



Introduction to Particle Physics

(for non physics students)



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Angels and Demons is fiction.

What are the facts?

Angels and Demons is fiction.

What are the facts?



ANTI-MATTER
FRANK CLOSE

How Old is the Universe?



20.00) Creation Big Bang



eat; drink; sleep



05.00 SUN → EARTH 06.00



breakfast; come to lectures



09.30 Oldest Fossils

09.59;30" First Humanoids



09.59 -   The Millenium

10.00 NOW



TeV 10^{16} K

LHC

LEP



even earlier univ.



early univ.

$< 10^{-9}$ sec.

MeV

100 sec.

KeV 10^7 K



eV 10^4 K

300 K yrs.

300K



meV

3K



Next
....



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.



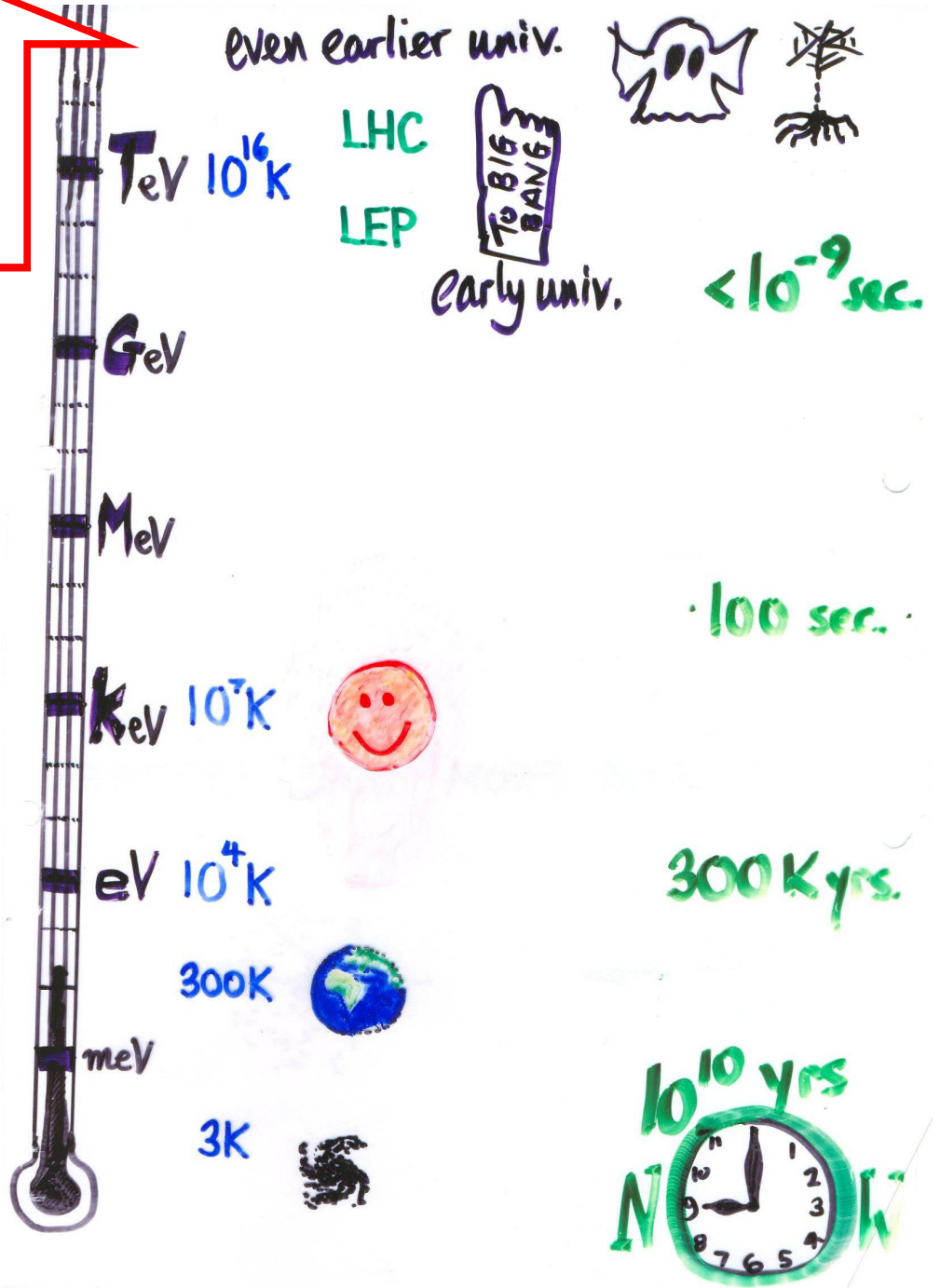
300K yrs.

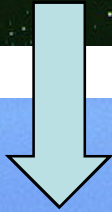
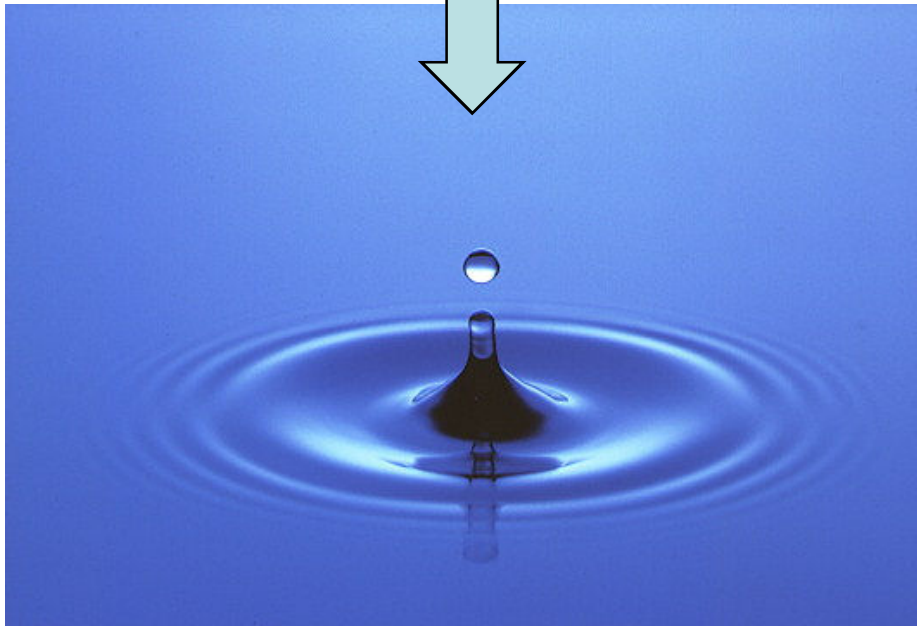
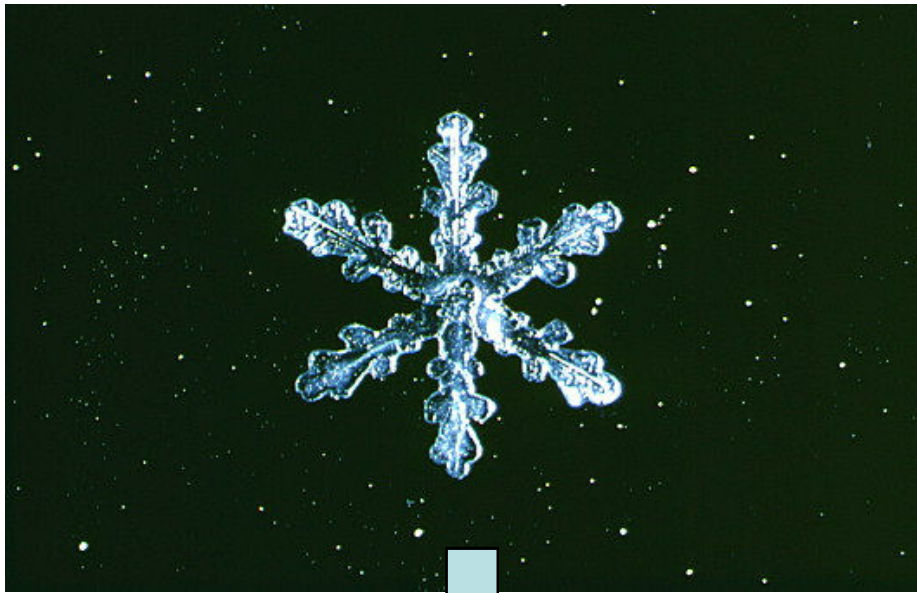




Next

....





**patterns
and structures
when cold
(low energy)**



**Symmetry
when warm
(high
energy)**

MATTER

ANTIMATTER

**...why didn't it mutually destruct?
...why is there anything left?**

Matter and the Universe

Physique des Particules

Cosmologie

Physique Nucleaire

Astrophysique

Physique du Solide

Astronomie

Chimie-Biologie

Geophysique

Mecanique



10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 1 10^3 10^6 10^9 10^{12} 10^{15} 10^{18} 10^{21} 10^{24}



fm pm nm μ m mm m km Mm Gm Tm Pm Em



← > 40 orders of magnitude →

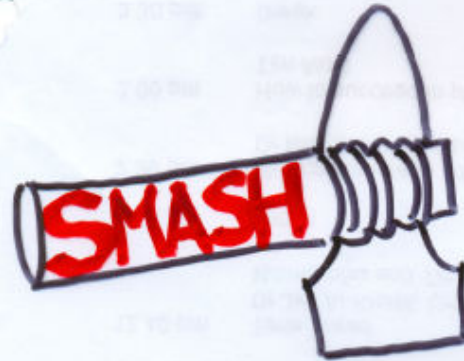
**What
is matter
made of ?**

How to learn what things are made of

LOOK



SMASH



HEAT

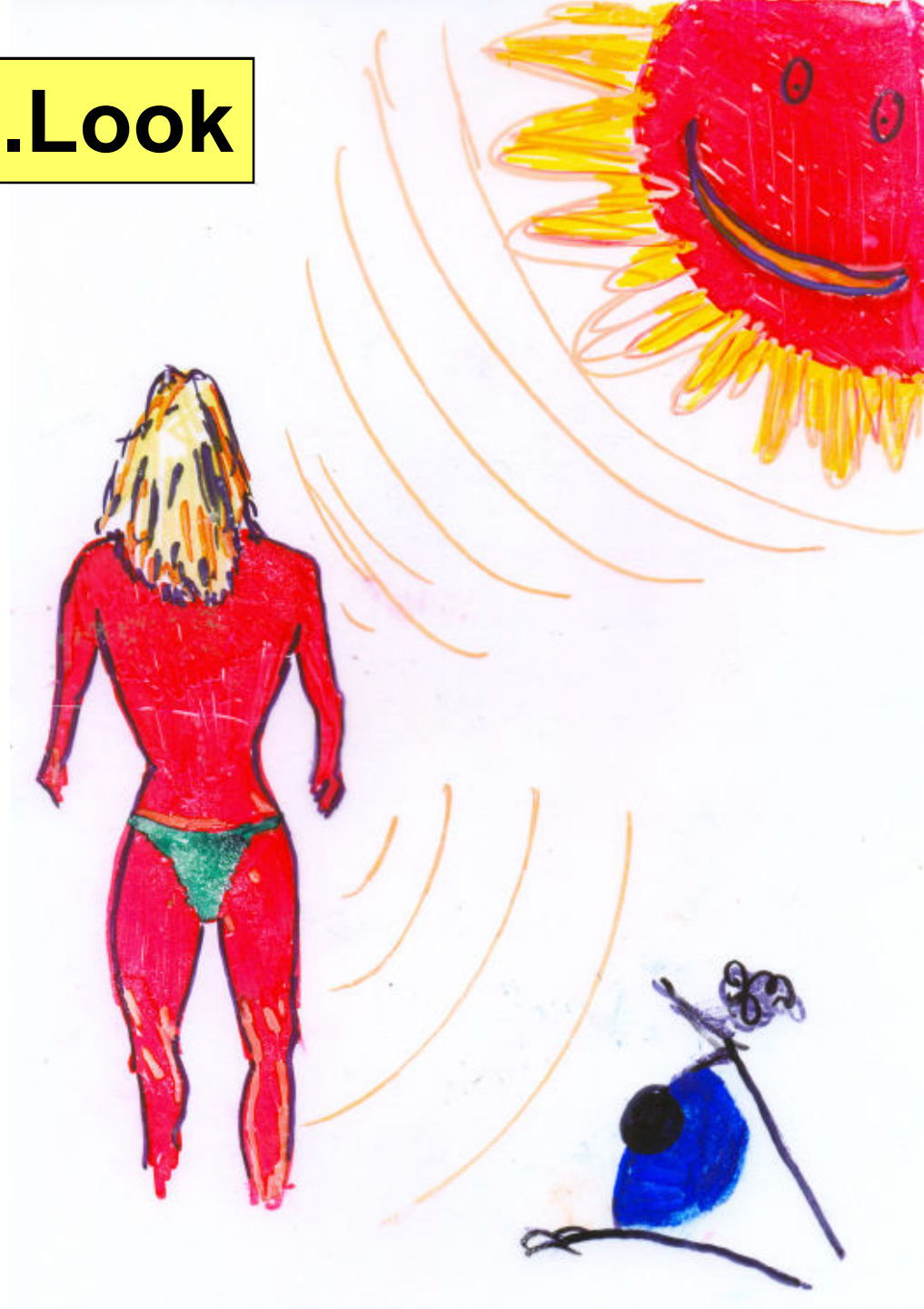


1.Look

Light source

Object

Eye



1.Look

Light source

Object

Eye



Catch 22:

