Introduction to Particle Physics

(for non physics students)

4. UNIFIED UNIVERSE

(no strings attached)

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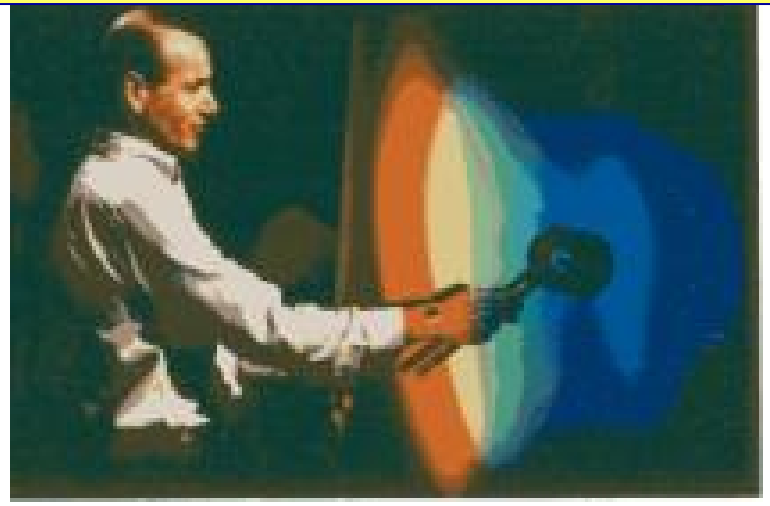
UNIVERSITY OF OXFORD



FORCES Summary

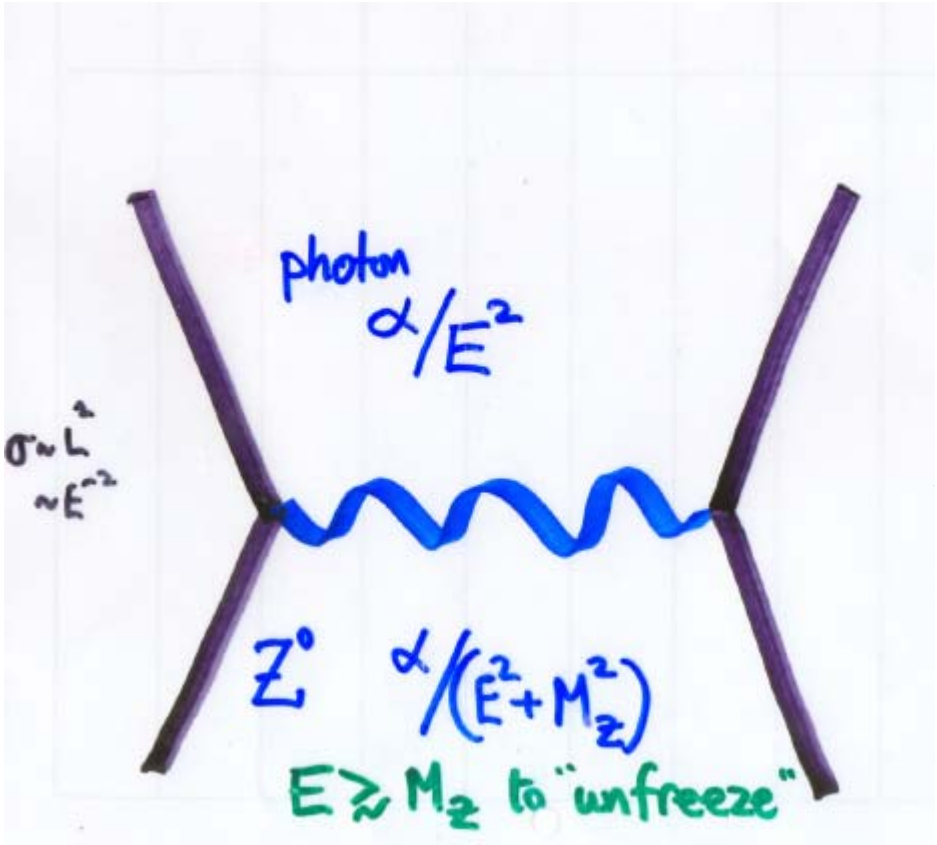
(remember that waves ⟷ particles)

NAME	action	CARRIER
Gravity	keeps us on ground	graviton ?
Electromagnetic	electrons in atoms solids stops us falling to centre of Earth	photon (γ)
Weak	β- radioactivity p → He in Sun	W^+ W^- Z^0
Strong	quarks glued inside p, n ... p, n in nuclei	gluons (g) 8 different

Only the weak force carriers have MASSes

$M_W \sim 80\ GeV/c^2$

$M_Z \sim 91\ GeV/c^2$

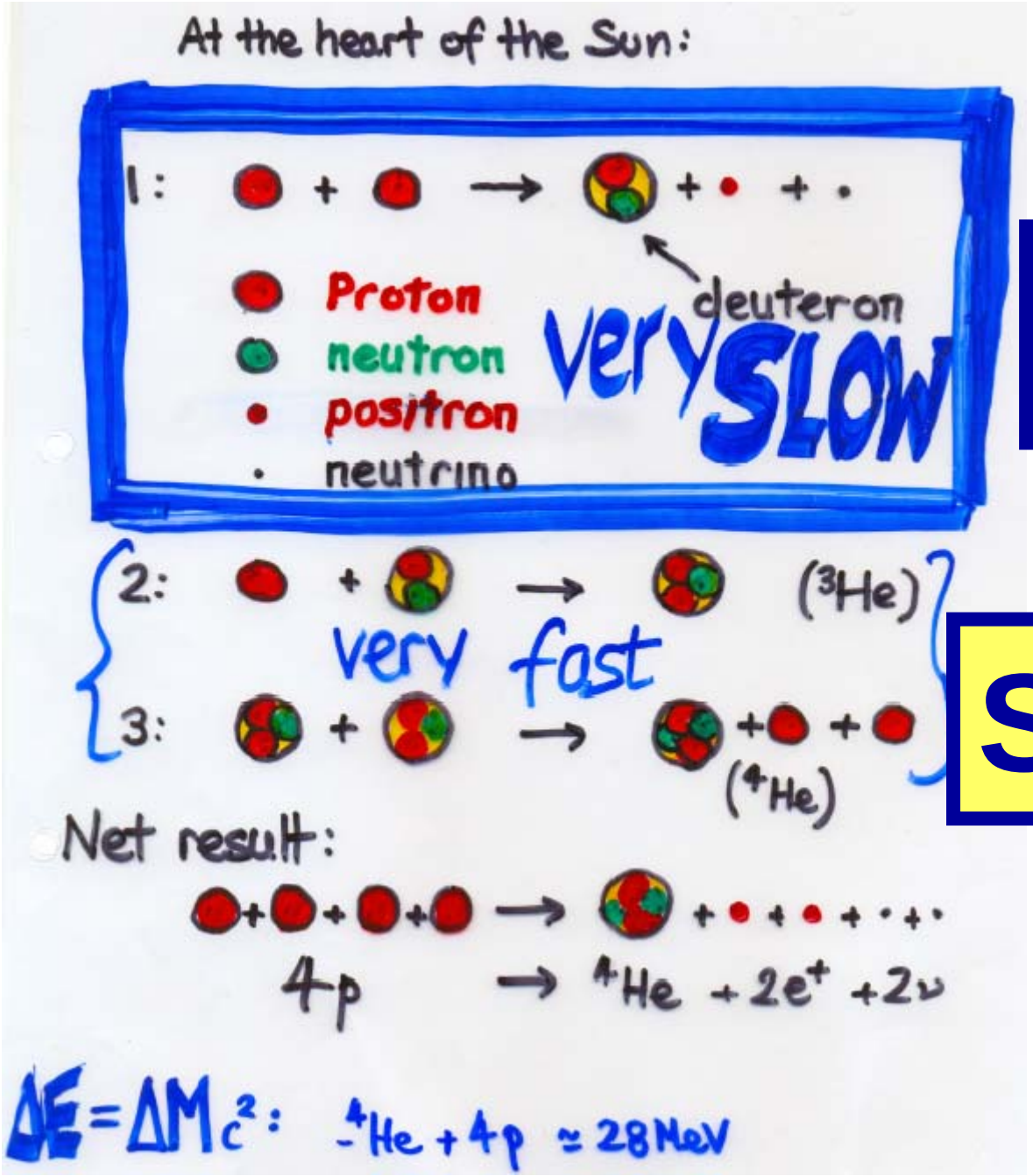


Feynman rules:

If energy E flows through the transmitted “virtual” particle (photon; Z) it costs 1/(E^2+M^2)

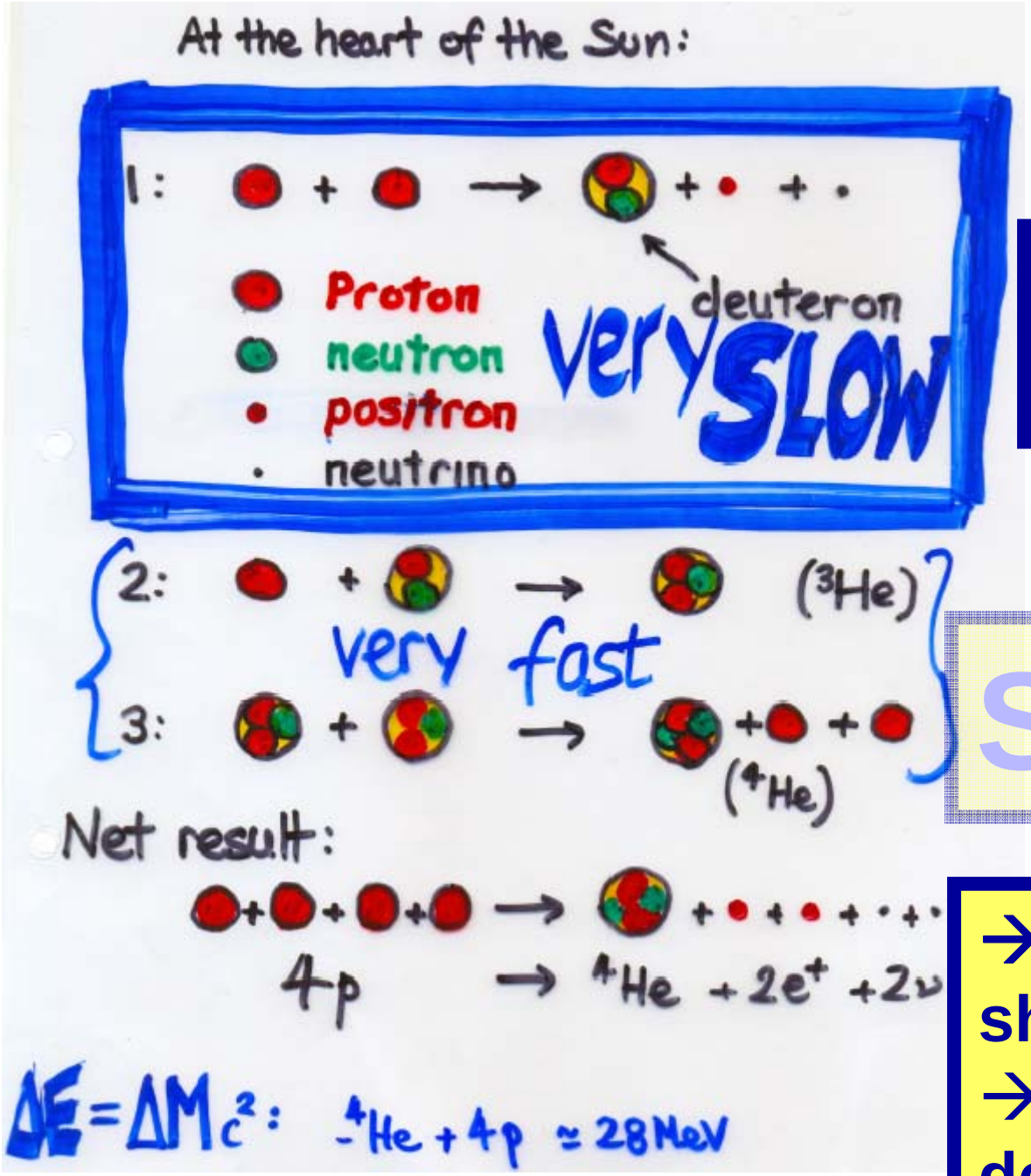
If E >> M the cost is 1/E^2….like the case of the photon

Only appears weak at low energy. Unified at high energy


At the heart of the Sun:
1:
deuteron
Proton
neutron
positron
neutrino
very SLOW
2:
(3He)
very fast
3:
(4He)
Net result:
4p → 4He + 2e+ + 2ν
ΔE = ΔMc²: 4He + 4p ≈ 28 MeV

