)

There's nothing
else for the
photons to do!

The Universe has
suddenly become
transparent to
photons