There's a limit to what we can see with our eye

Beyond (normal) vision

	m
Eye Limit	10^{-4}
Bacteria	10^{-5}
Wavelength of Light	10^{-6-7}
Atom	10^{-10}
Nucleus	10^{-14-15}
Quarks and Electrons	10^{-18}
.	
.	
.	
Planck Length $\sqrt{\frac{Gh}{c^3}}$	10^{-35}

Catch 22:

There's a limit to what we can see with our eye

To look at smaller things we need to use instruments that can "extend" our vision

Beyond (normal) vision

	m
Eye Limit	10^{-4}
Bacteria	10^{-5}
Wavelength of Light	10^{-6-7}
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Nucleus	10^{-14-15}
Quarks and Electrons	10^{-18}
.	
.	
.	
Planck Length $\sqrt{\frac{Gh}{c^3}}$	10^{-35}

How to learn what things are made of



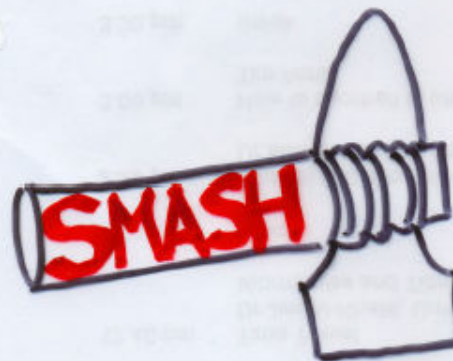
The problem is the wavelength of light compared with the size of what you're trying to look at



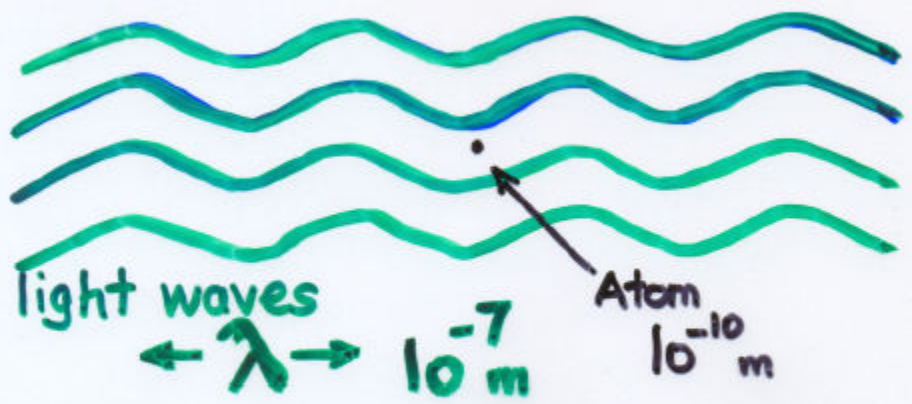
How to learn what things are made of



resolution
Wave λ length

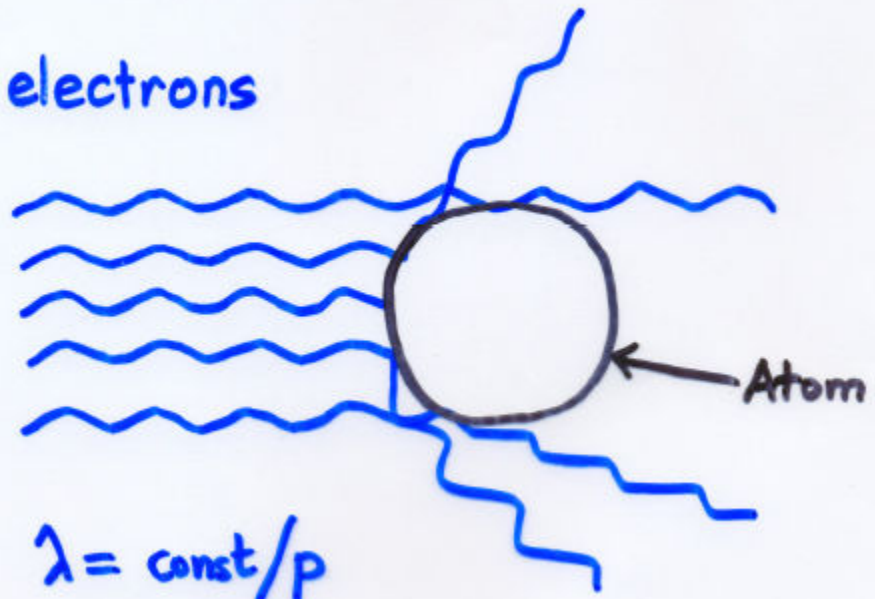


How to see small things



Electron microscope

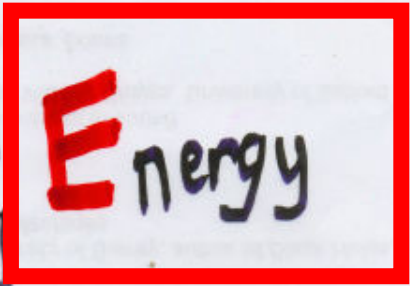
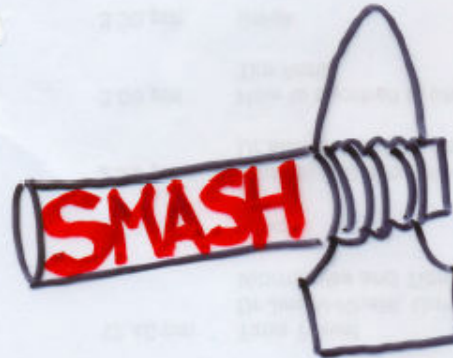
electrons



How to learn what things are made of



resolution
Wave λ length



Temperature

2. Smash

...some definitions
for **ENERGY**.

Joules are too big
for particle energies....

and

0.000000000000000000000001
Joules is too messy....

So we need more
Practical Units

eV, keV, MeV, GeV
and welcome to **TeV**

...some definitions
for **ENERGY**

Joules are too big
for particle energies....

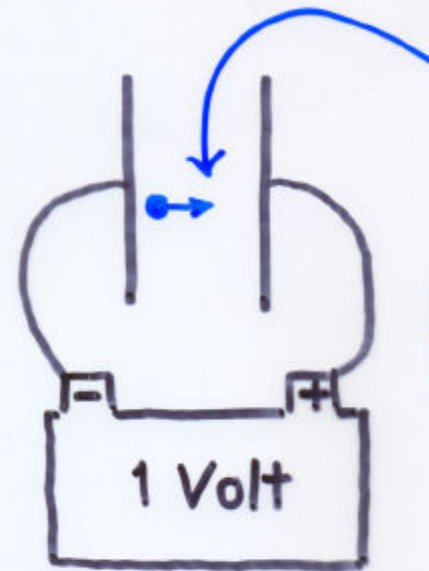
and

0.000000000000000000000001
Joules is too messy....

So we need more
Practical Units

eV, keV, MeV, GeV
and welcome to TeV

Practical Units



electron
(energy **E**)

$$\begin{aligned} E &= 1 \text{ eV} \\ &= 1.6 \times 10^{-19} \text{ J} \end{aligned}$$

$$1 \text{ keV} = 10^3 \text{ eV}$$

$$1 \text{ MeV} = 10^6 \text{ eV}$$

$$1 \text{ GeV} = 10^9 \text{ eV}$$

$$1 \text{ TeV} = 10^{12} \text{ eV}$$

$$\text{LEP} = 200 \text{ GeV}$$

$$\text{LHC} = 14 \text{ TeV}$$

Einstein

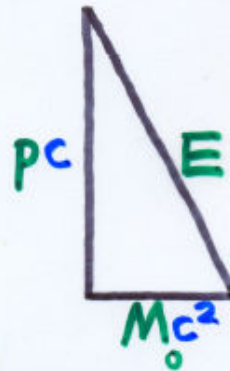
Energy

and

$$E = mc^2$$

Einstein: $E = Mc^2$

Special Relativity



$$E^2 = (pc)^2 + (M_0 c^2)^2$$

use units such that $c=1$

$$\begin{aligned} E & \text{ (GeV or MeV)} \\ P & \text{ (GeV/c or MeV/c)} \\ M & \text{ (GeV/c}^2 \text{ or MeV/c}^2) \end{aligned}$$

$$M_{\text{electron}} = 0.5 \text{ MeV/c}^2$$

$$M_{\text{proton}} = 938 \text{ MeV/c}^2 \approx 1 \text{ GeV/c}^2$$

$$M_{\text{top}} = 170 \text{ GeV/c}^2$$

proton diameter = length scale:
 $10^{-15} \text{ m} = 1 \text{ fermi (femtometer)}$

LOOK or SMASH

Wavelength

and

Energy

profoundly related

How to learn what things are made of

LOOK

resolution
wave λ length

$$hc/\lambda$$

$h\nu$

Energy



Temperature

LOOK or SMASH

Wavelength

and

Energy

profoundly related

How to learn what things are made of

LOOK

resolution
Wave λ length

$$hc/\lambda$$

$$10^{-6} \text{ eV m}$$

$$1 \text{ eV} \leftrightarrow 10^{-6} \text{ m}$$

$$h\nu$$

Energy



Temperature

How to learn what things are made of

LOOK ^{resolution} wave λ length

SMASH  Energy

HEAT  Temperature

3. Heat

... also
profoundly
related.....