WEAK

STRONG



WEAK

STRONG

→ why sun has shone for 5 Byr…
→Intelligent life developed

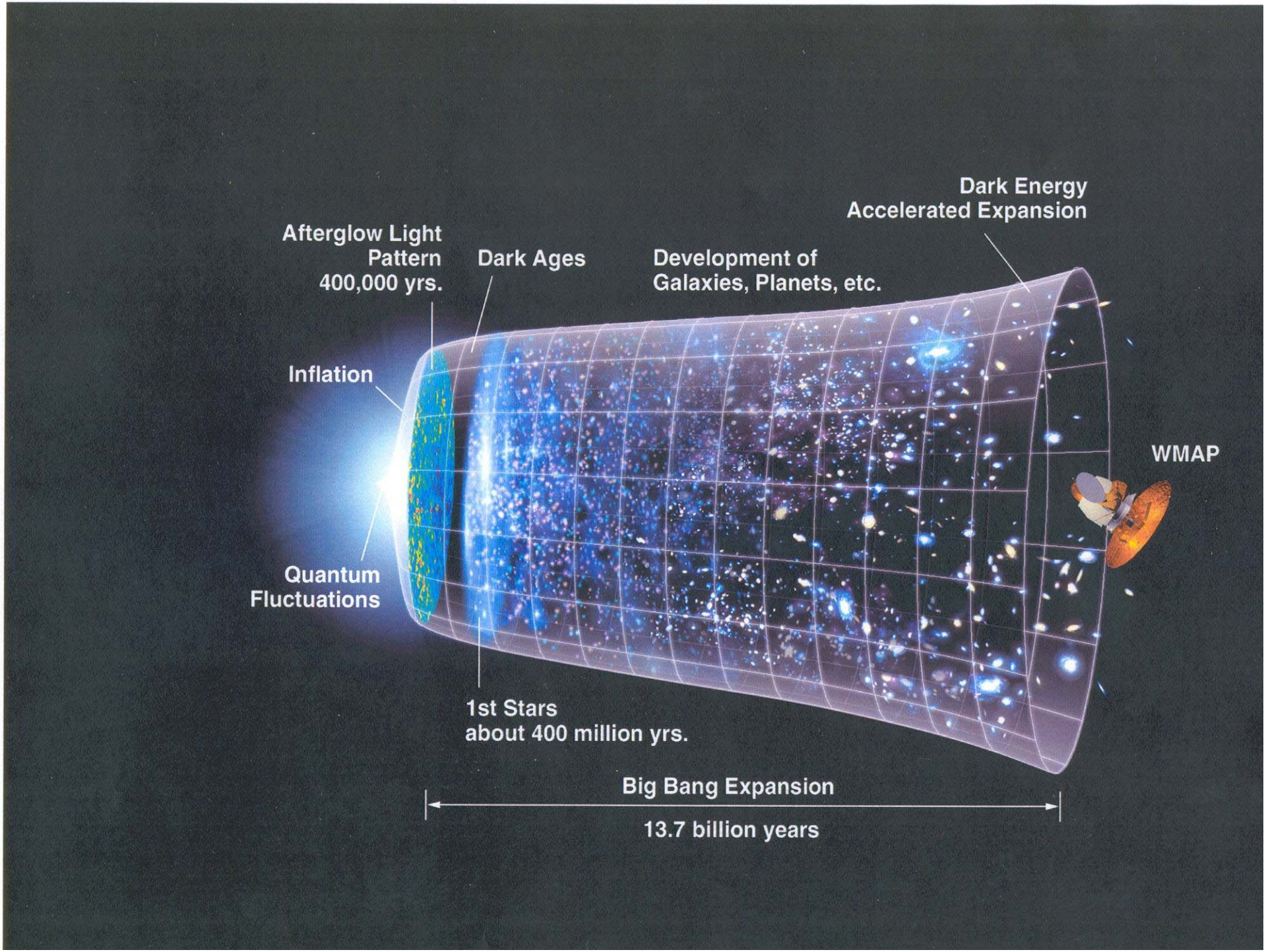
The weak force is feeble in the Sun ..

..because 10,000,000K ~ 1 keV << 80 GeV

…this is why the sun has stayed active long enough for us to have evolved and be having this conversation.

→We exist because m(W) is not zero

→ Mass matters


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

Big Bang → e + p

Thermal Equilibrium:

Temperature (energy) drops →

After 1 μsec → one way only:

But at the same time:

then like processes 2 and 3 in the Sun* until all the neutrons have gone

*making Helium

or

particles so far apart in the expanding universe that they no longer interact

$T = 1\,\mu sec$ after BIG BANG

neutrinos are free
("the first fossils in the Universe)

move at high speed
and if they have mass they
start clustering together
→ contribute to formation of galaxies

Billion ν per atom
⇒ if $m(\nu) > m(\text{proton})/10^9 \simeq 1\,eV$
they will dominate mass
density of the Universe

⇒ m_ν big question
for future of universe
and its formation

Universe expands - and cools expansion rate

Rate depends on pressure which depends on the temperature in the gas and the number of neutrinos inside the gas volume (density) and this # depends on number of neutrino species

T = 3 minutes after BIG BANG

75% protons

24% Helium Nuclei

+ small amount of deuterons

+ free electrons.

Helium abundance*; +traces of other light elements

depends on expansion rate of the Universe which depends on number of neutrino species

Deuterium abundance

depends on density of "ordinary matter" in the Universe.

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if 3 ν species

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Deuterium abundance

depends on density of "ordinary matter" in the Universe.

IF density of ordinary matter $\ll$ total in universe

→ part of DARK MATTER puzzle

Time Passes. Temp drops

300,000 years later $E<10eV$ $T<10^4K$

electrons combine with nuclei
and make neutral atoms

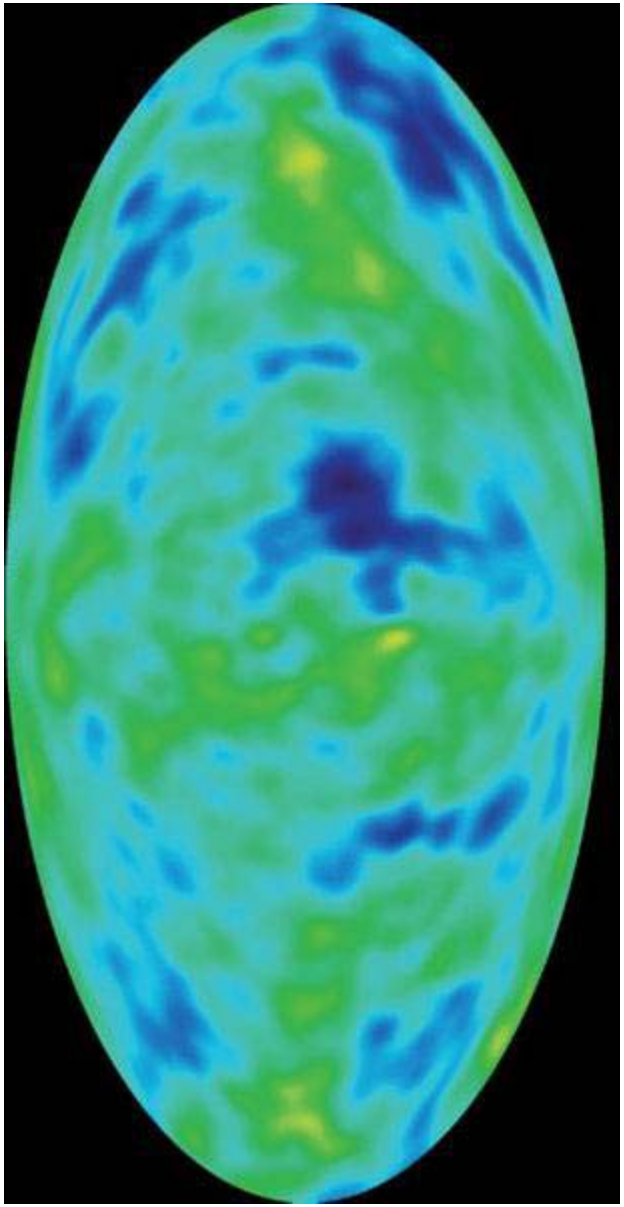
electromagnetic radiation was set free

Universe becomes transparent

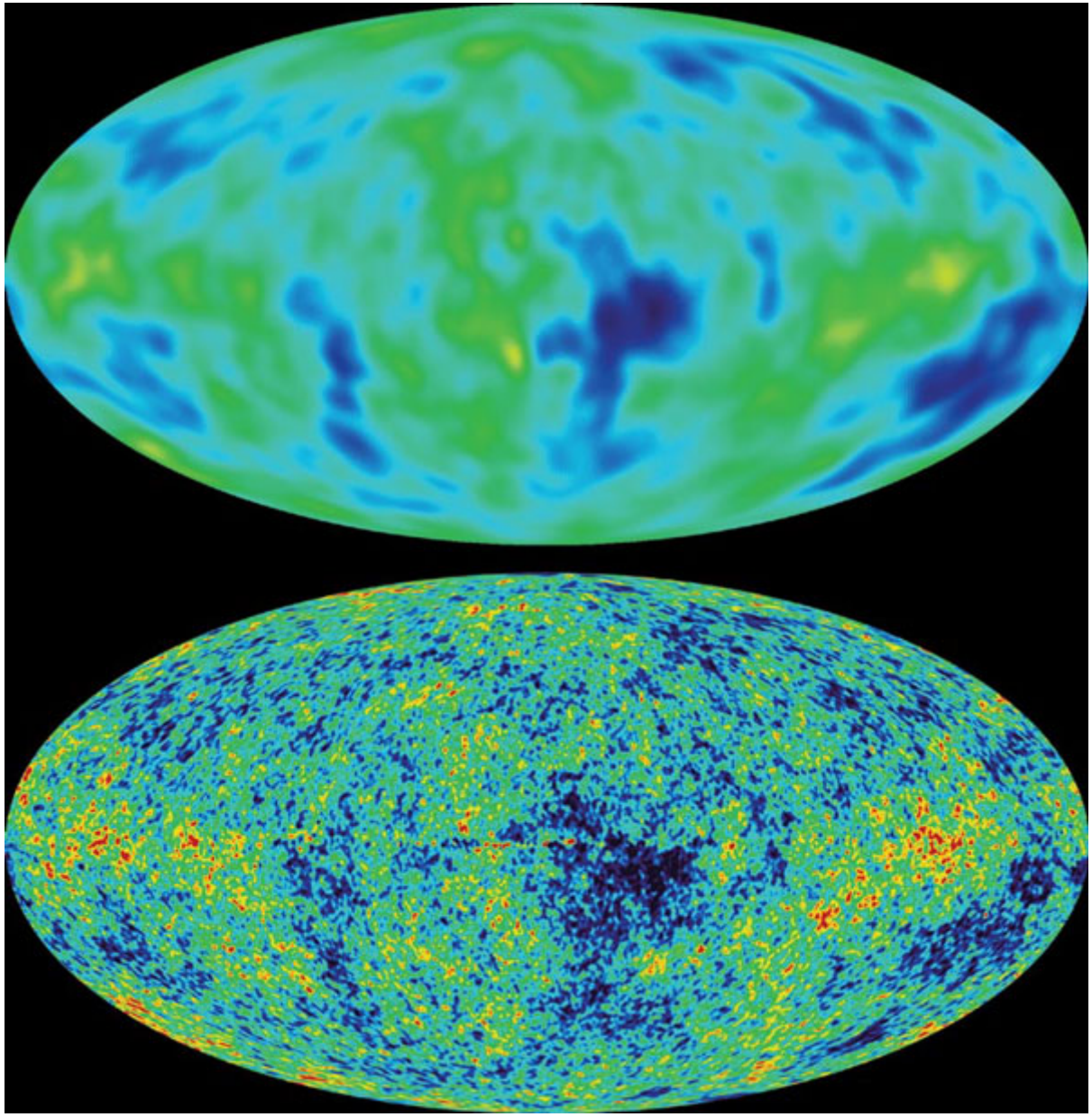
10^{10} years later

Emag λ stretched : Microwave Bgrd.
Black body background 3K

(small fluctuations in Mwave rad
= hints of proto structures, galaxies
in early universe)