How to learn what things are made of

LOOK

resolution
Wave λ length

$$hc/\lambda$$

$h\nu$

SMASH

Energy

HEAT

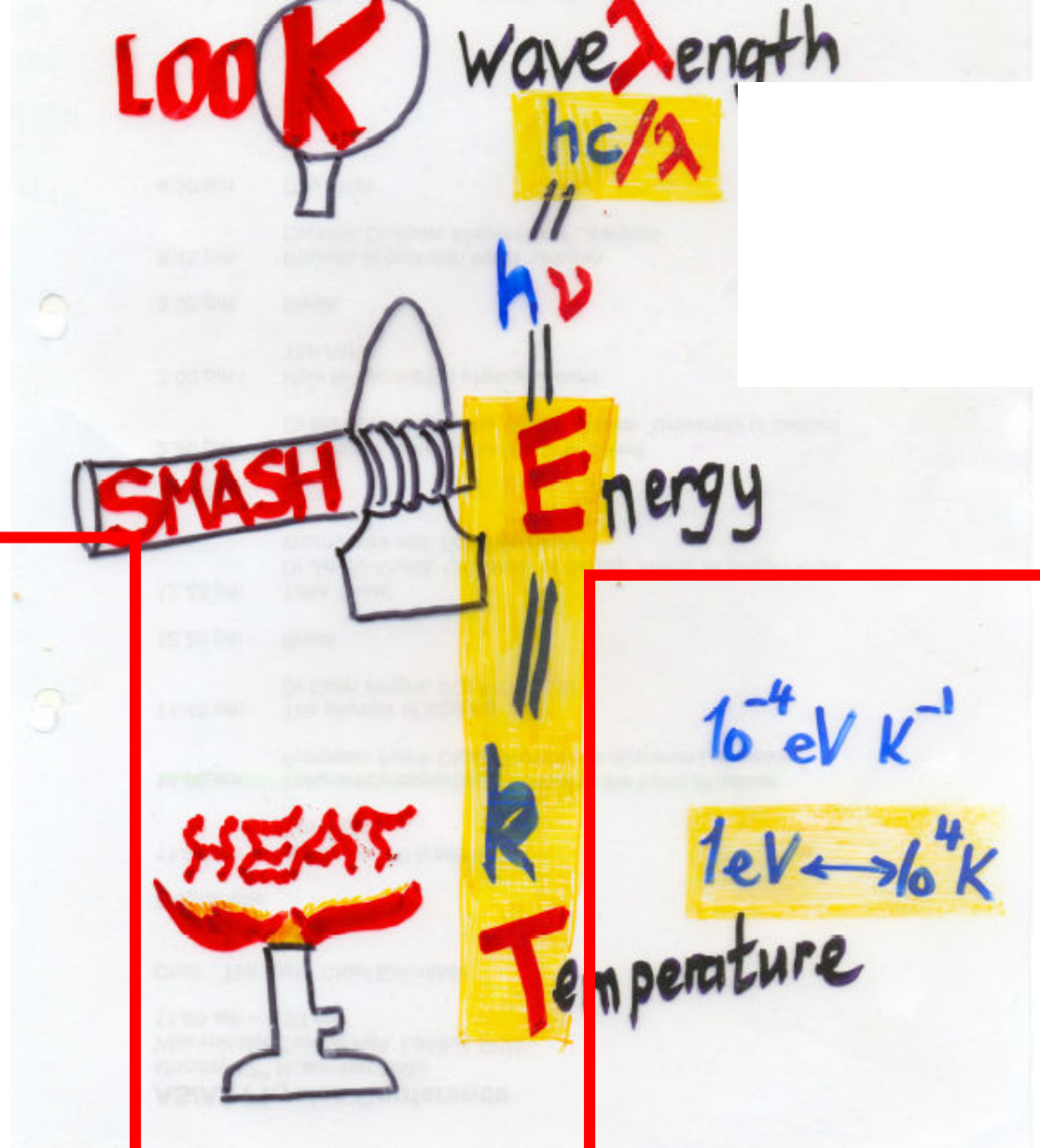
Temperature

SMASH or HEAT

Energy

and

Temperature



SMASH or HEAT

Energy

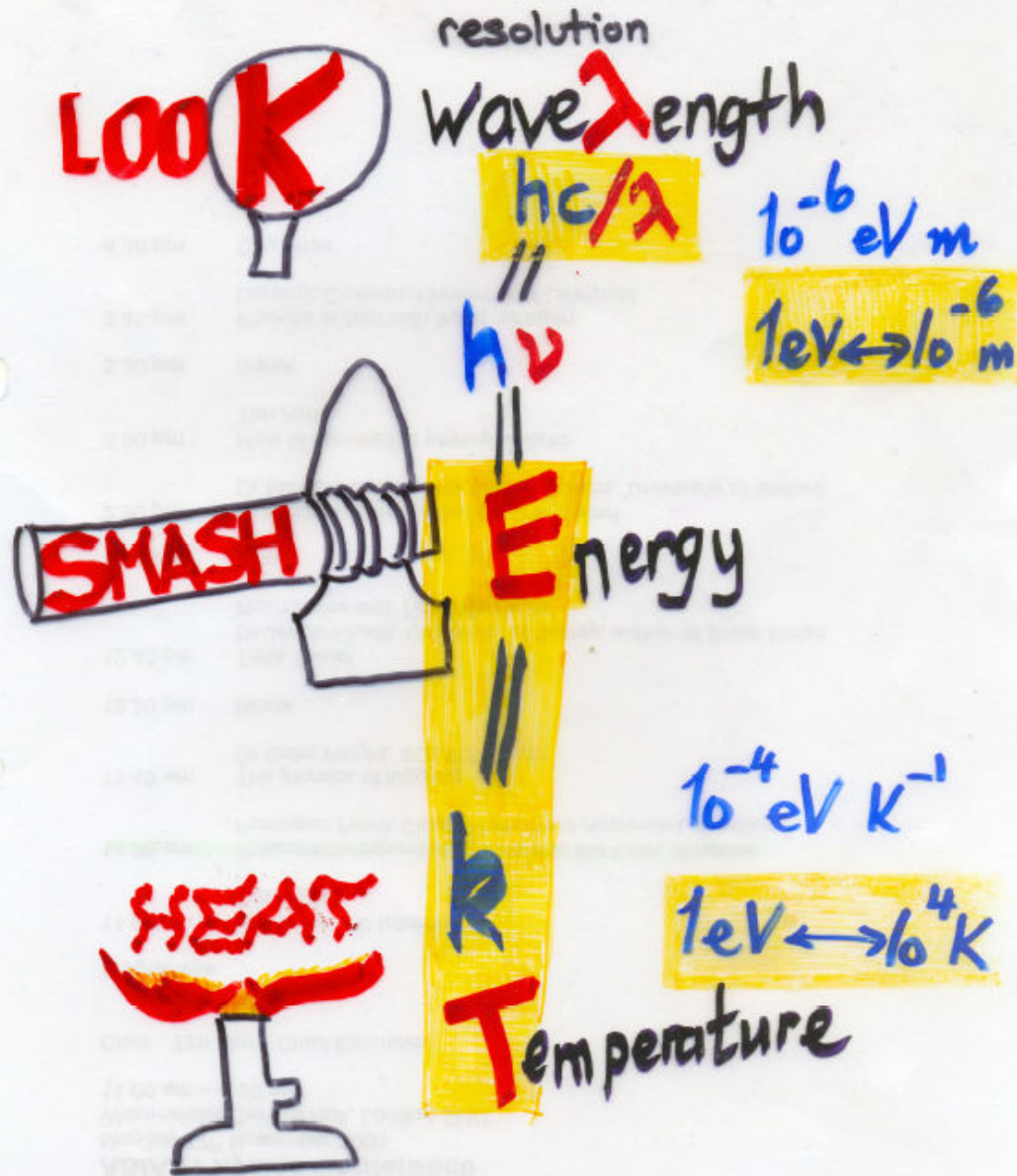
and

Temperature

$10^{-4} \text{ eV K}^{-1}$

$1 \text{ eV} \leftrightarrow 10^4 \text{ K}$

How to learn what things are made of



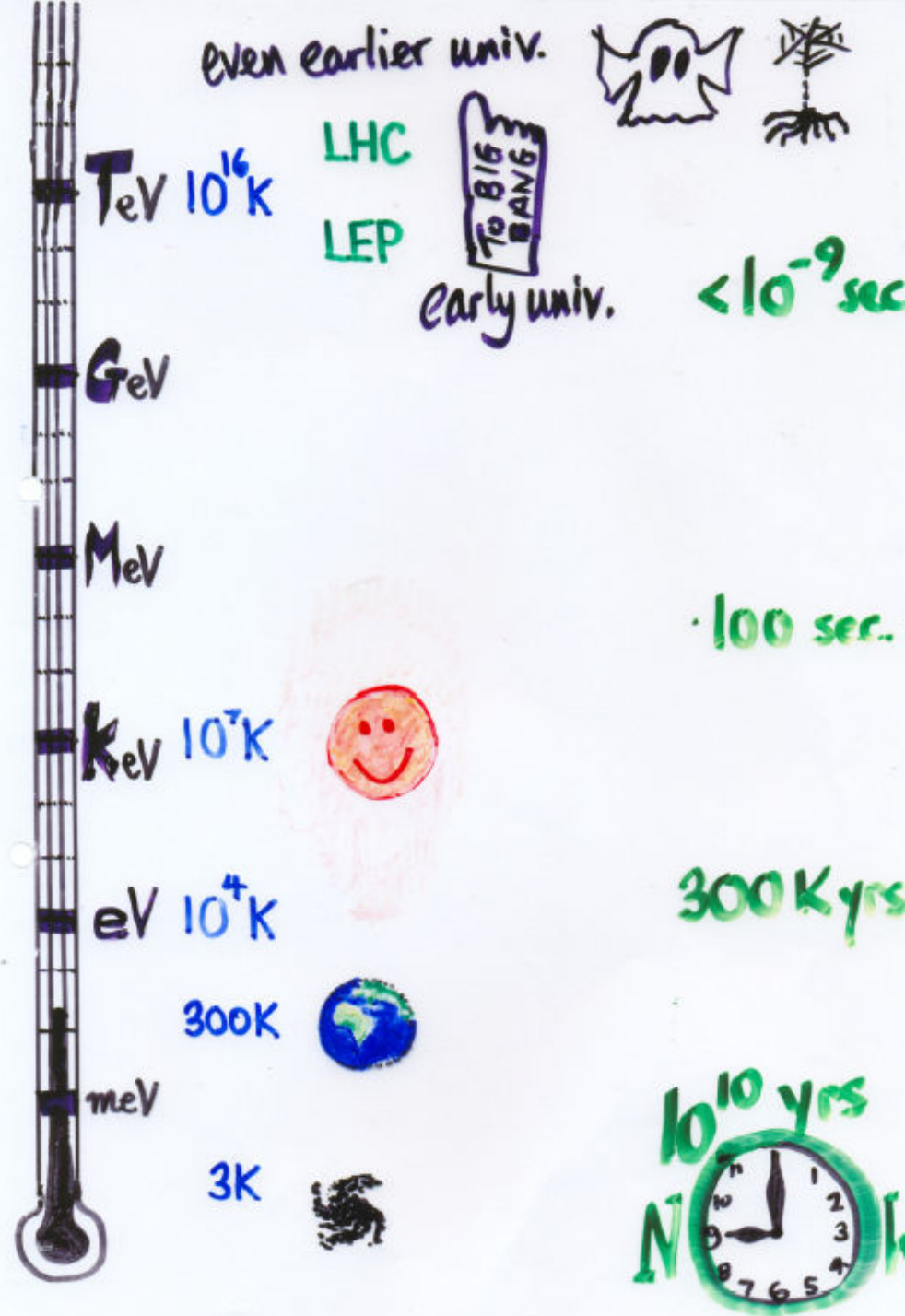
Beyond (normal) vision

	eV	m
Eye Limit		10^{-4}
Bacteria		10^{-5}
Wavelength of Light	1-10eV	10^{-6-7}
Atom		10^{-10}
Nucleus	100MeV-1GeV	10^{-14-15}
Quarks and Electrons	1TeV	10^{-18}
.		
.		
.		
Planck Length $\sqrt{\frac{\hbar G}{c^3}}$	10^{20} GeV	10^{-35}

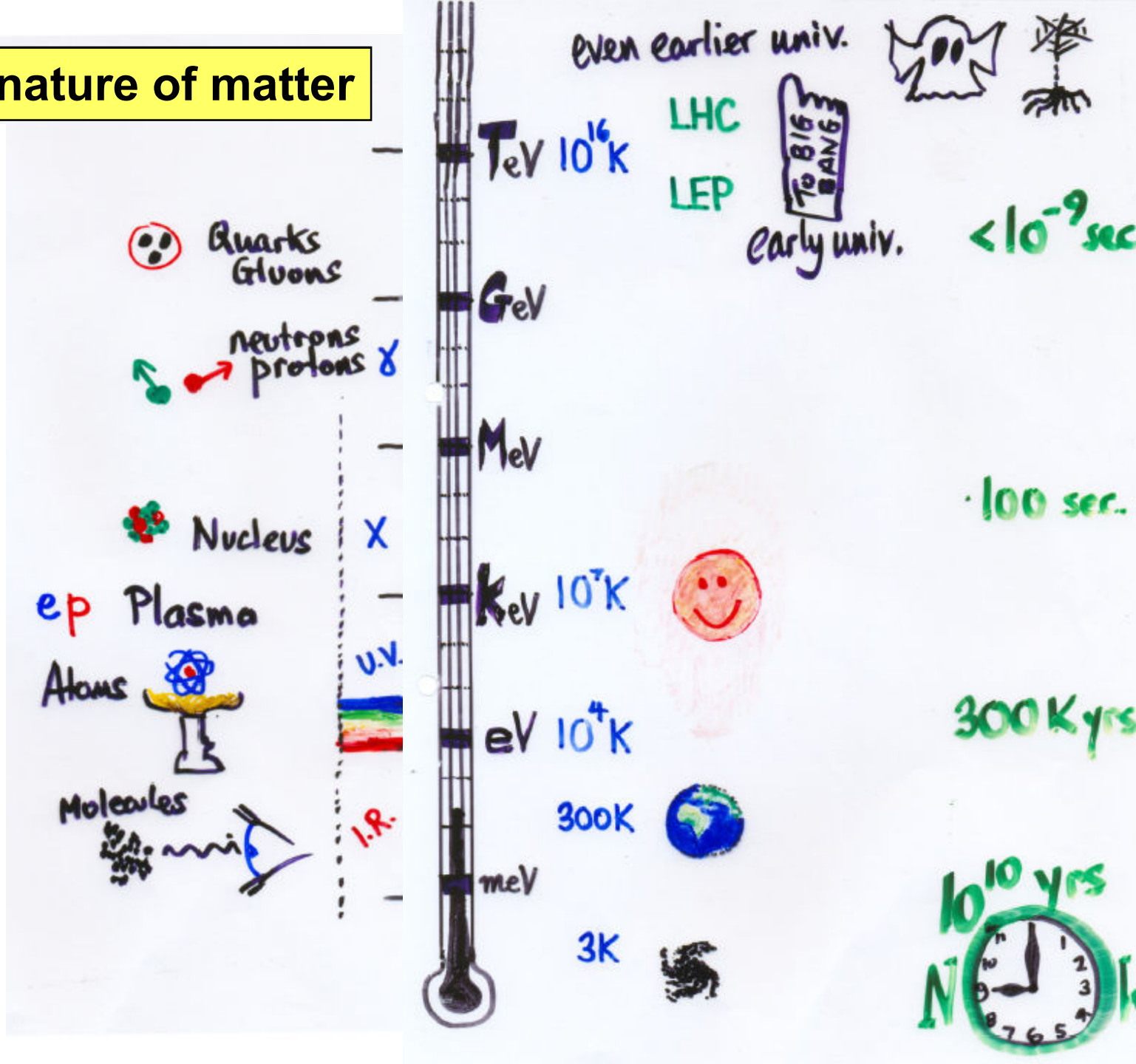
The Universe

in

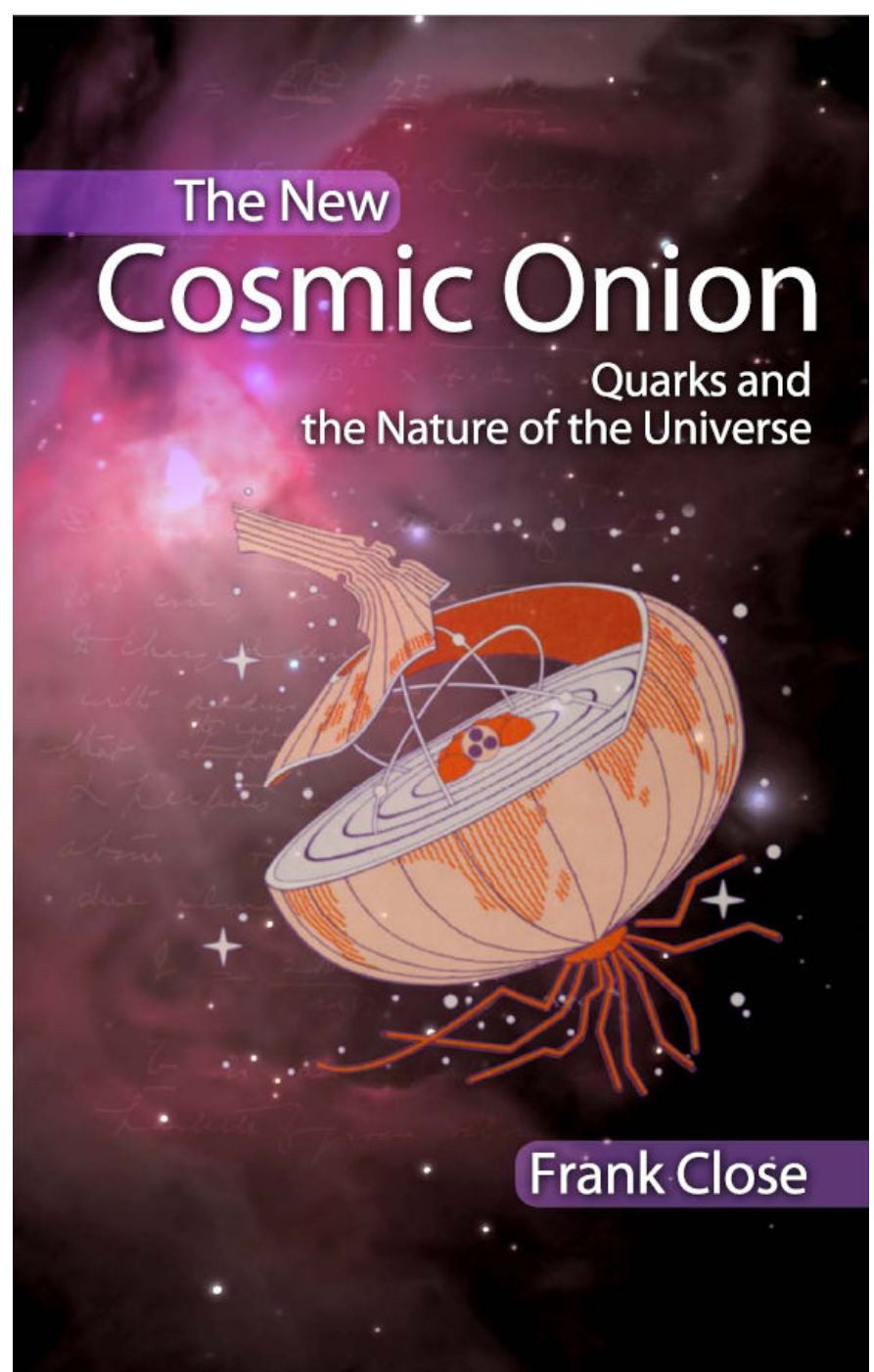
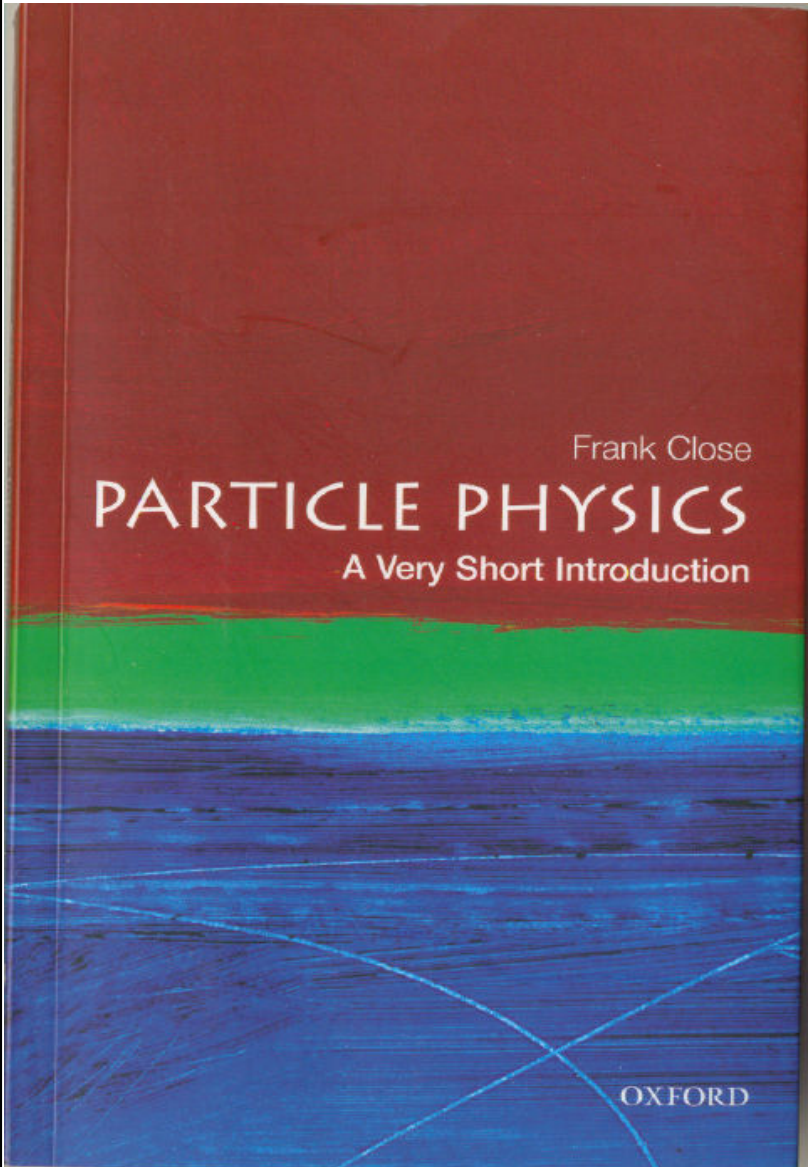
Temperature
Energy and
Time



...and the nature of matter



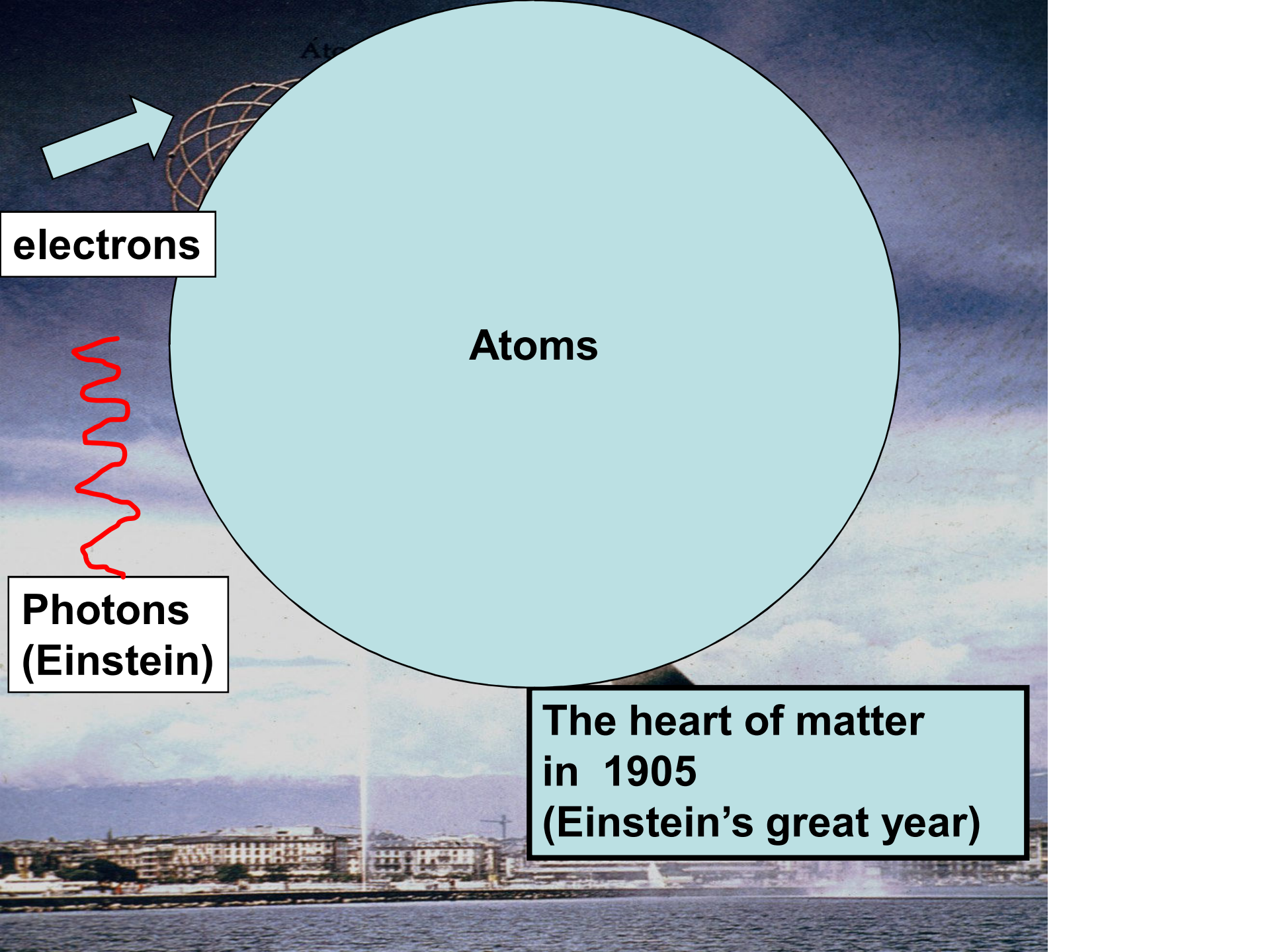
A Very Short Introduction



Particles in Three Minutes

A quick survey of how we got here....