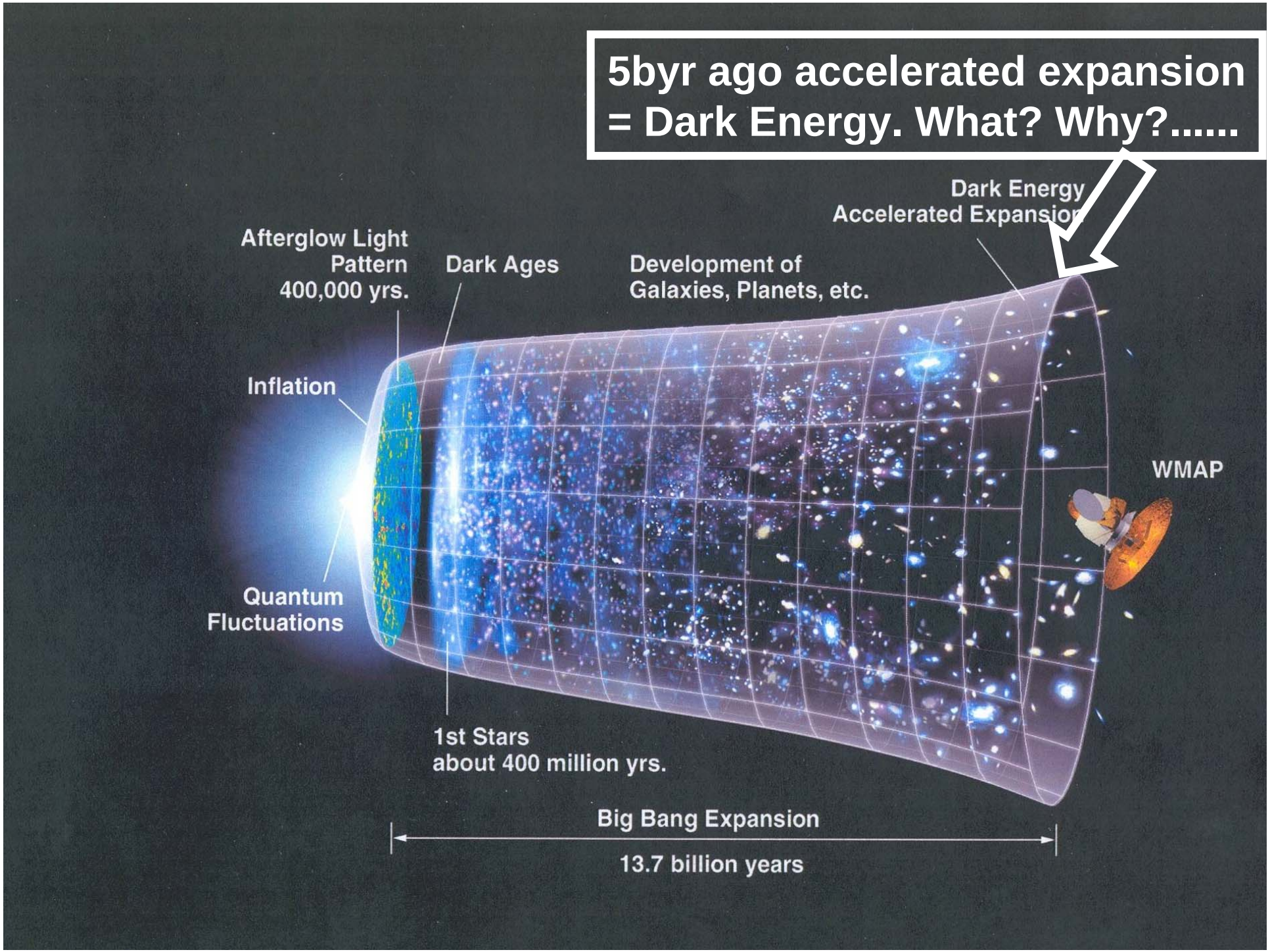


3K microwave bgnd now seen to have structure



COBE 2000

WMAP 2003


5byr ago accelerated expansion
= Dark Energy. What? Why?.....
Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
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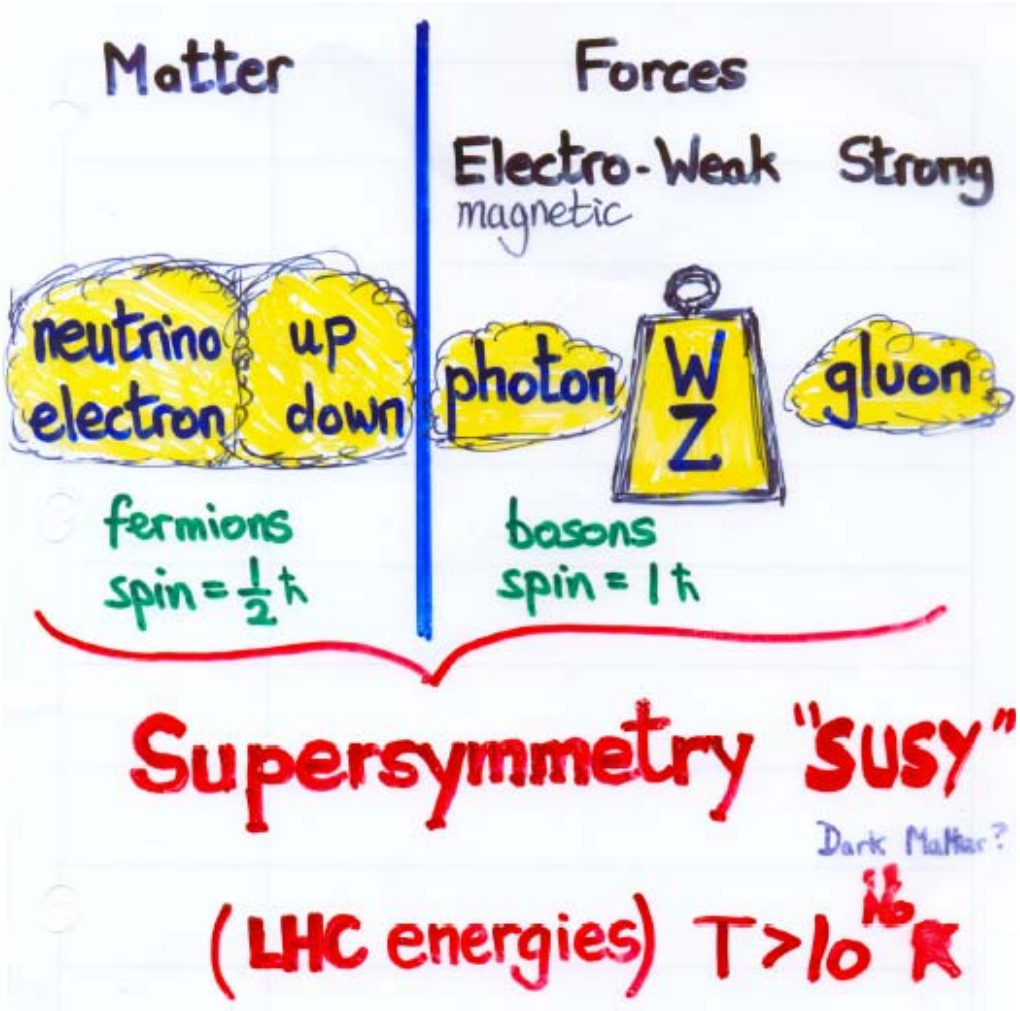
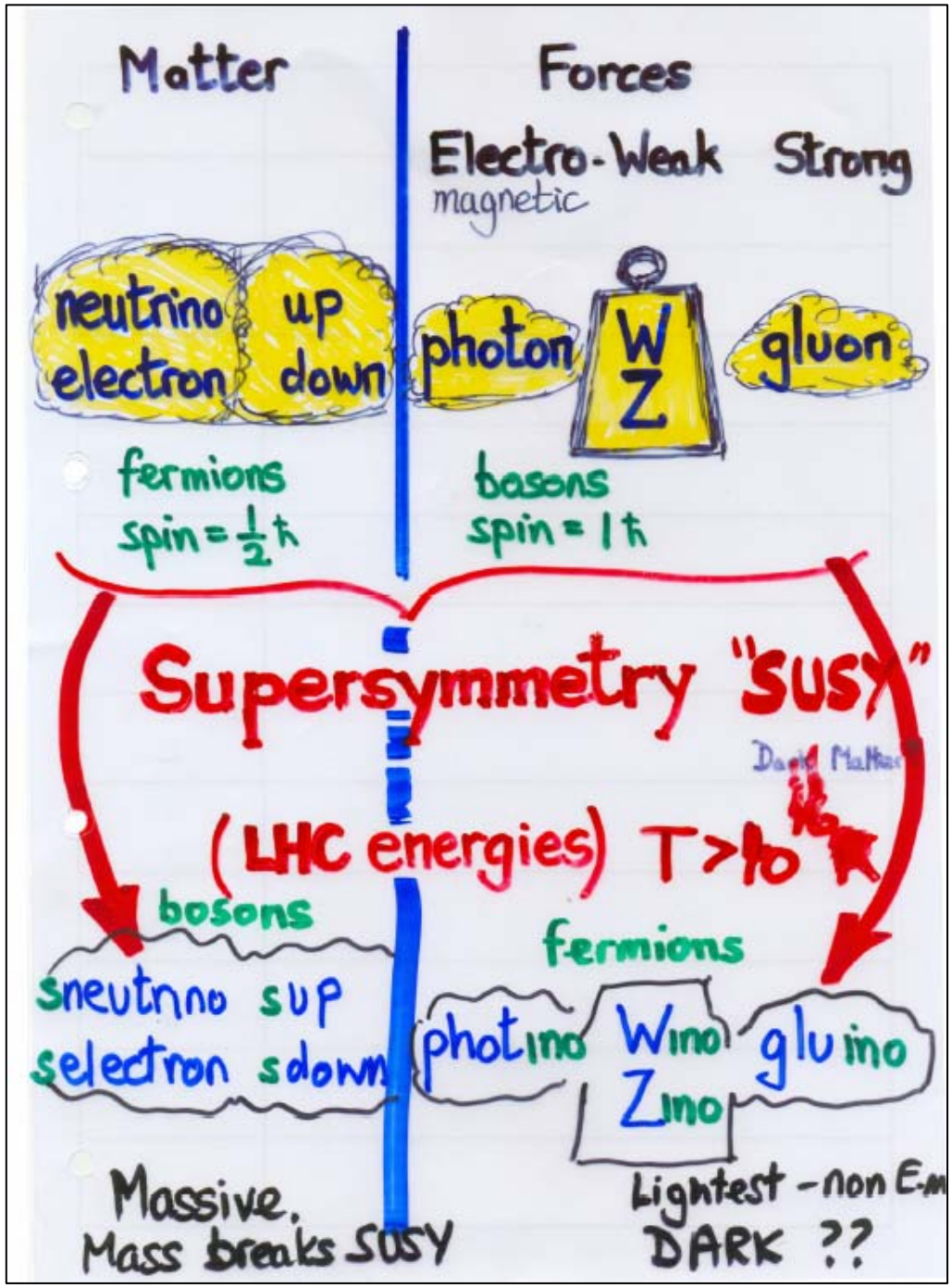
One further symmetry??





Whole new families to be found

Particle Physics @ CERN.

Standard Model of Ptles + Forces.

- Quarks + Leptons. — Spin ½ fermions
- γ $W^{\pm}Z$ gluons — Spin 1 gauge bosons
- Higgs — Spin 0 boson

High Energy ⟷ Early Universe

Origins of matter.

[Structures + patterns at $E \lesssim 1$ TeV
[Symmetry revealed at $E \gtrsim O(\text{TeV})$

Forces (and particles) unified – SUSY.

Some current big puzzles.

- Dark Matter, Solar ν, massive ν ? (all the same?)
- Why 3 generations
  What is difference between M and $\bar{M}$? } the same?
- ? → The Fifth Dimension

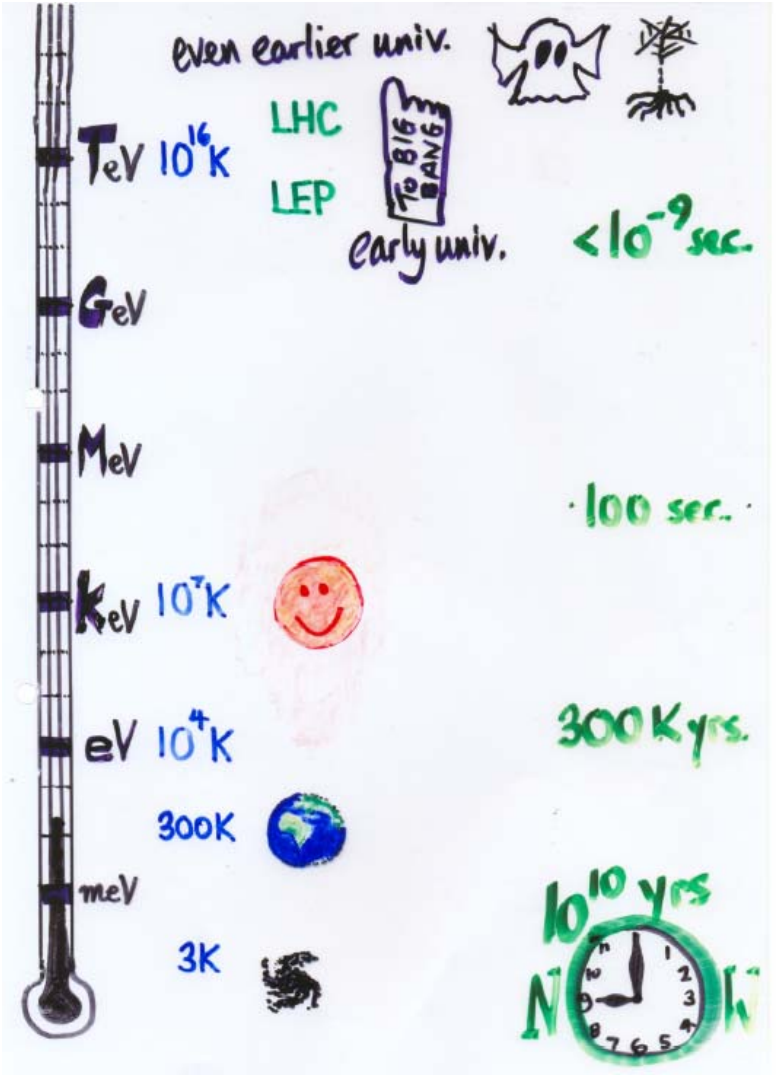
Finale: A glimpse of the future

recall from lecture 1…..

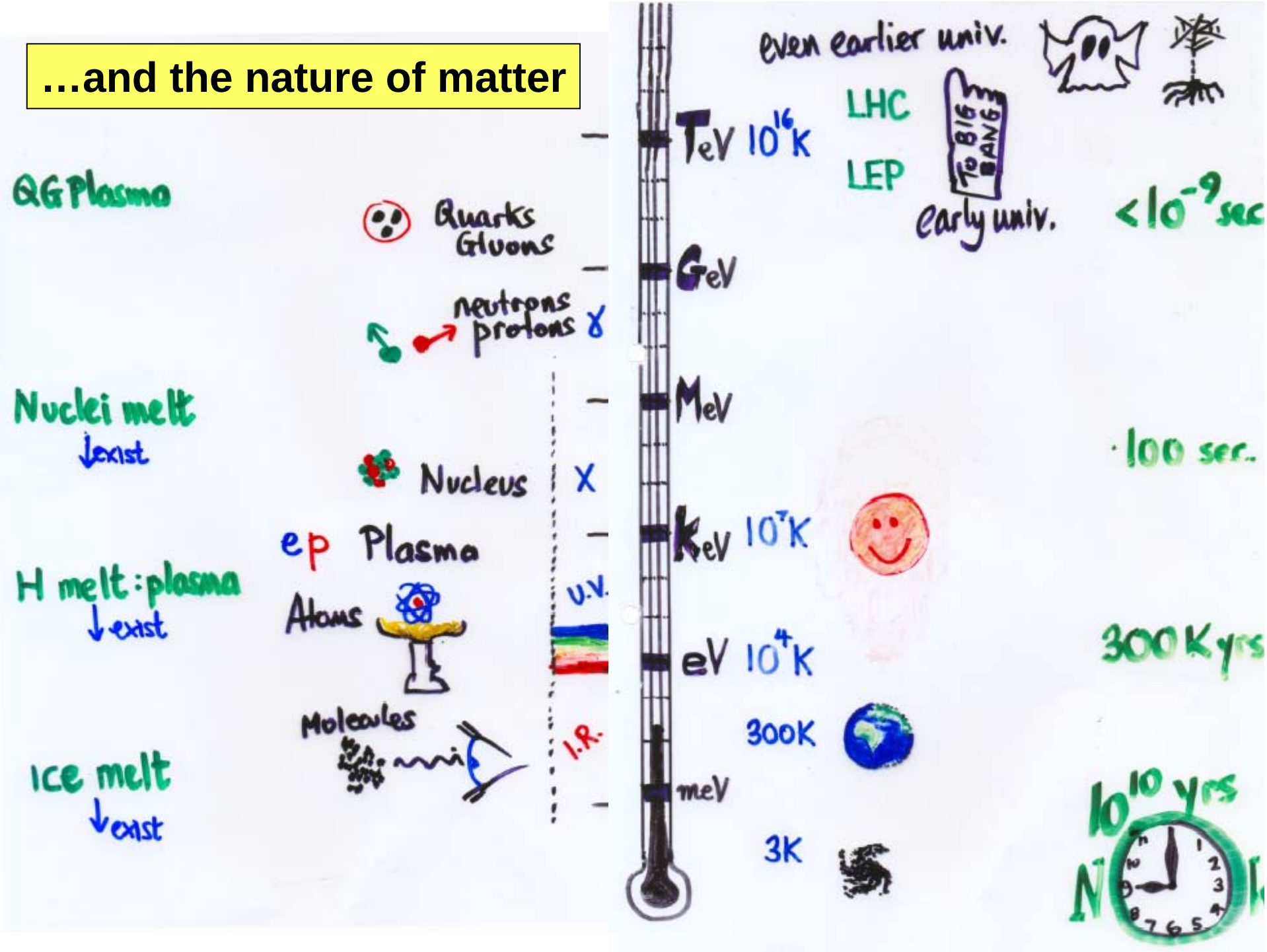
The Universe

in

Temperature
Energy and
Time



…and the nature of matter



…and patterns (that change)

QG Plasma

Quarks Gluons

neutrons protons γ

Nuclei melt
↓exist

Nucleus X

ep Plasma

H melt: plasma
↓exist

Atoms

U.V.