....and where we think we're going next.

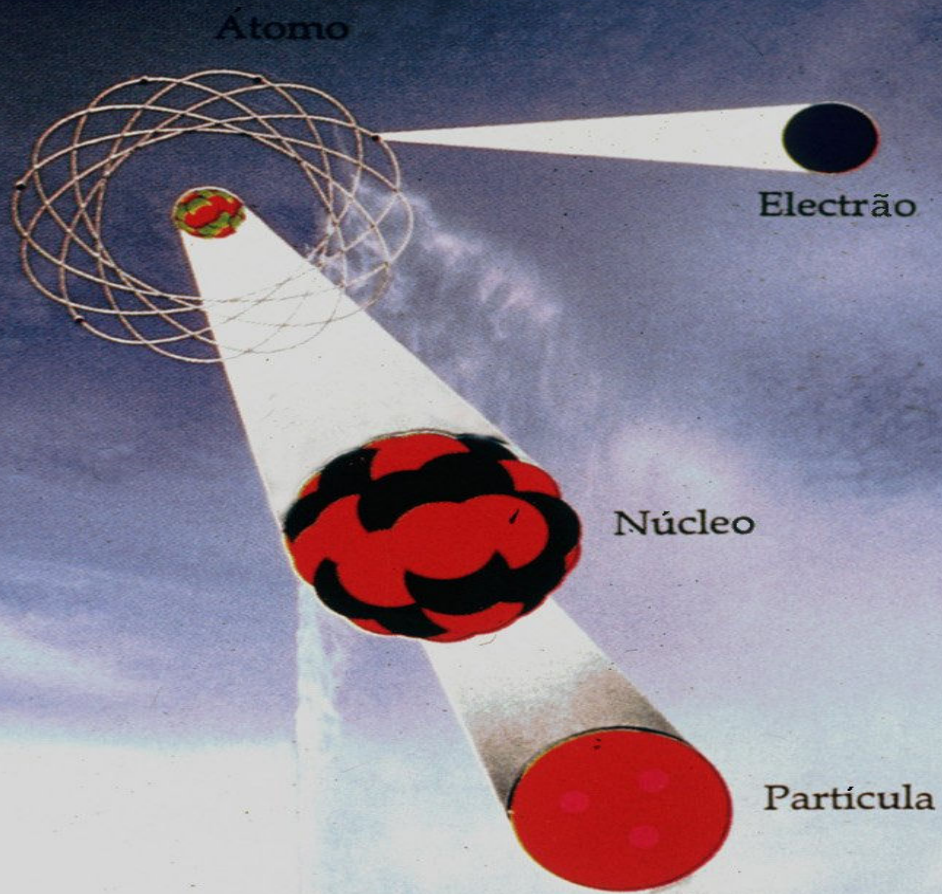


Atoms

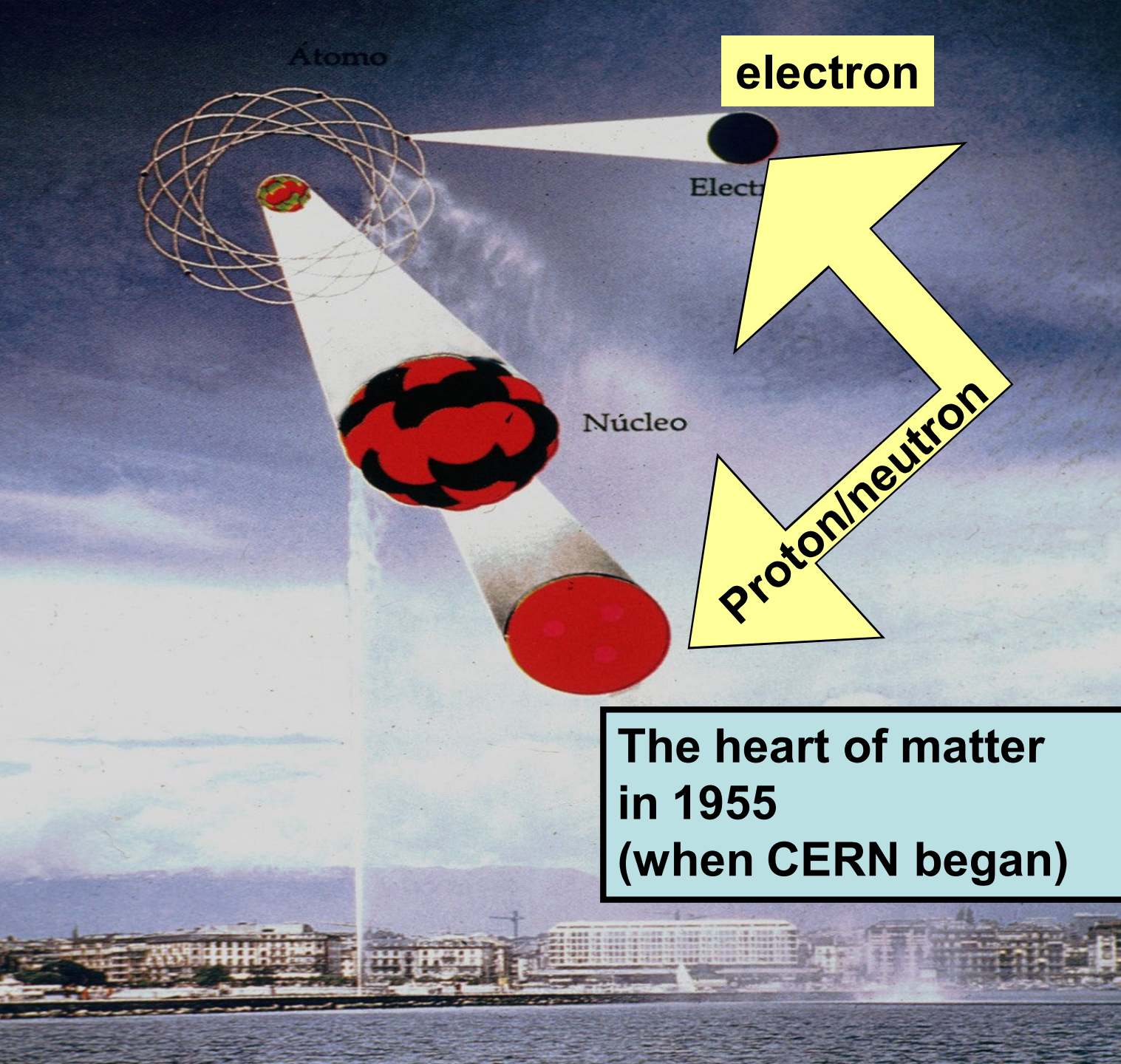
electrons

**Photons
(Einstein)**

**The heart of matter
in 1905
(Einstein's great year)**



**The heart of matter
in 1955
(when CERN began)**



electron

Electron
and
Proton
utterly
different.

proton
2000
times
heavier

The heart of matter
in 1955
(when CERN began)