Molecules

I.R.

ice melt
↓exist

TeV

GeV

MeV

KeV

eV

meV

No mass. Unified Theory

Standard Model MASS

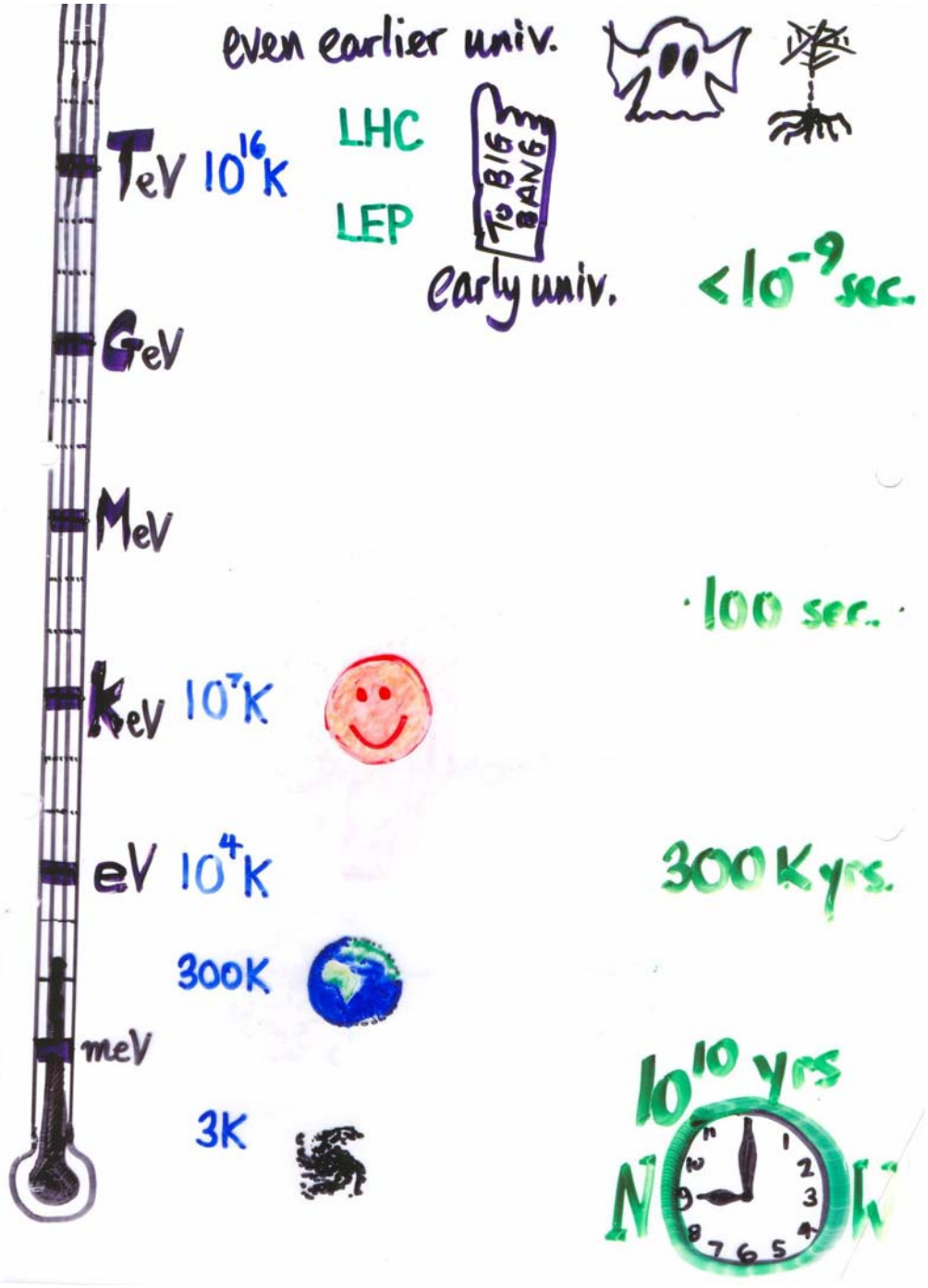
t	b	τ	ν	W
c	s	μ	ν	Z
u	d	e	ν	γ_g

Nuclear Isotopes

Mendeleev

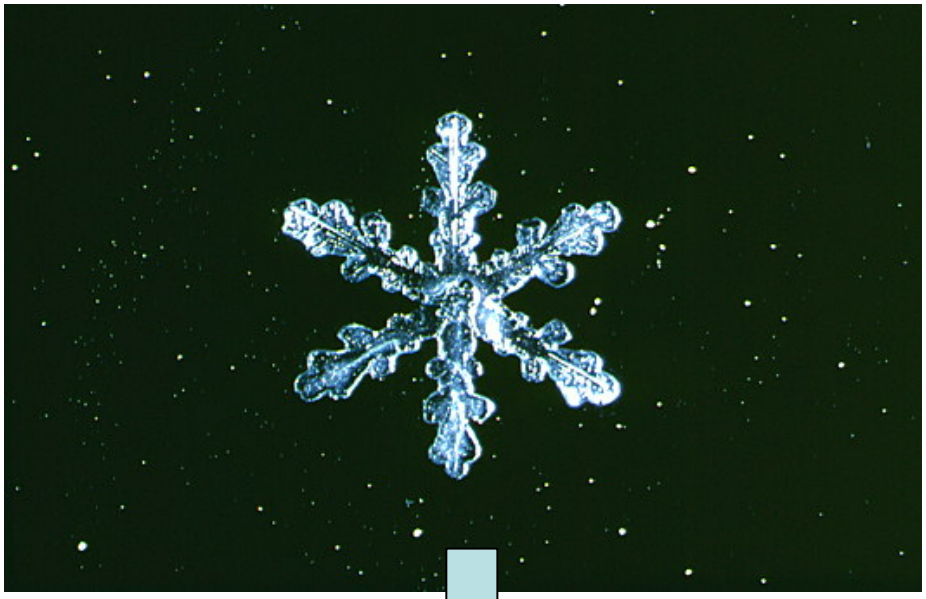
Snowflake pattern

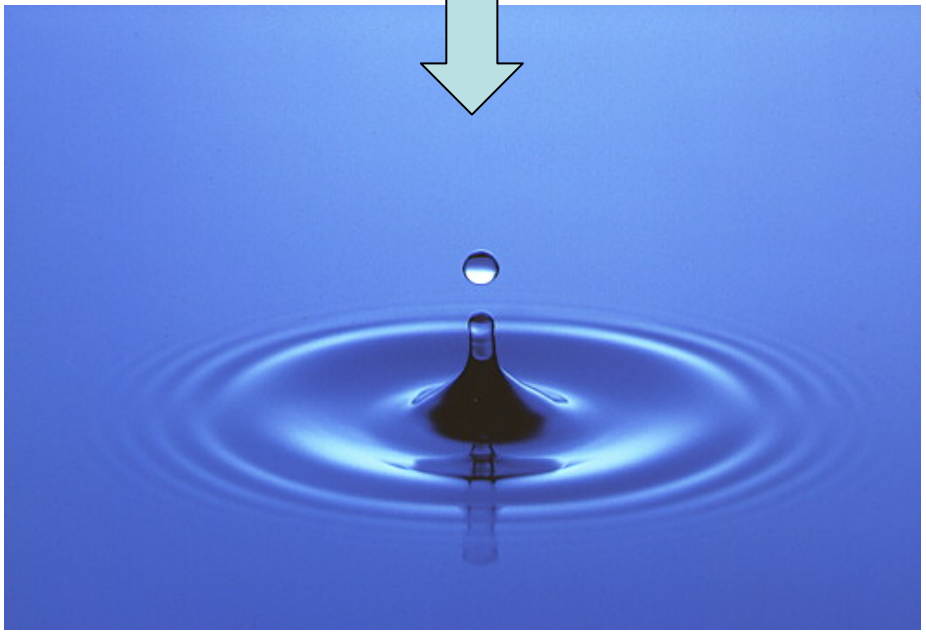
Temperature and symmetry in the universe



The Idea

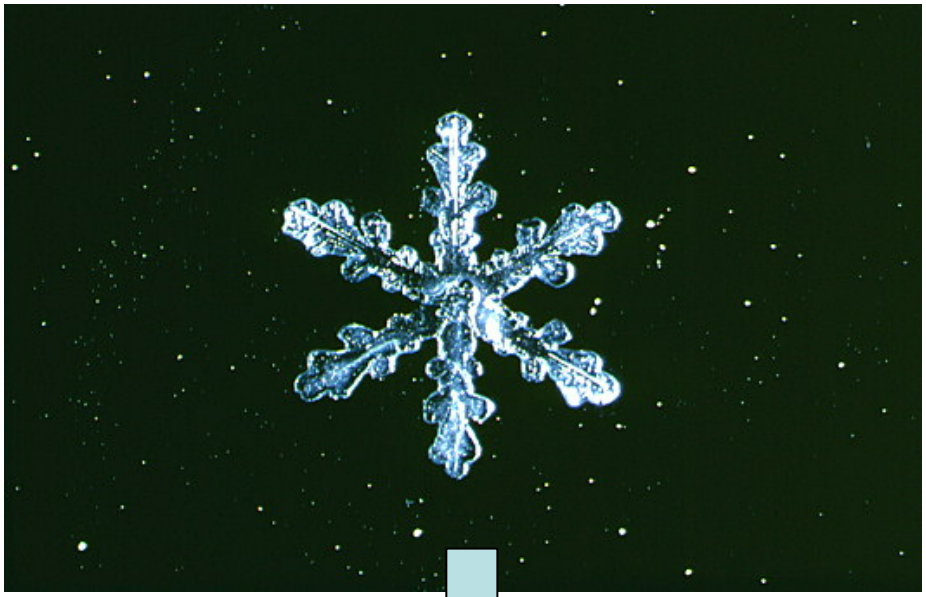
(I will tell you when to be cautious about inhaling)

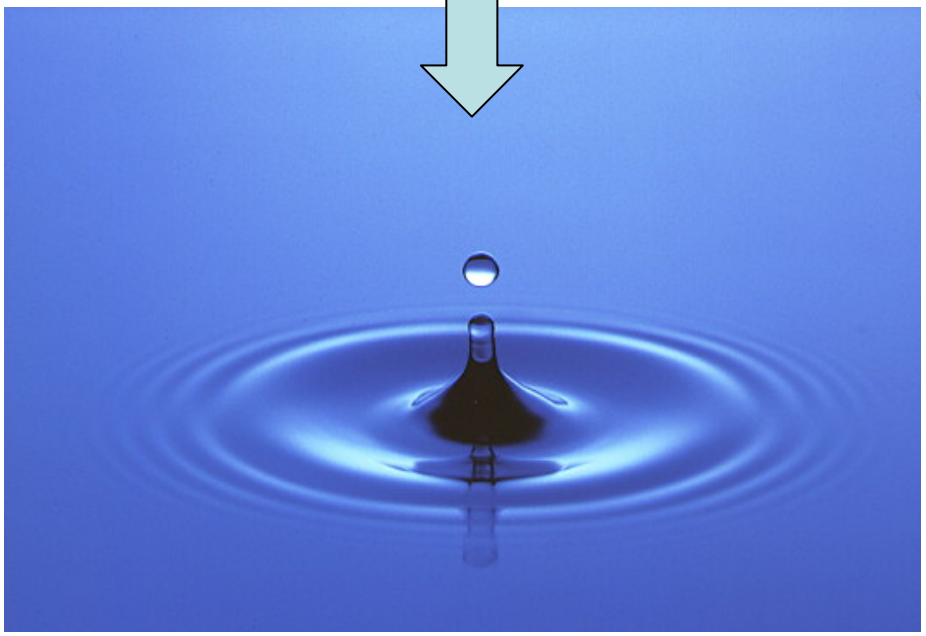




patterns and structures when cold (low energy)

Symmetry when warm (high energy)





FORCES 1955-2005

COLD

Electromagnetic
Weak
Strong

WARM

ElectroWeak
Strong (QCD)