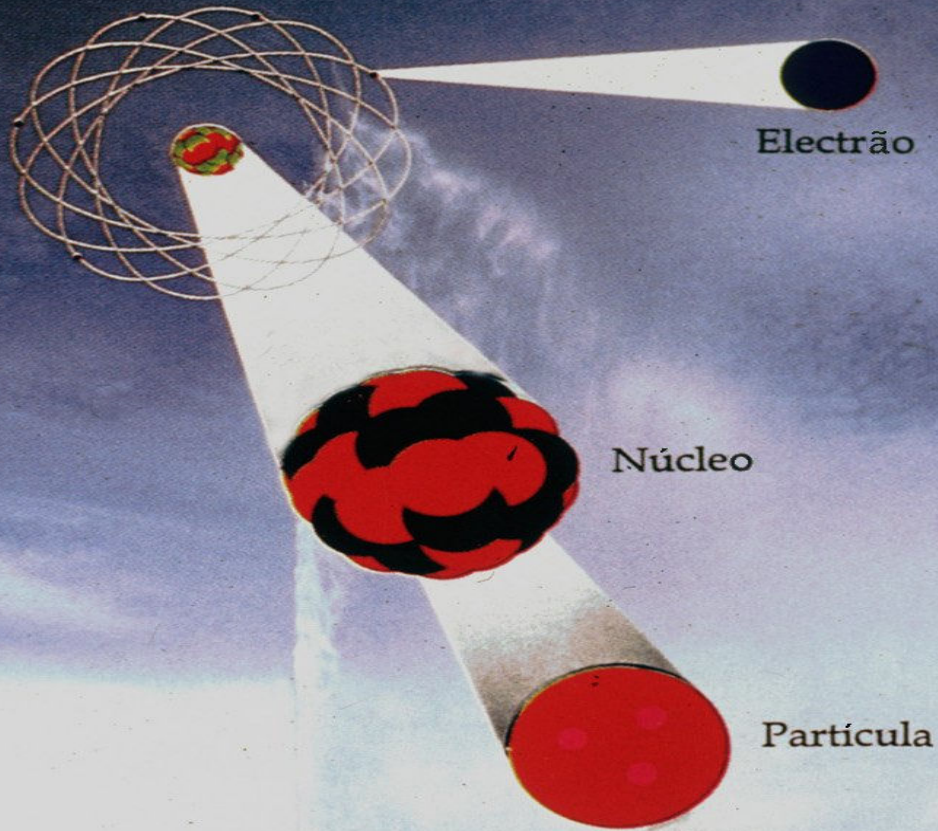
10000
times
bigger

1955

ELECTROMAGNETIC force binds electrons

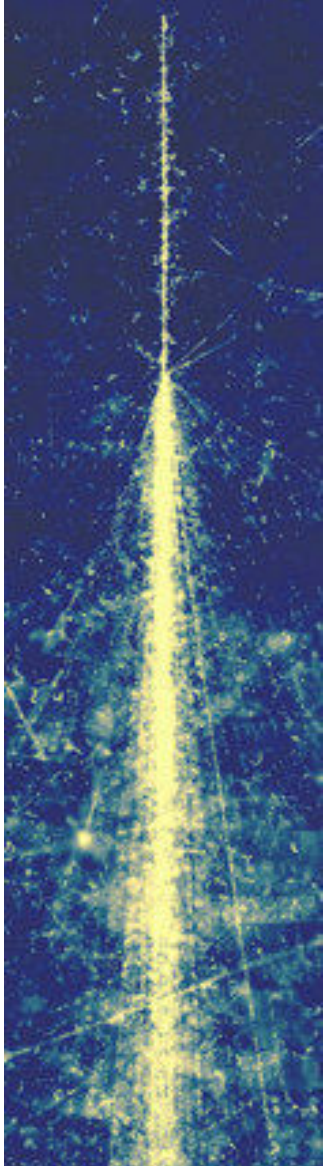
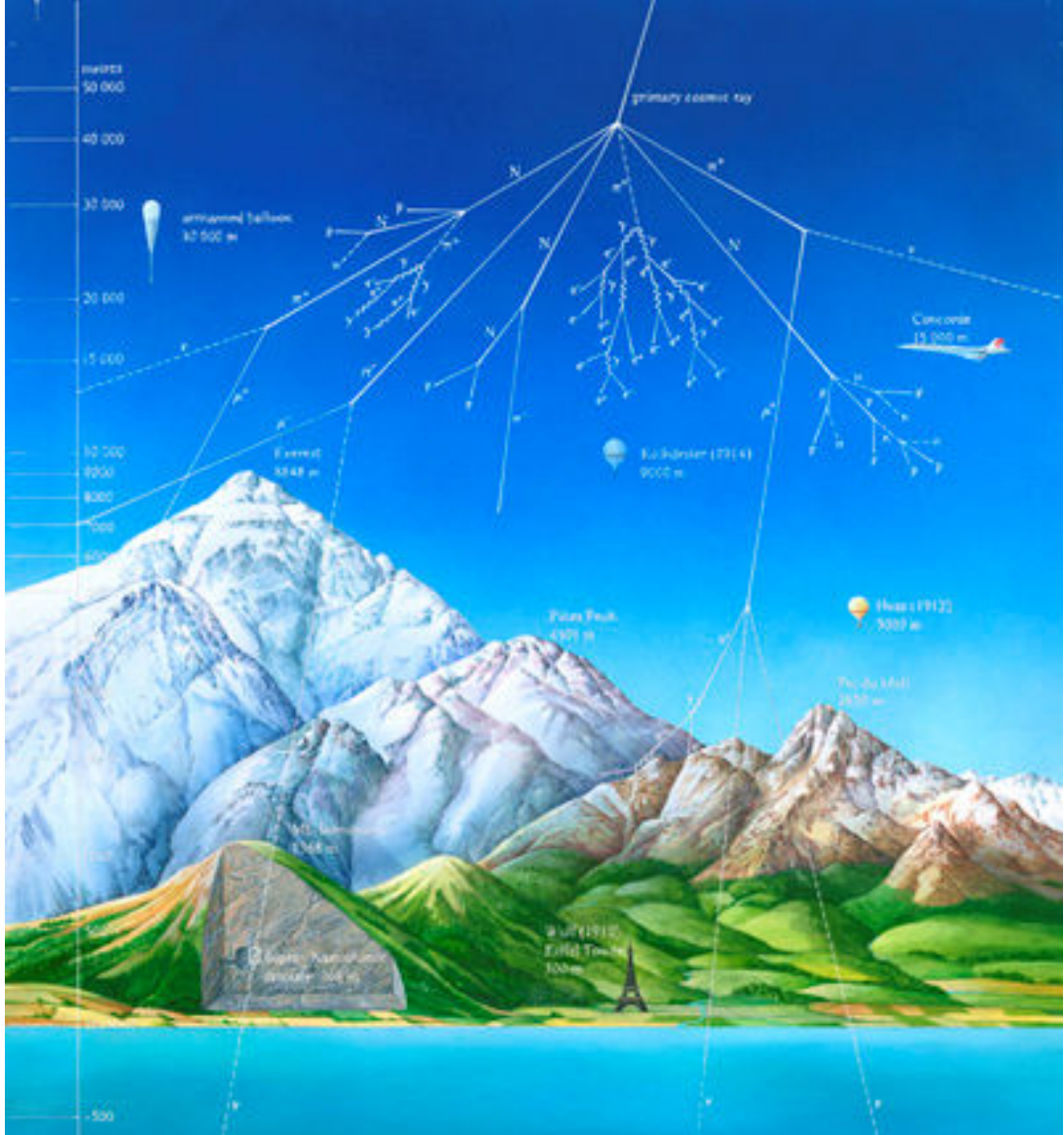
FORCES

in the
atom

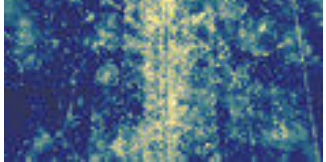


STRONG force binds nucleus

WEAK force = radioactivity



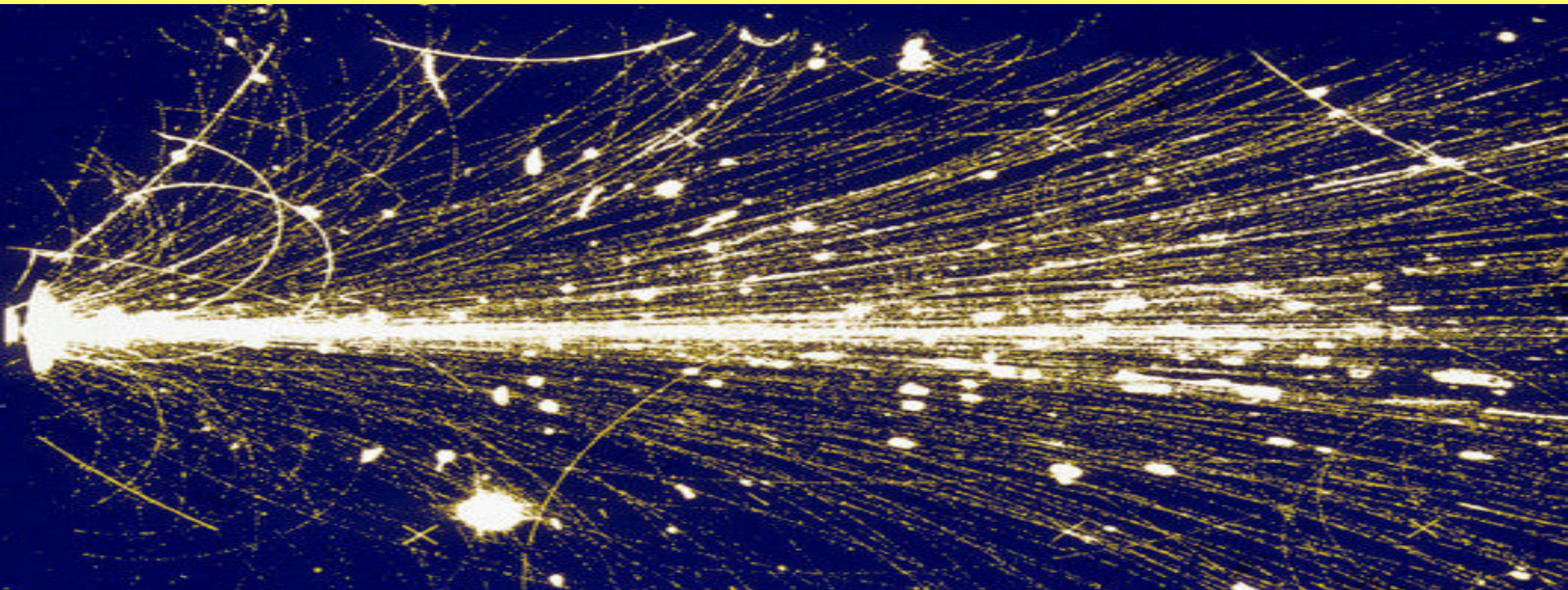
Cosmic Rays had revealed STRANGE particles



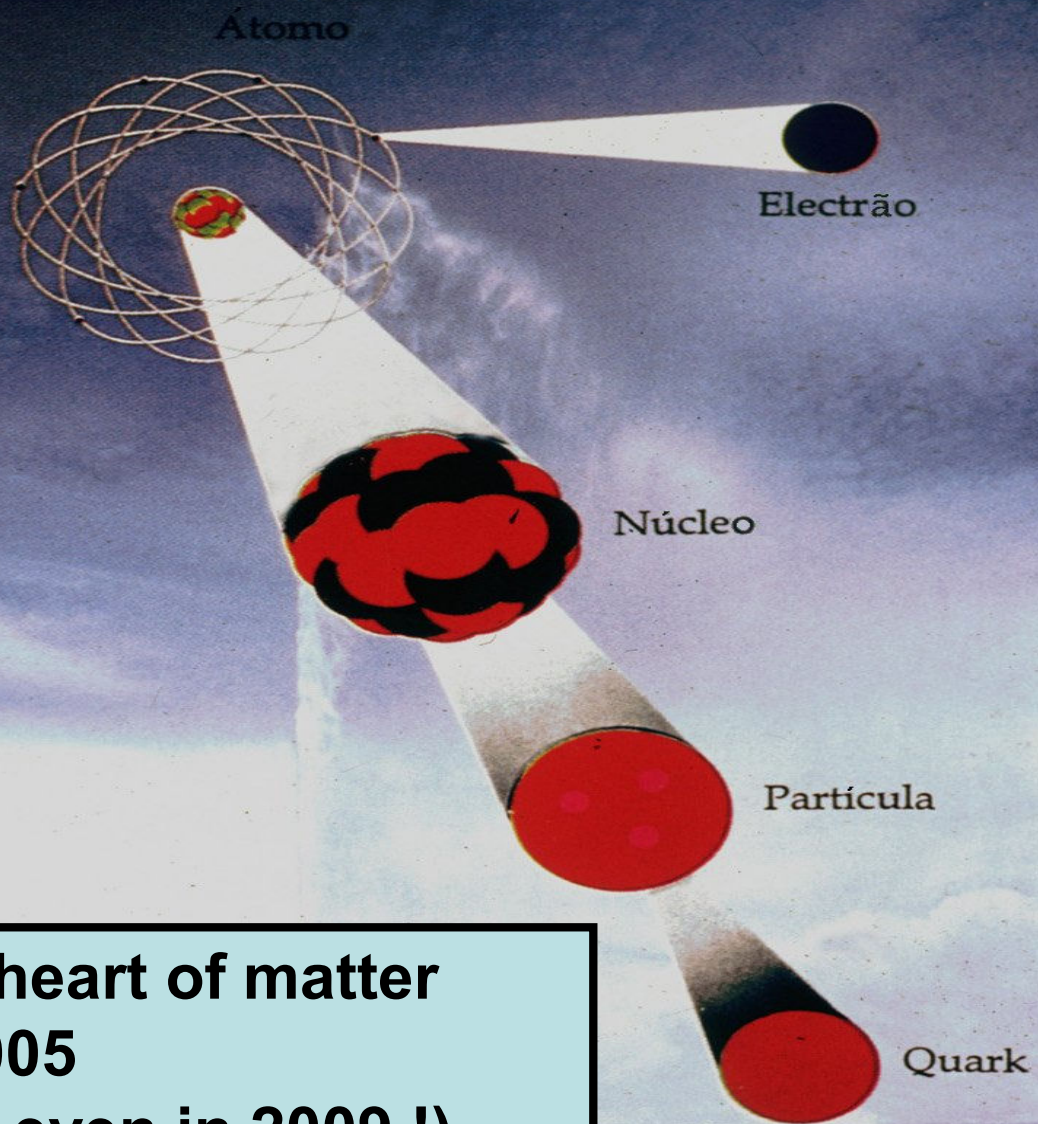
1955 CERN accelerators replicate cosmic rays on Earth...