HOT

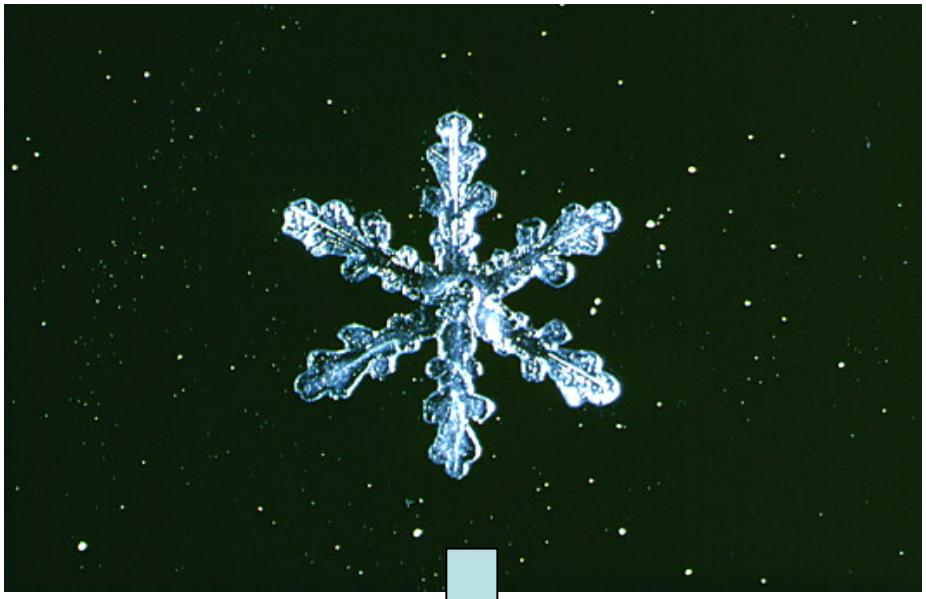
GrandUnified
Force

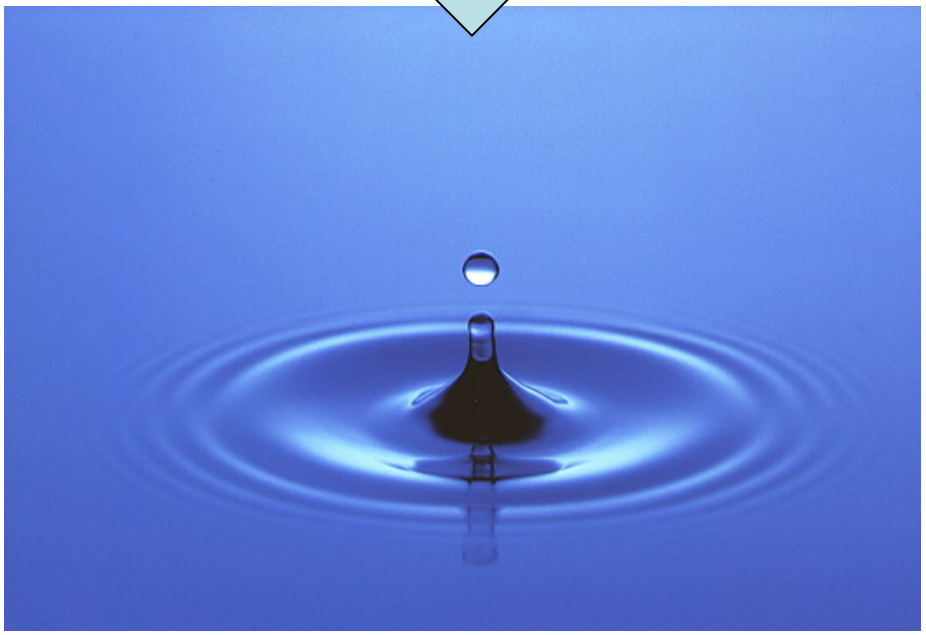
Standard Model of **Quarks Leptons and forces**

= pattern based on **mass**

“cold” =“low” energy

= **below 1 TeV**





Standard Model of **Quarks Leptons and forces**

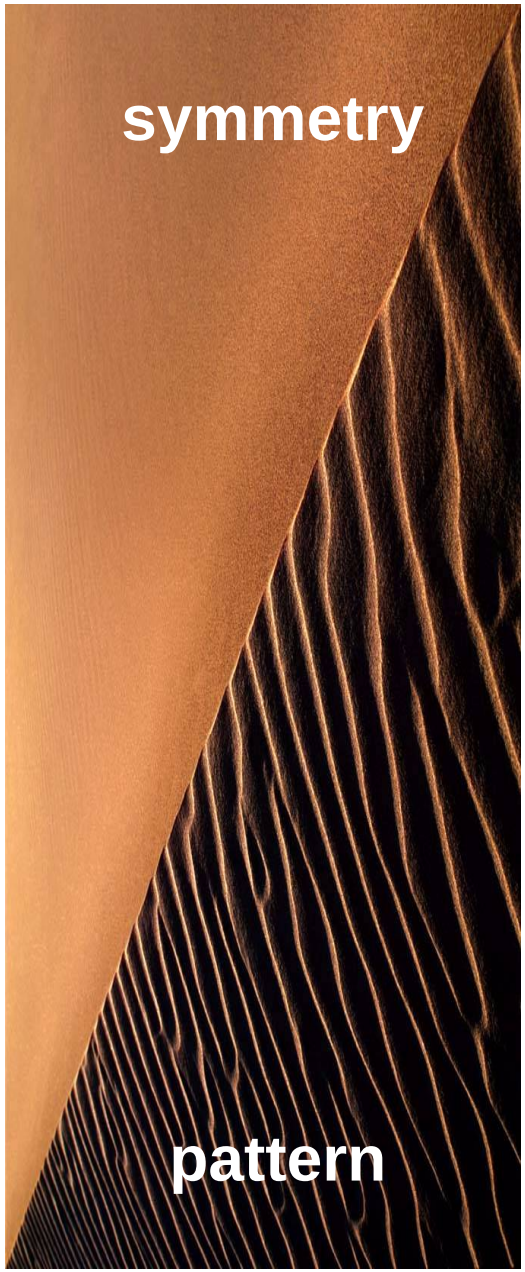
= pattern based on **mass**

“cold” =“low” energy

= **below 1 TeV**

super**Symmetry**
when **“warm”**
(= high energy **> 1TeV)**

Higgs Boson
Supersymmetry
Nature of Reality



even earlier univ.

LHC

LEP

To BIG BANG

early univ.

$< 10^{-9}$ sec.

TeV 10^{16}K

GeV

MeV

100 sec.

KeV 10^{7}K

eV 10^{4}K

300 K yrs.

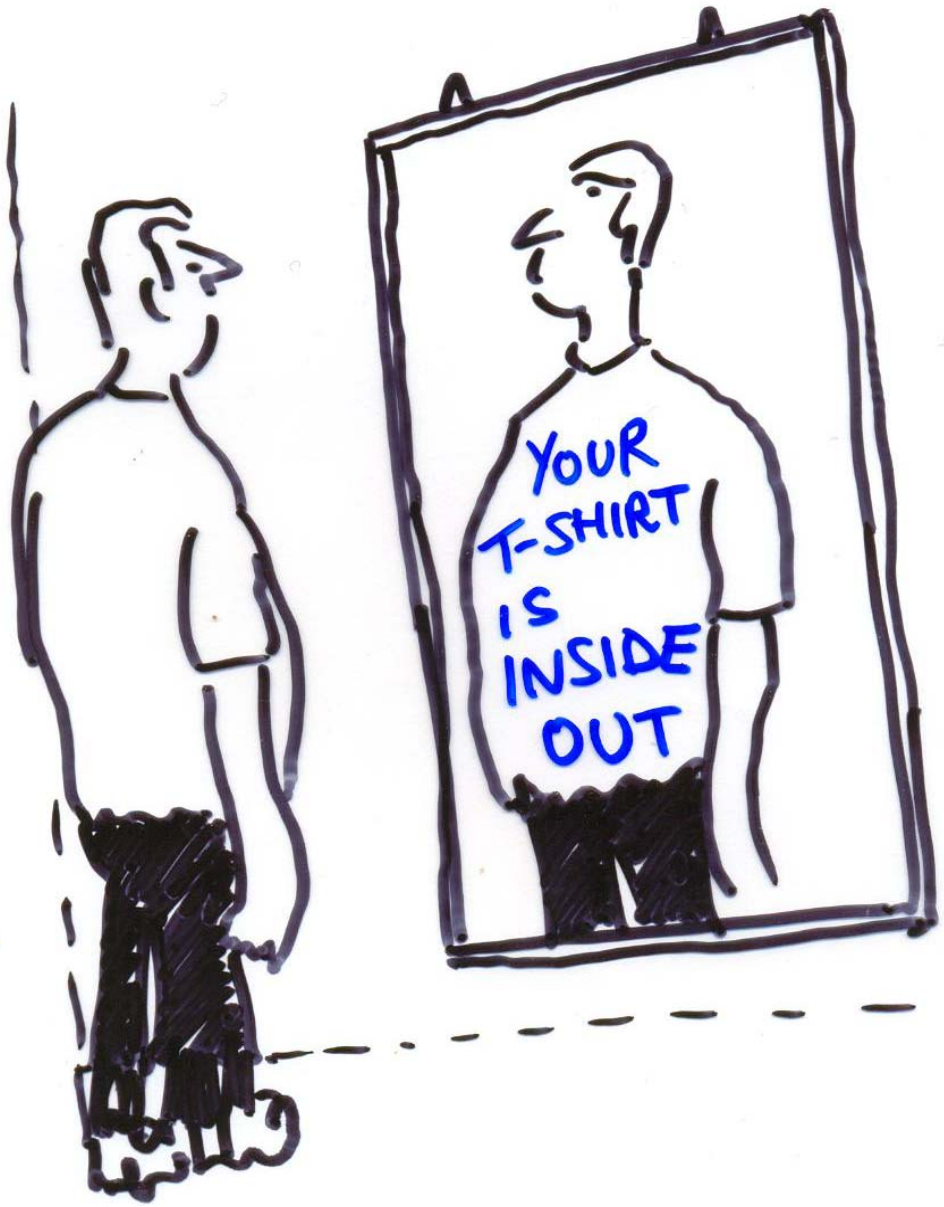
300K

meV

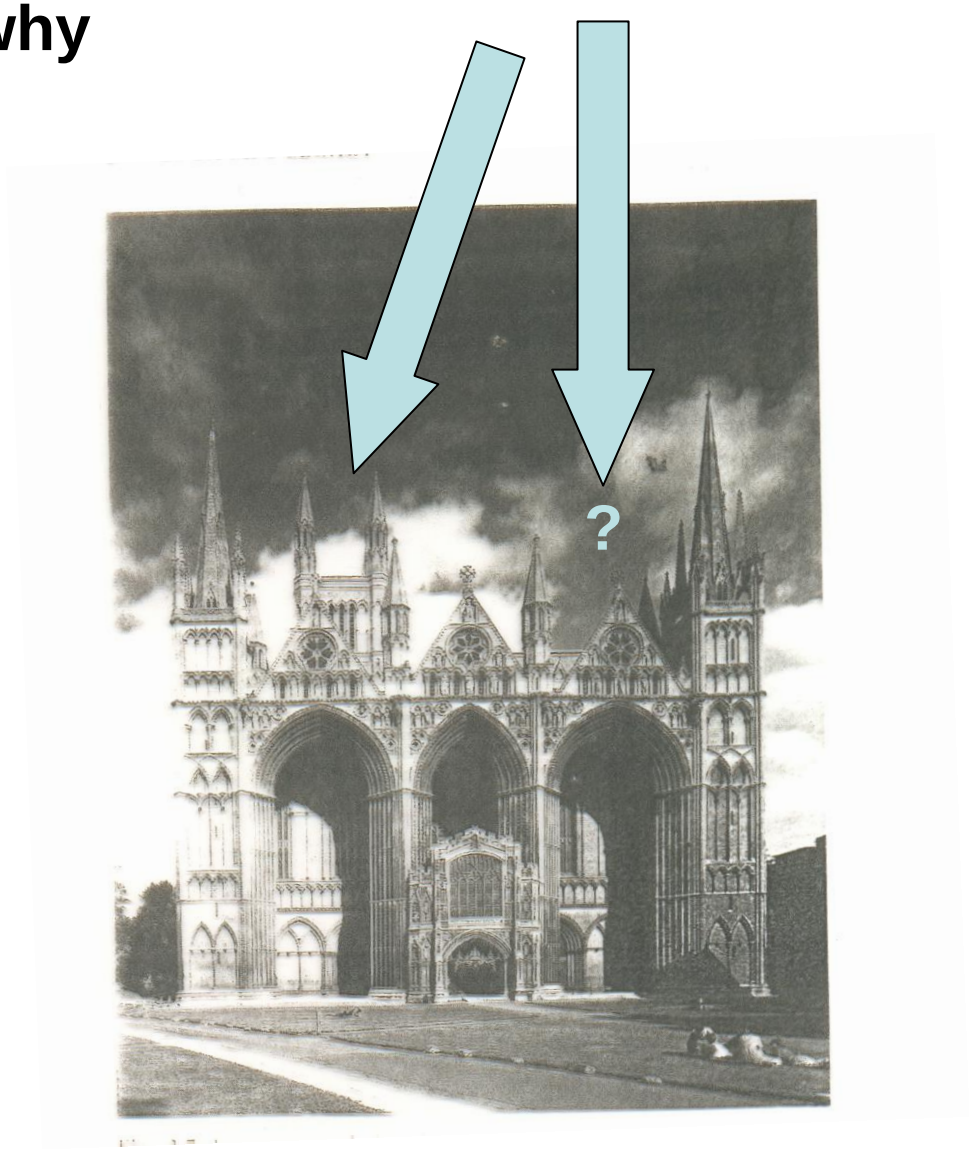
3K

10^{10} yrs

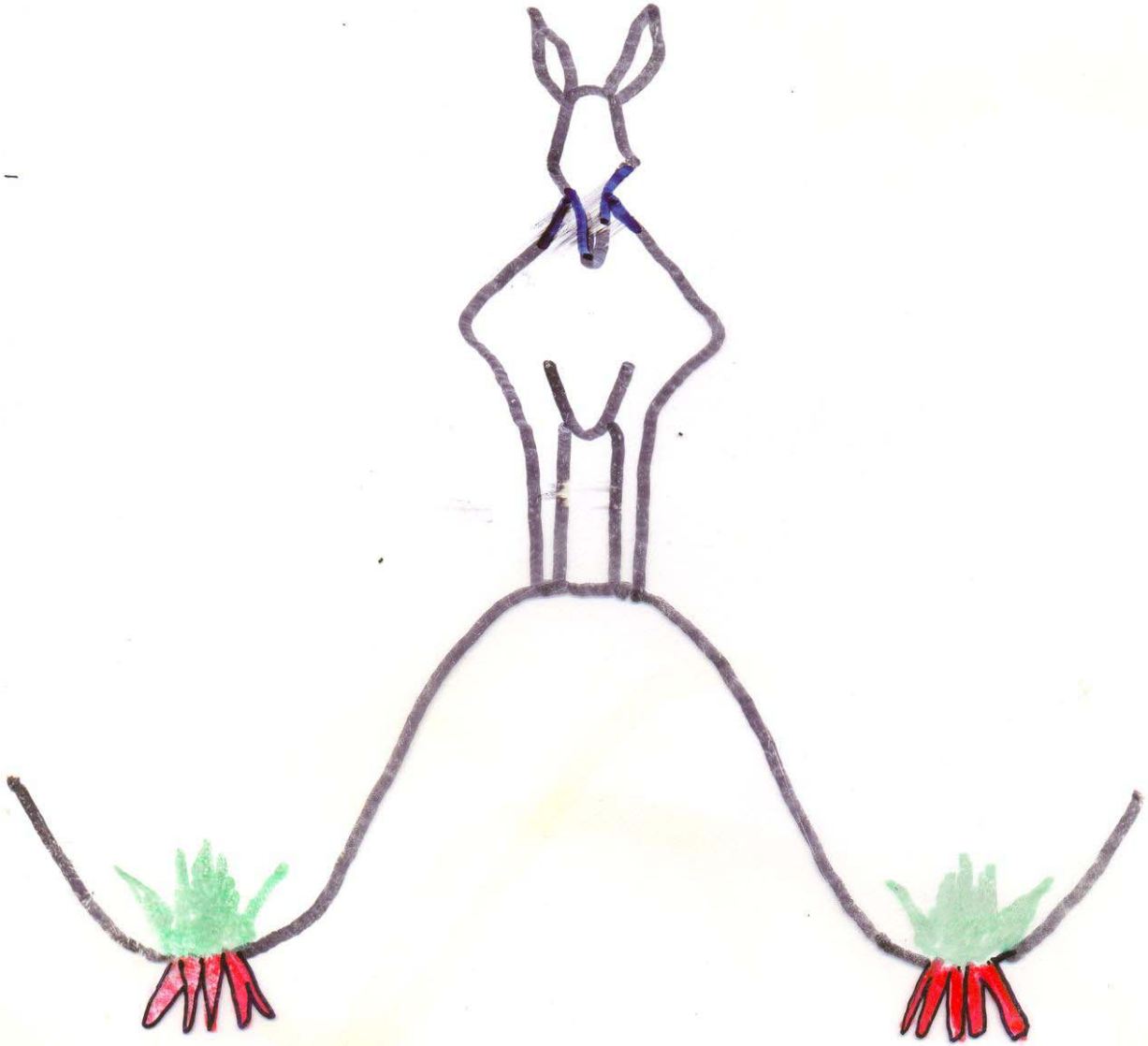
5. symmetries can disappear or change



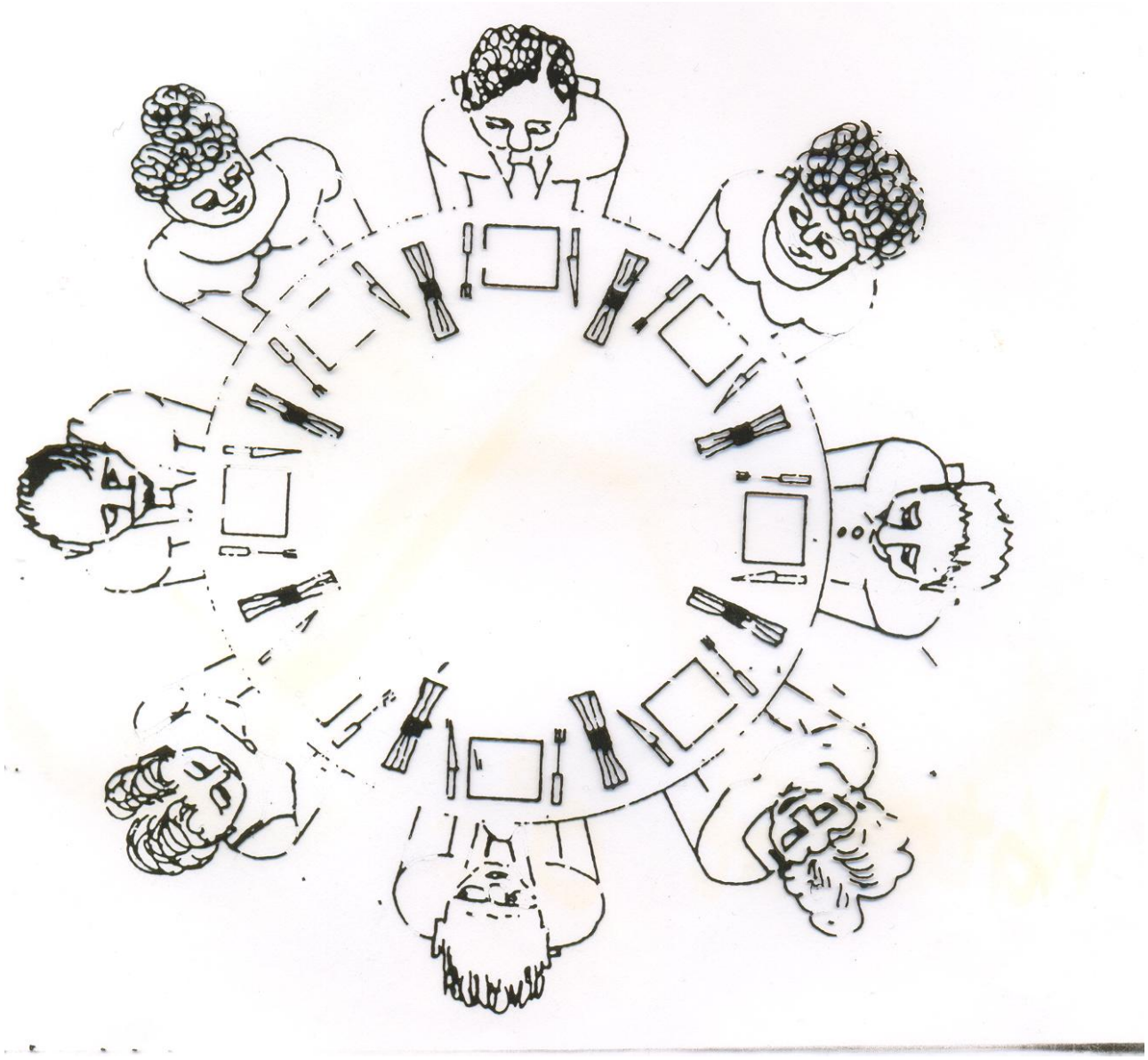
We like symmetry and when its absent we want to know why