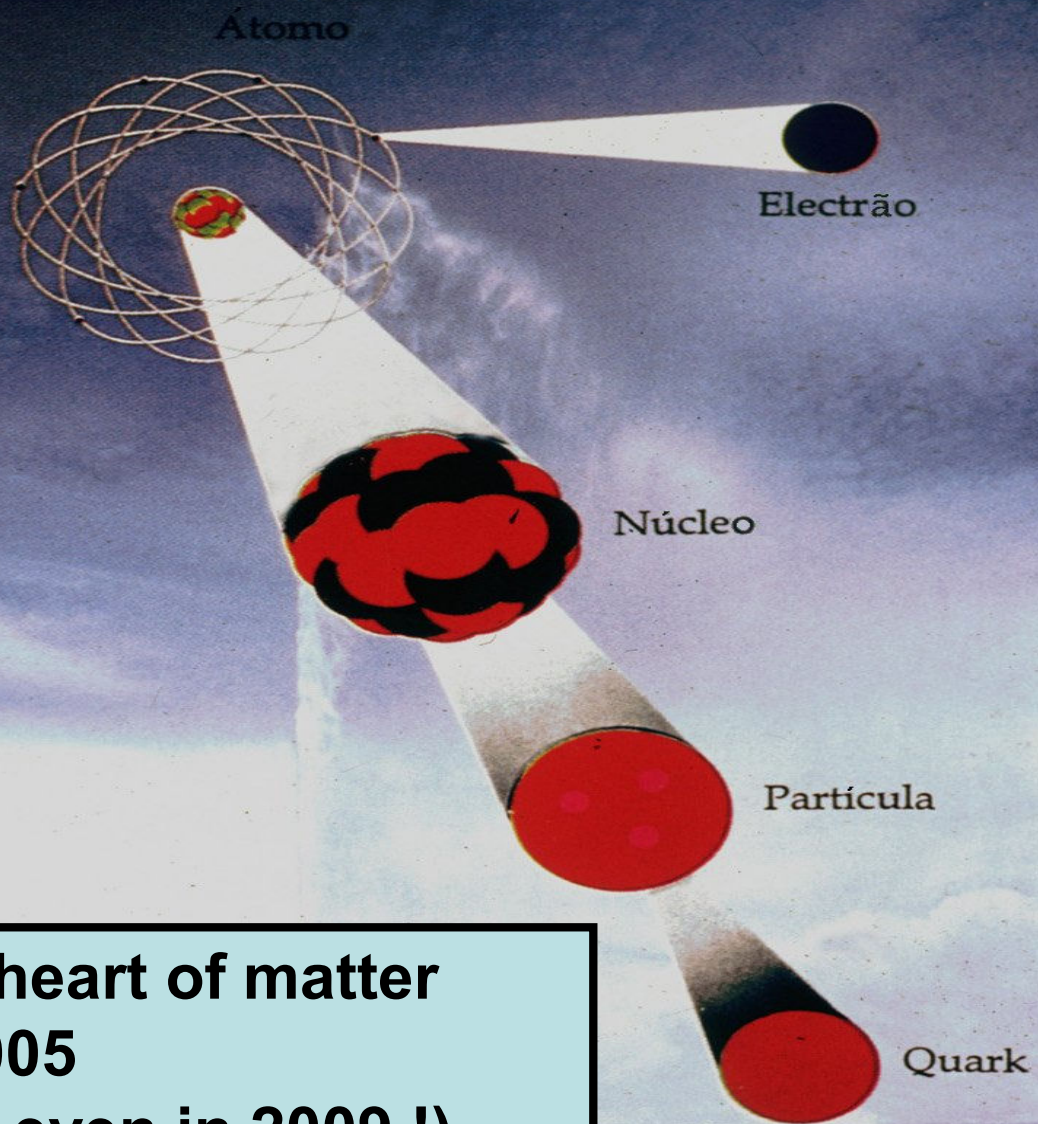
..record the images and reveal the real heart of matter....



.....the beginnings of modern high energy particle physics



**The heart of matter
in 2005
(and even in 2009 !)**



The heart of matter
in 2005
(and even in 2009 !)

Electron
and
quark
very
similar
in

Mass
Size
Spin

and in
how
they
respond
to the
FORCES

2009

ELECTROweak force binds electrons

FORCES

in the
atom

United
electroweak/QCD



Electrão

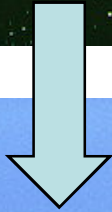
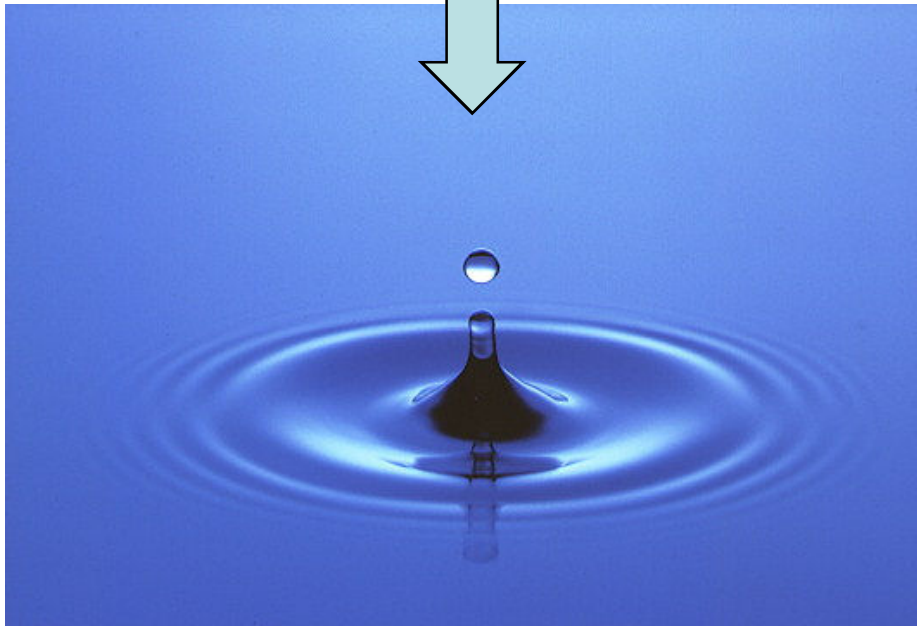
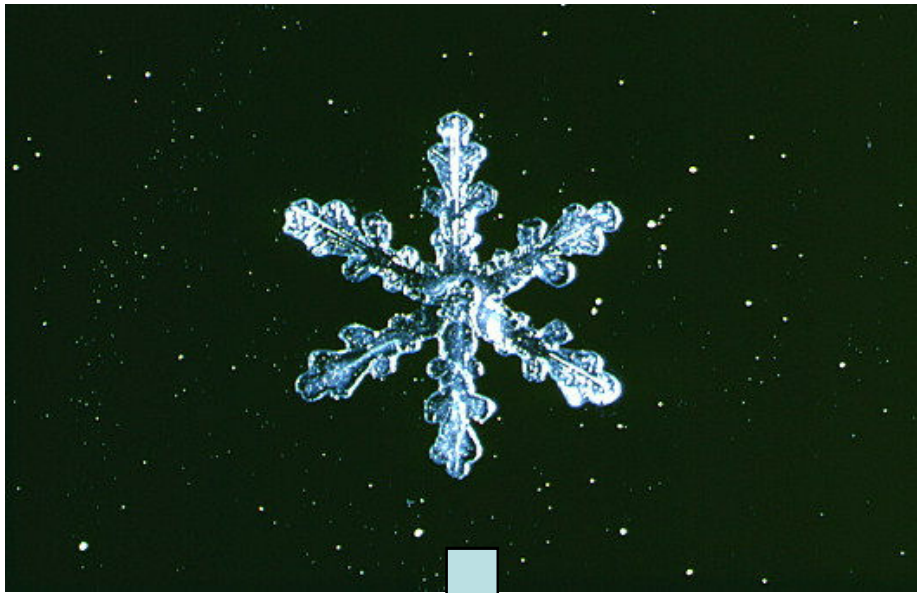
Núcleo

Partícula

Quark

electroWEAK force = radioactivity

Colour QCD force binds quarks

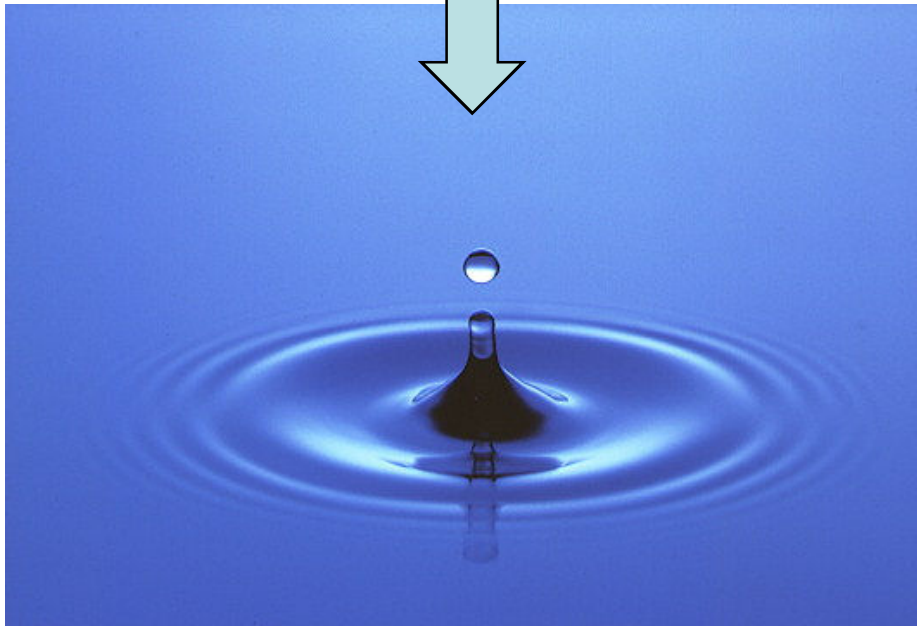
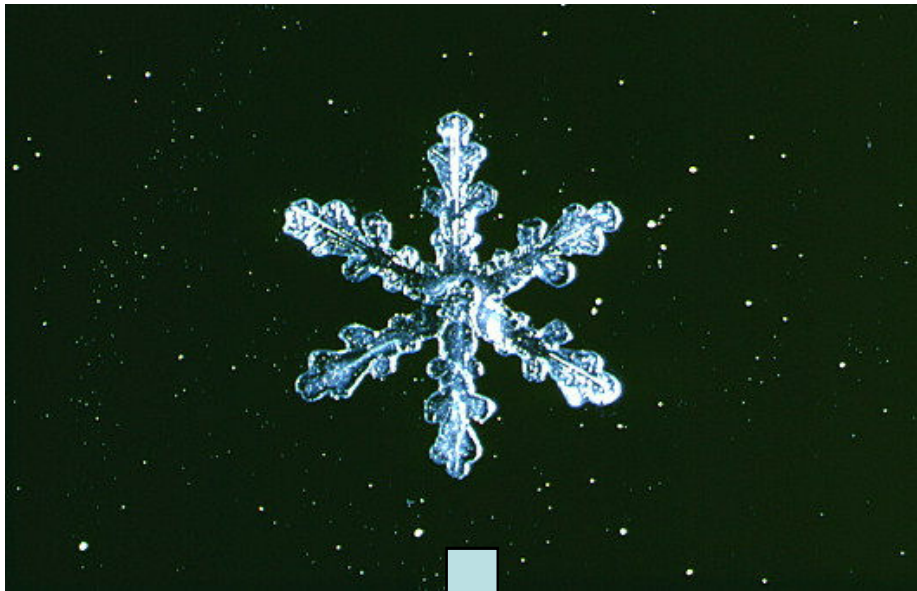