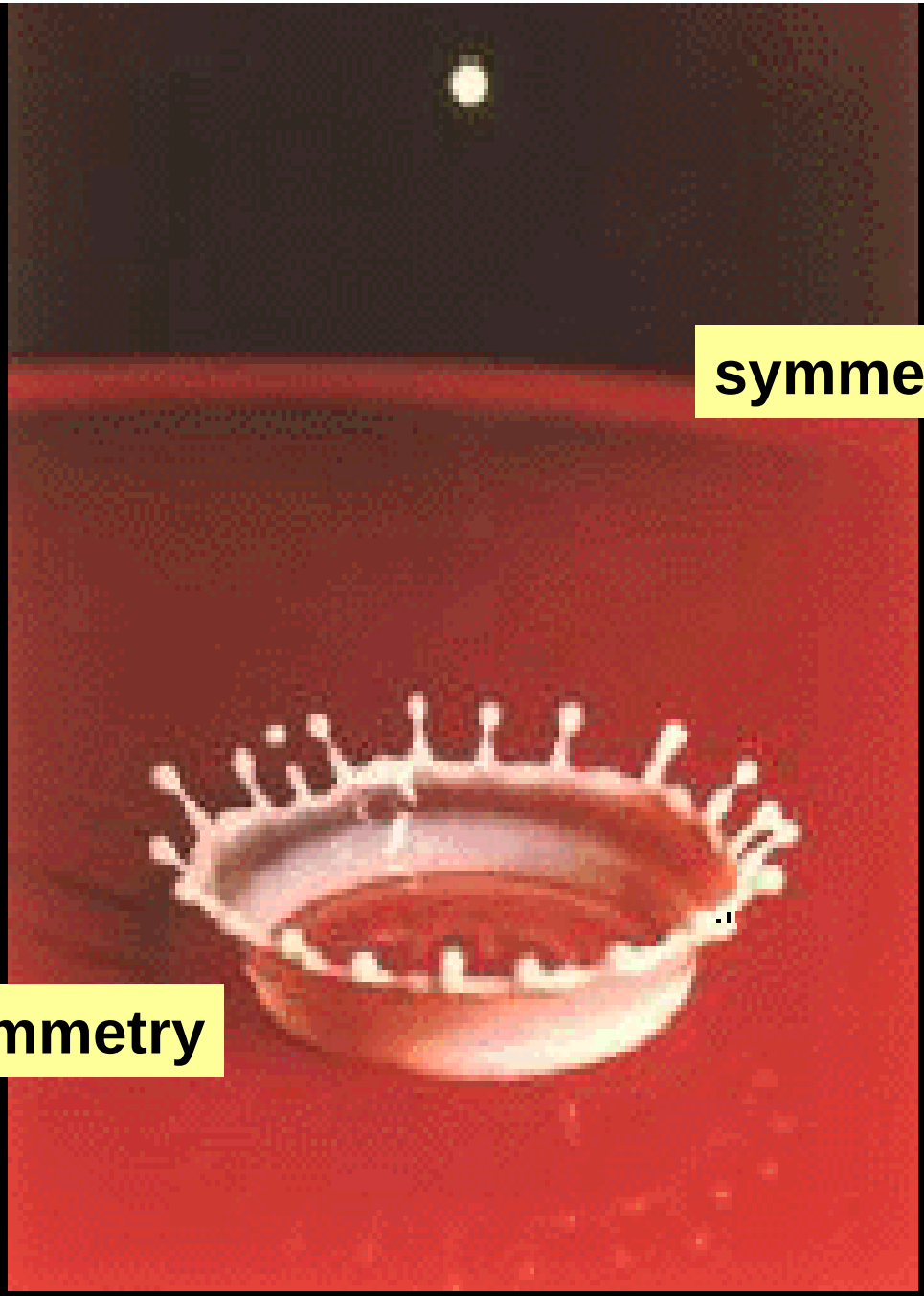


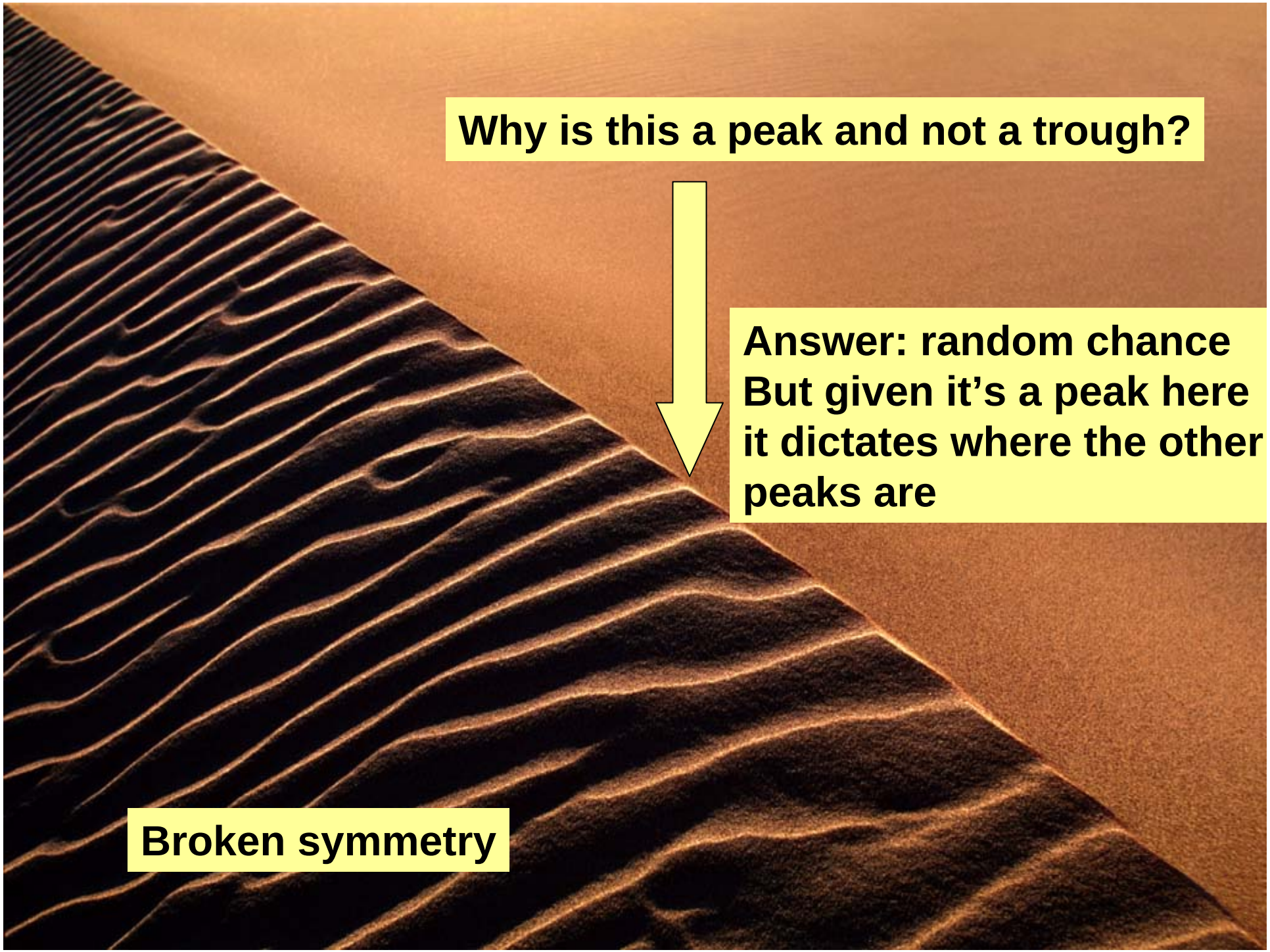
Buridan's Ass



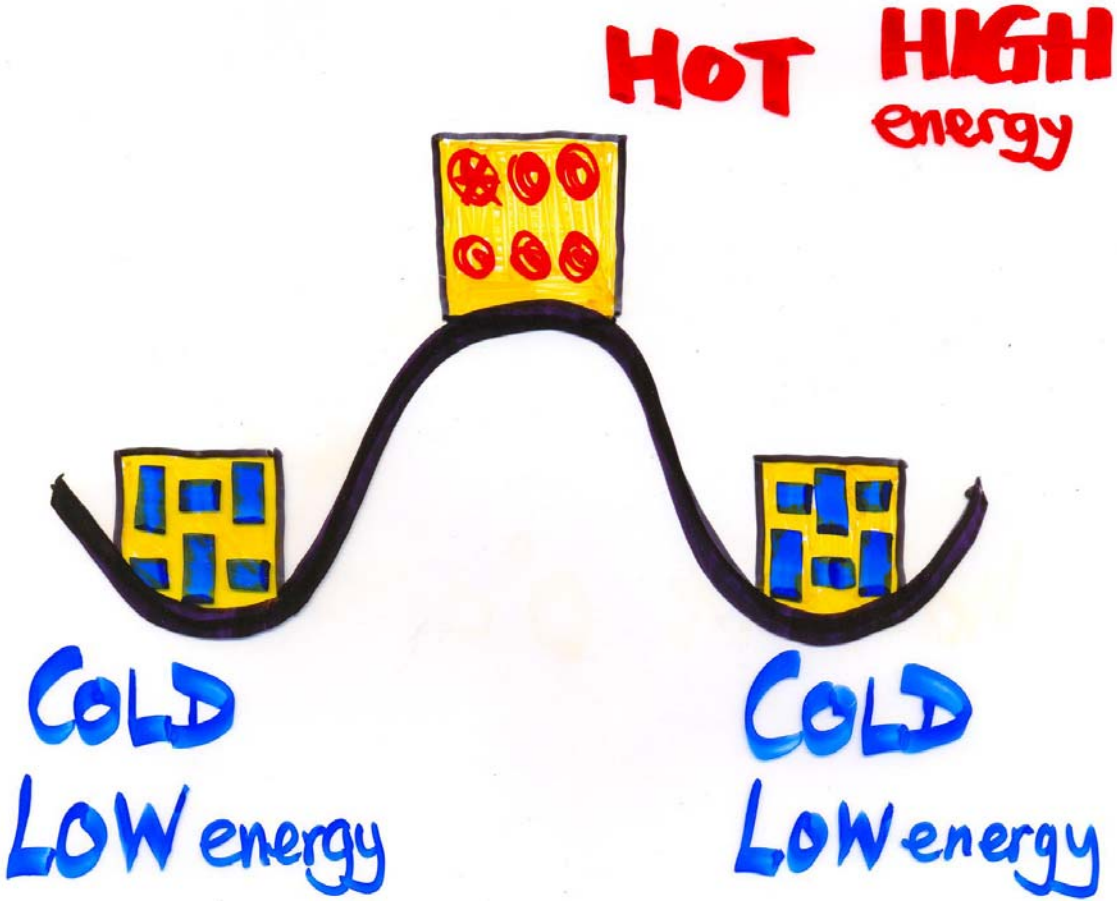
The problem of the symmetric dinner party

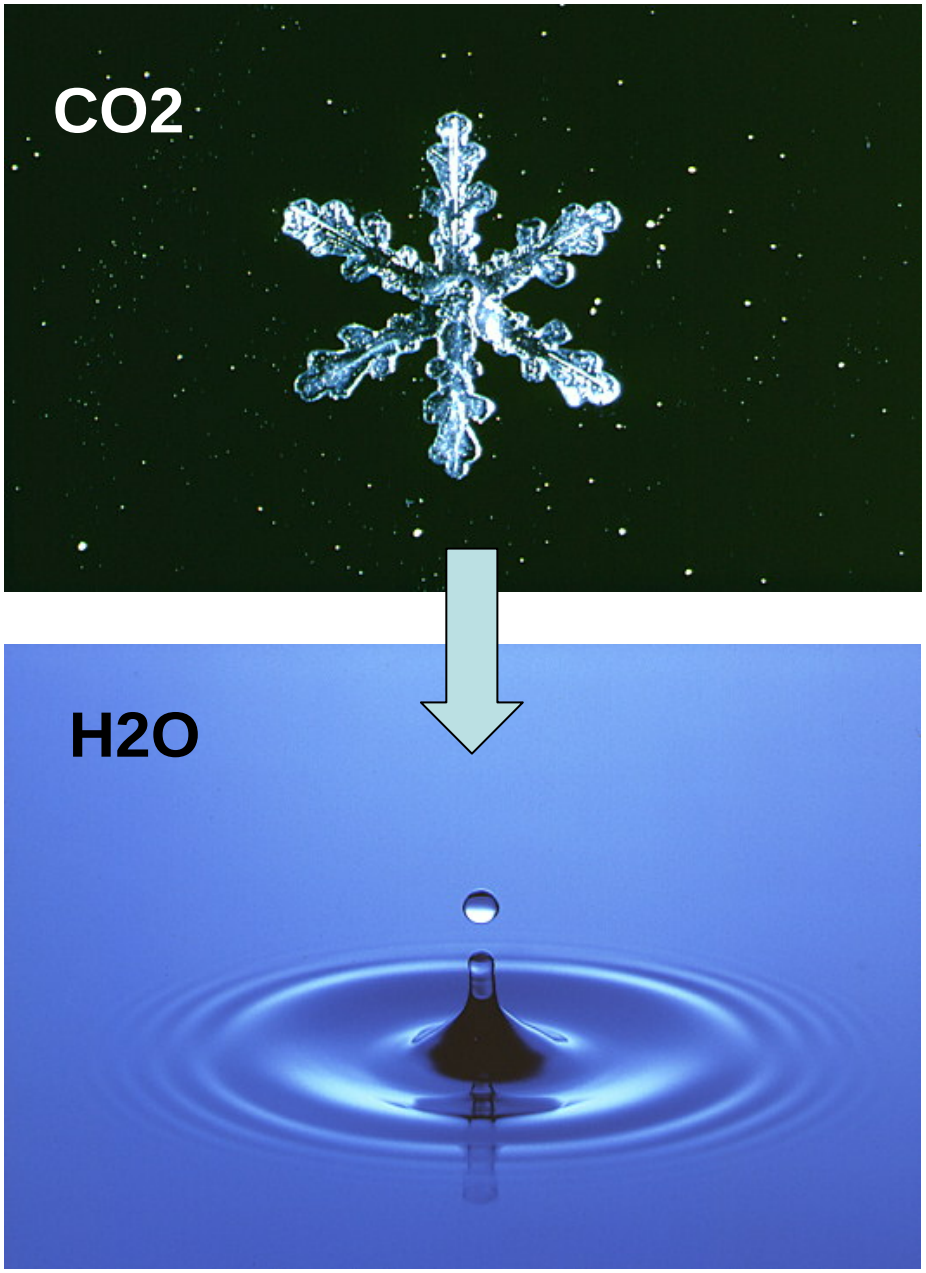



symmetry
Broken symmetry


Why is this a peak and not a trough?
Answer: random chance
But given it’s a peak here
it dictates where the other
peaks are
Broken symmetry

Magnets





patterns
and structures
when cold
(low energy)

Symmetry
when warm
(high
energy)

As the universe cooled after the hot big bang…..
We think that an elegant symmetry……..

… "froze" into structures …. And patterns

Such as Atoms ……. Mendeleev's periodic table,
And particles …. Quarks, forces and the Standard Model

… which is a pattern based on MASS

2008: heat up to energies above 1000 GeV = "1 TeV"
and discover the origin of MASS (= Higgs?)

No mass. Unified Theory

Next year

Standard Model MASS

t	b	τ	ν	W
c	s	μ	ν	Z
u	d	e	ν	γ_g

Nuclear Isotopes

Mendeleev

Snowflake pattern

TeV 10^{16}K

GeV

MeV

KeV 10^{7}K

eV 10^{4}K

300K

meV

3K

even earlier univ.

LHC

LEP

early univ. $< 10^{-9}$ sec

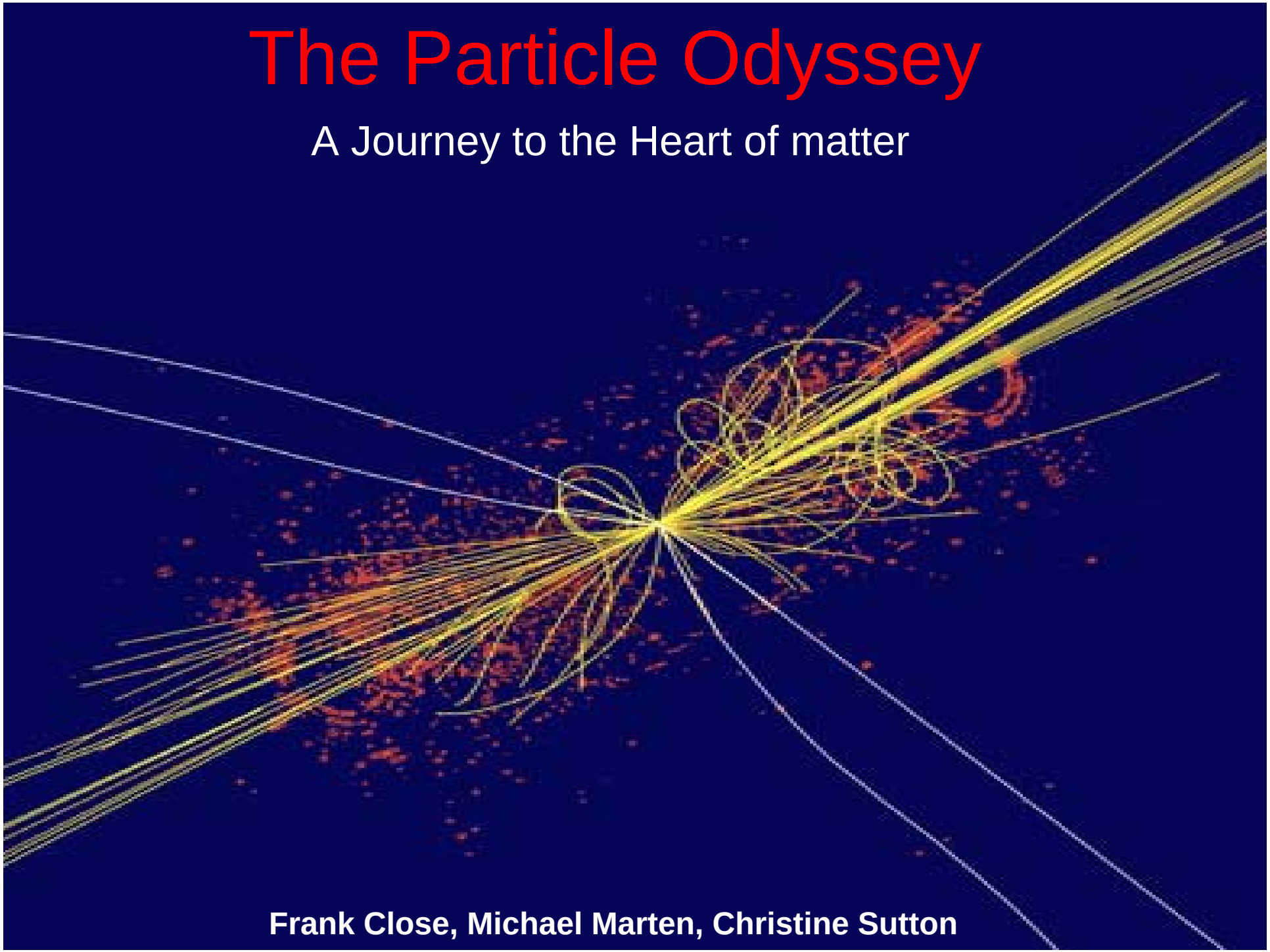
100 sec.

300 K yrs

10^{10} yrs

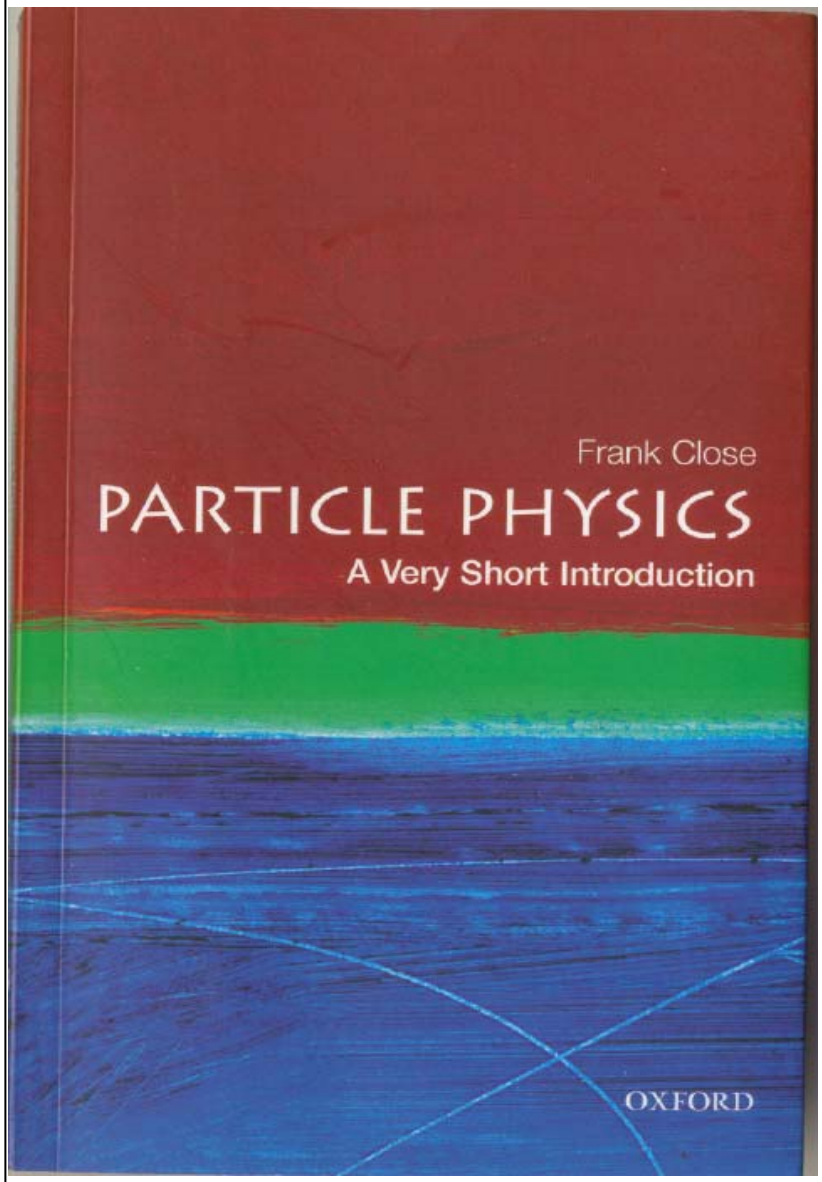
The Particle Odyssey

A Journey to the Heart of matter

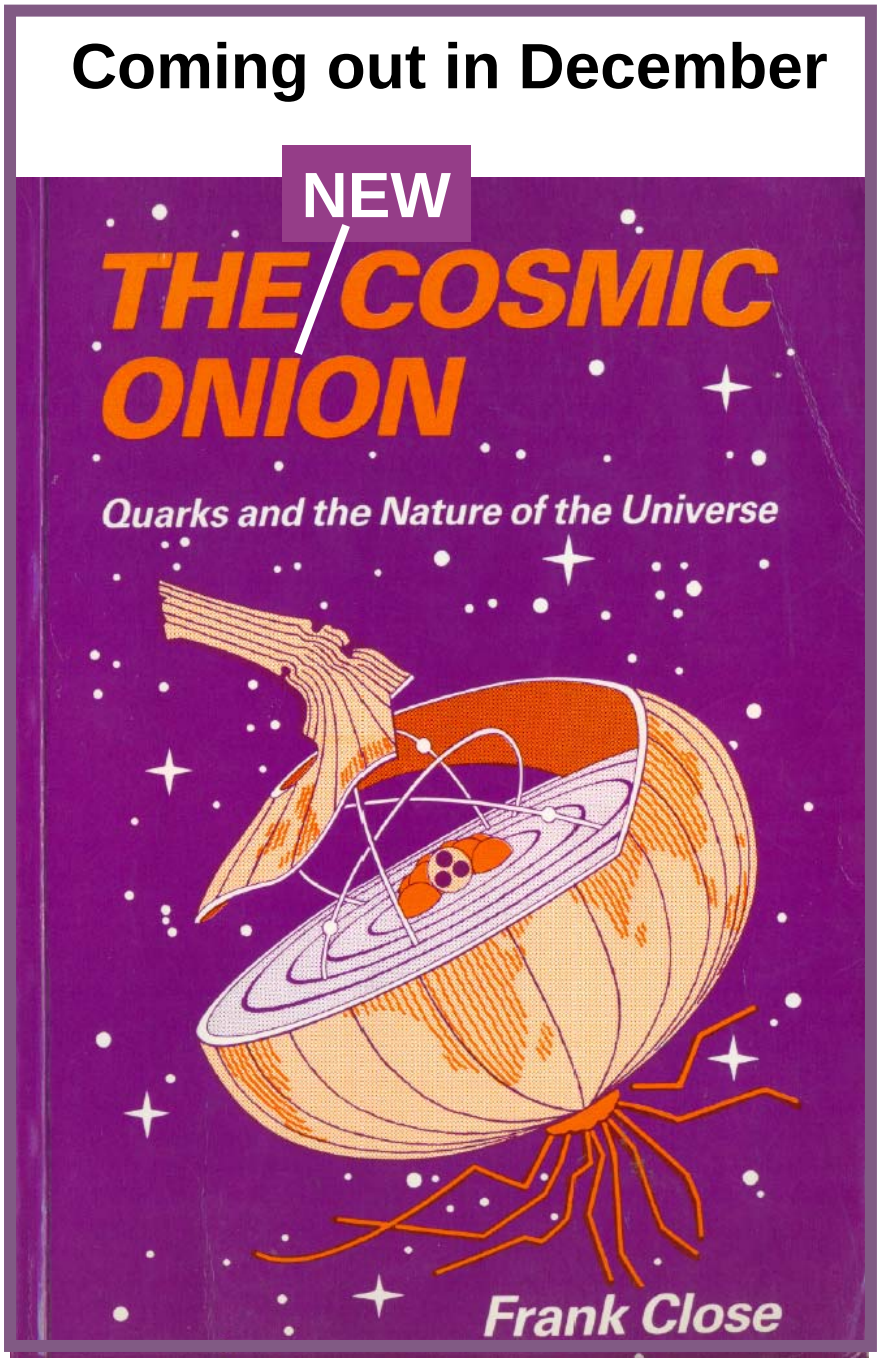


Frank Close, Michael Marten, Christine Sutton

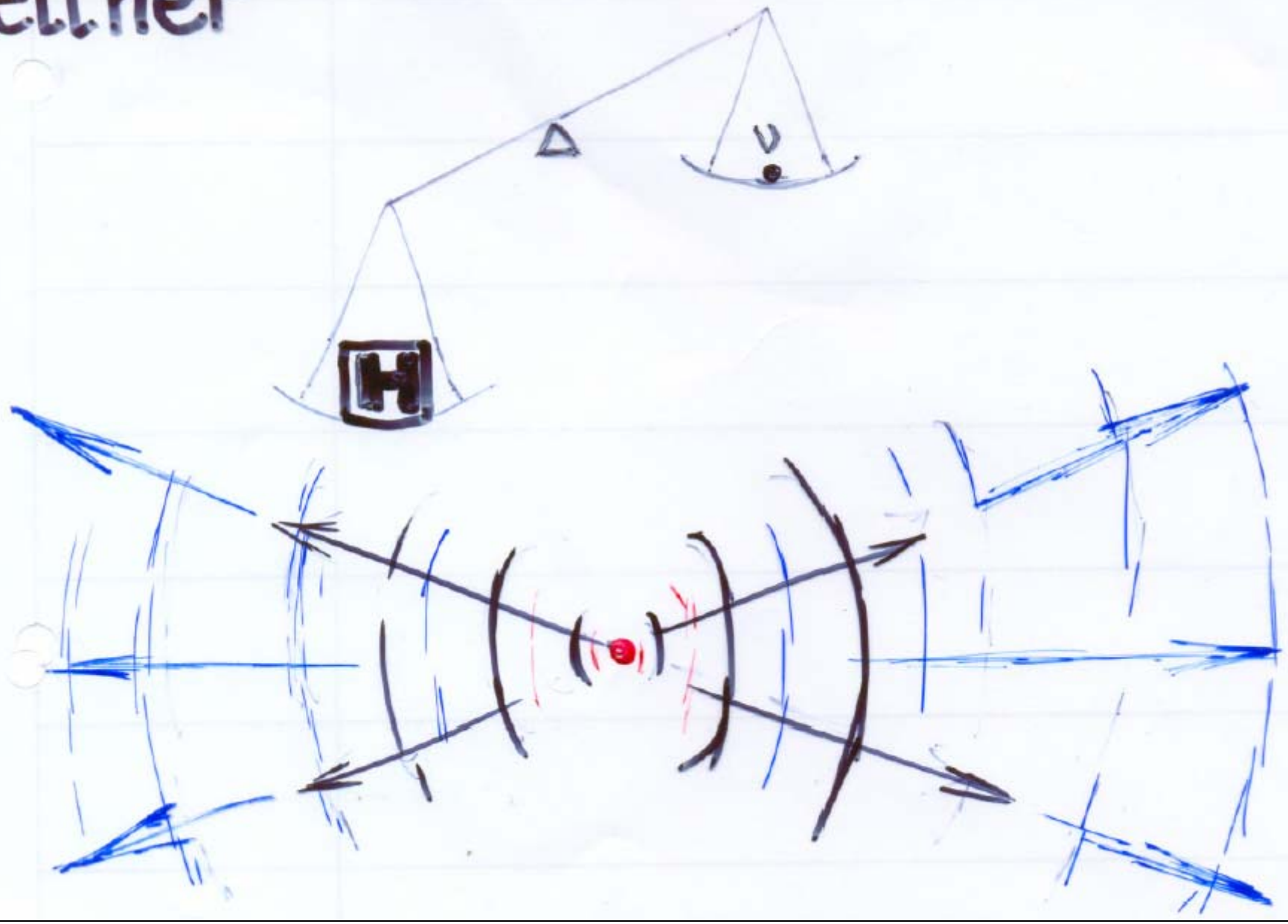
A Very Short Introduction

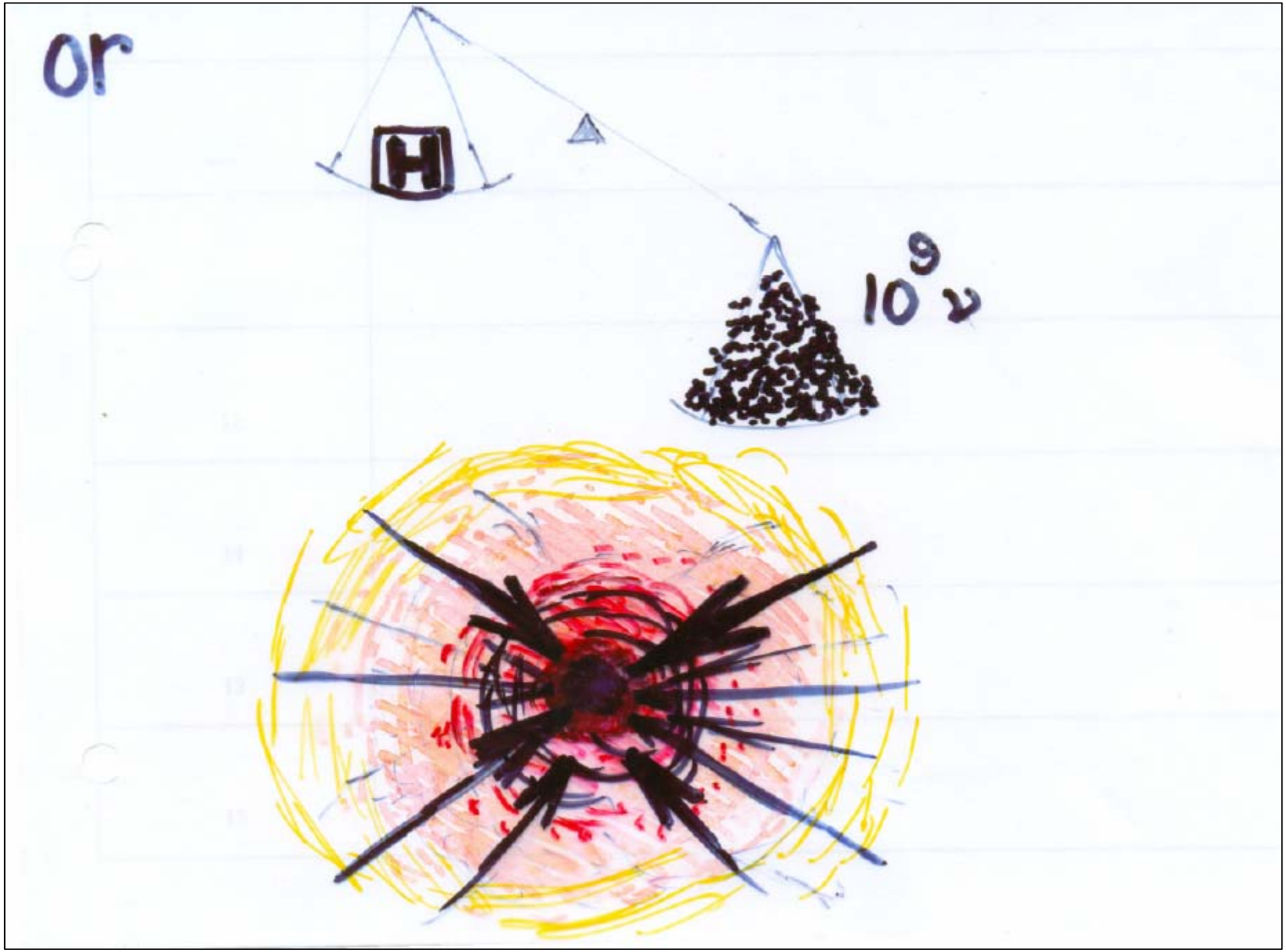


Coming out in December



either




or
H
10^9 ν