**patterns
and structures
when cold
(low energy)**



**Symmetry
when warm
(high
energy)**

FORCES 1955-2005



COLD

**Electromagnetic
Weak
Strong**

WARM

**ElectroWeak
Strong (QCD)**

HOT

**GrandUnified
Force**

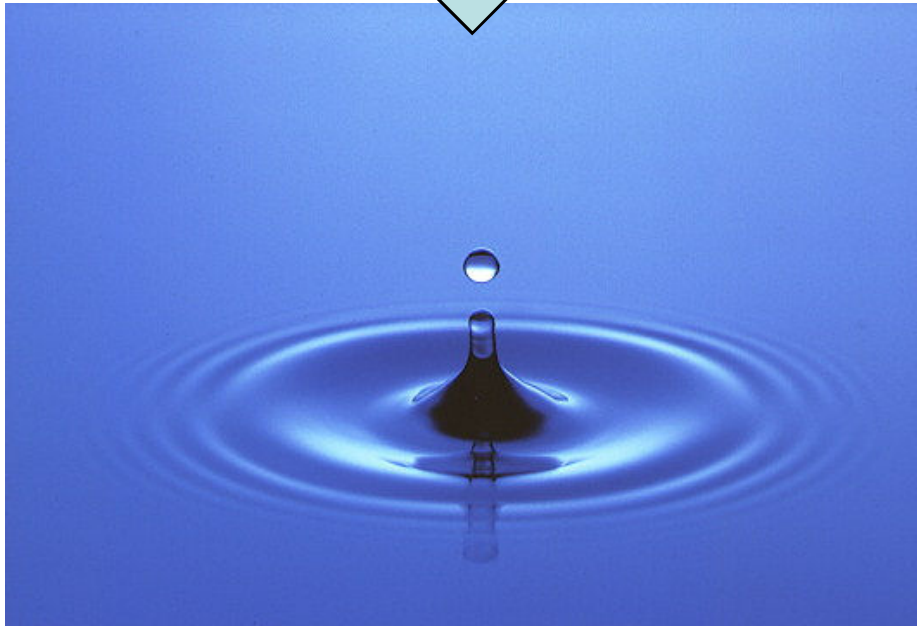
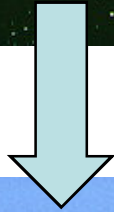
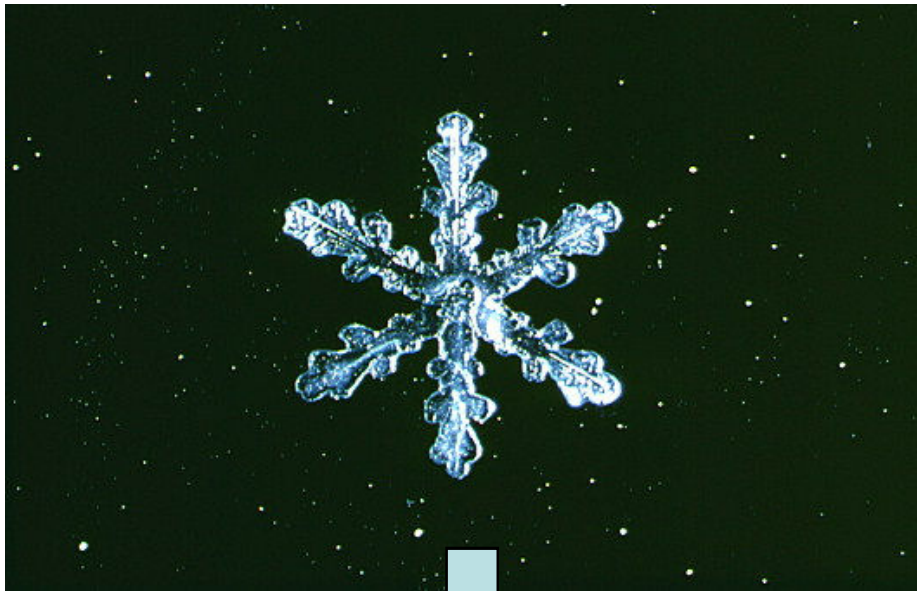


Standard Model of Quarks Leptons and forces

= **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**

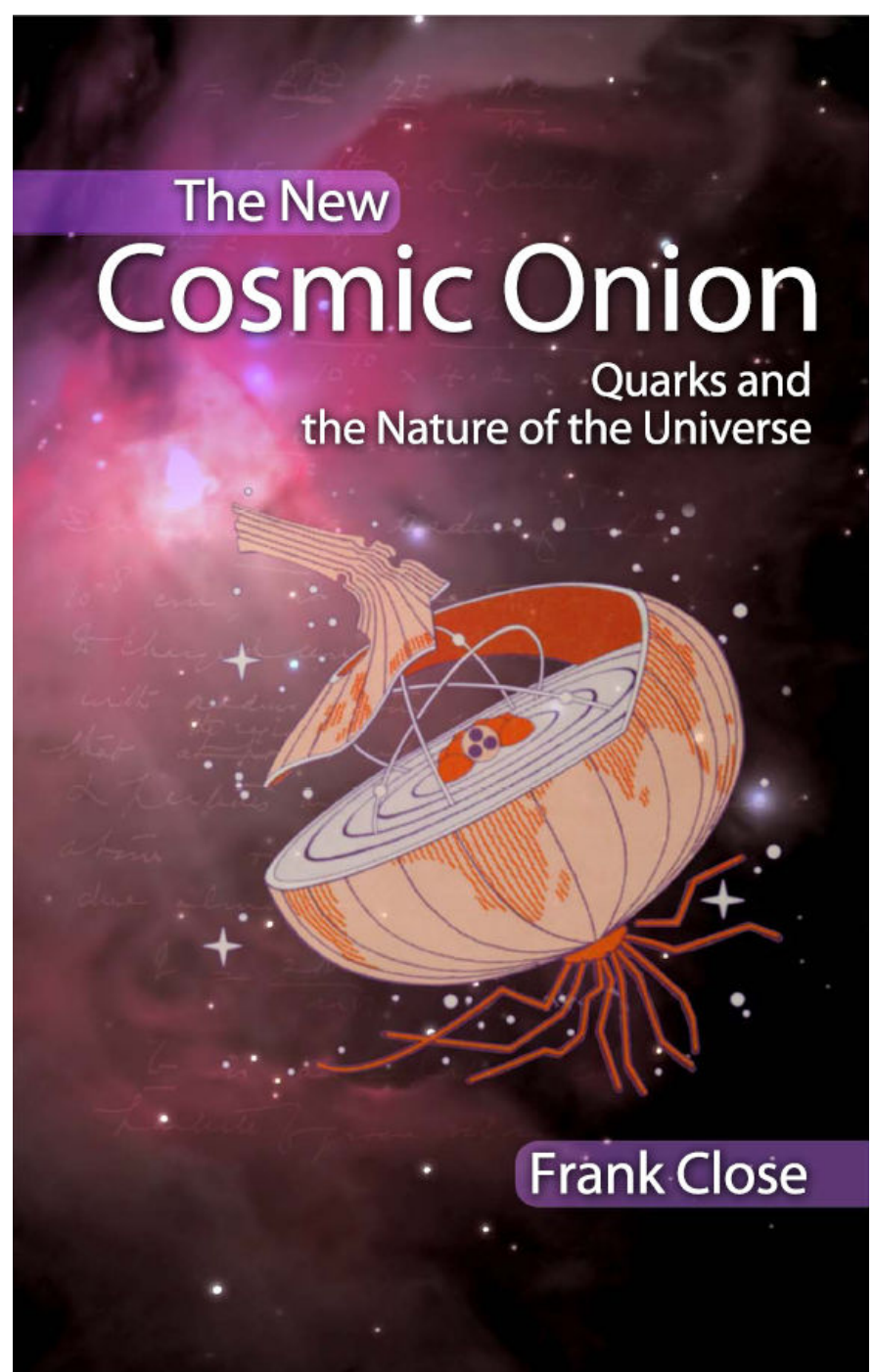
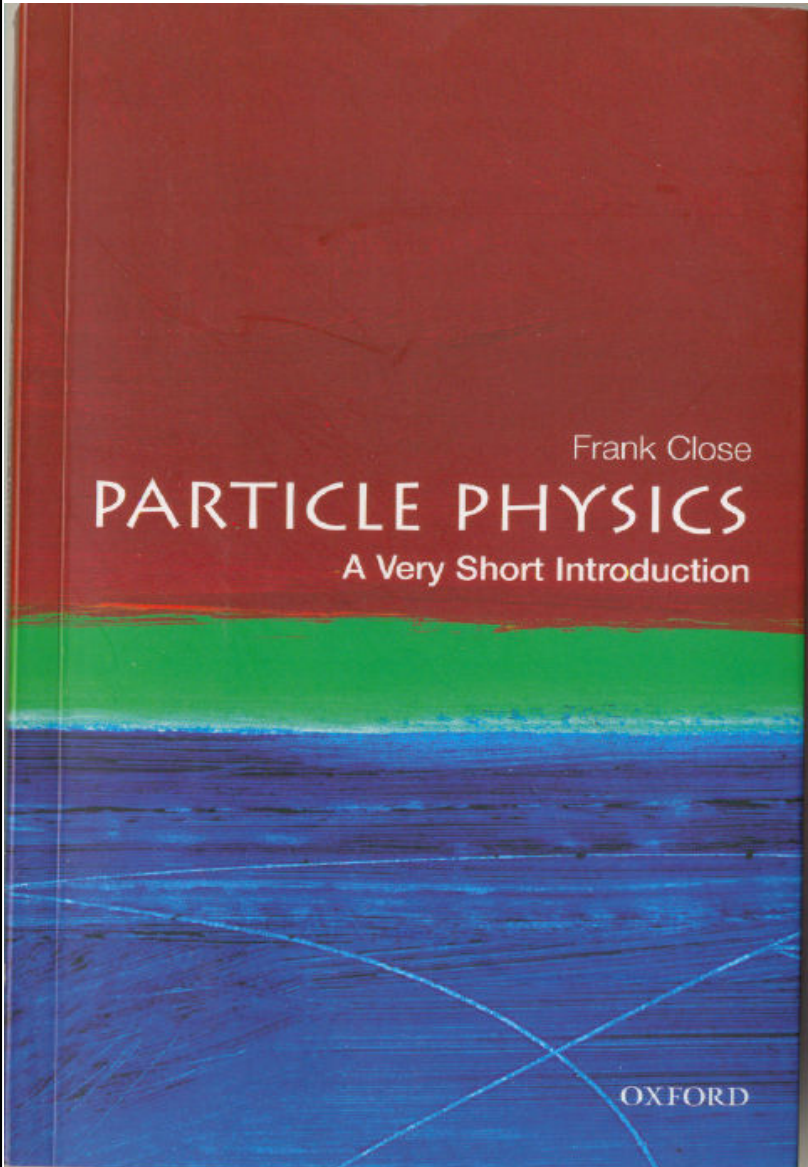


superSymmetry
when “**warm**”

(= high energy $> 1\text{TeV}$)

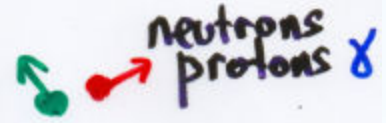
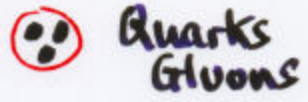
Higgs Boson
Supersymmetry
Nature of Reality

A Very Short Introduction



...and patterns (that change)

QG Plasma



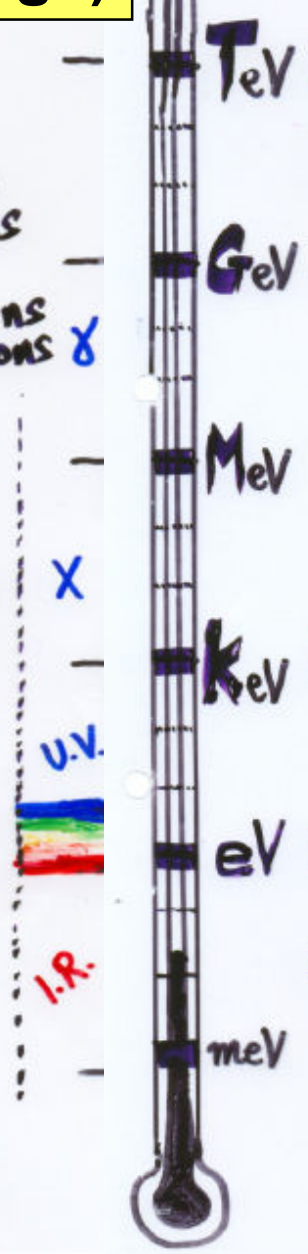
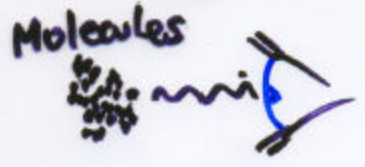
Nuclei melt
↓ exist



H melt: plasma
↓ exist



Ice melt
↓ exist



No mass. Unified Theory

Standard Model
MASS

t	b	τ	ν	W
c	s	μ	ν	Z
u	d	e	ν	γ

Nuclear Isotopes



Mendeleev



Snowflake pattern



No mass. Unified Theory

Standard Model
Model
MASS

t	b	τ	ν	W
c	s	μ	ν	Z
u	d	e	ν	γg

Nuclear Isotopes



Mendeleev



Snowflake pattern

