



Introduction to Particle Physics

(for non physics students)



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How Old is the Universe?



20.00) Creation Big Bang

(world cup 1st half; 2nd half; sleep)



05.00 SUN → EARTH 06.00

(breakfast; come to lectures)



09.30 Oldest Fossils

09.59; 30" First Humanoids

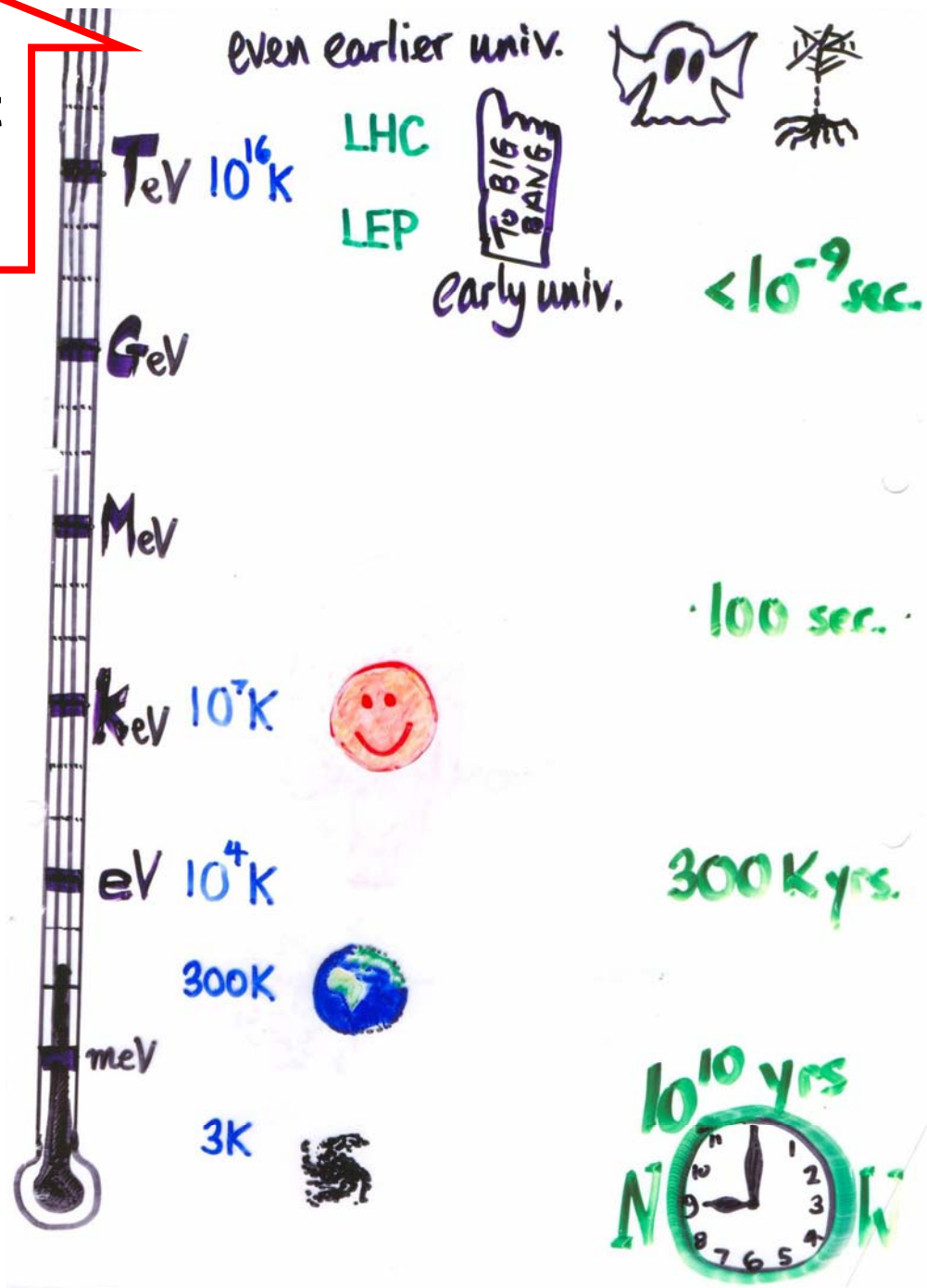


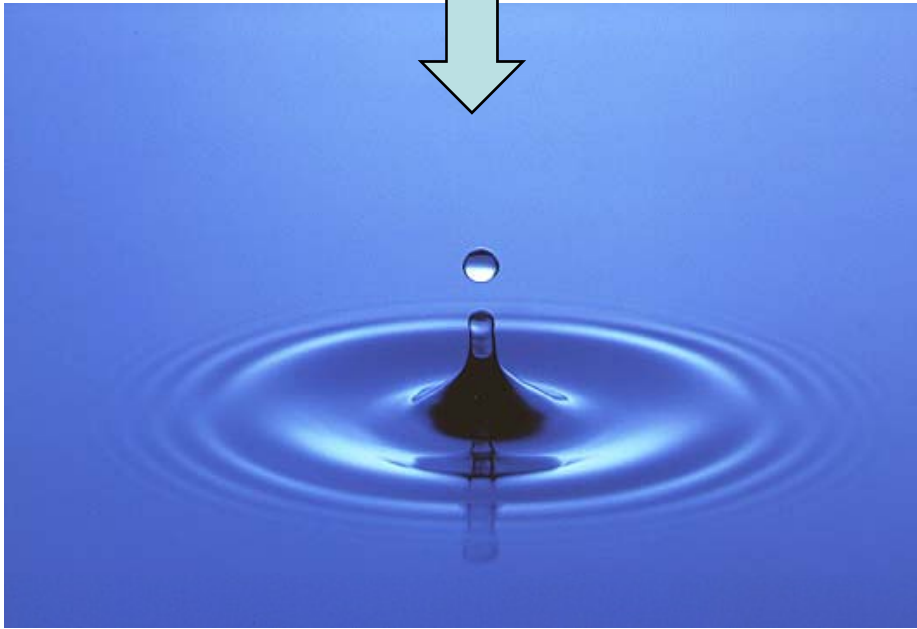
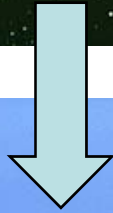
09.59 -  The Millenium

10.00 NOW

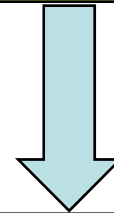


Next year

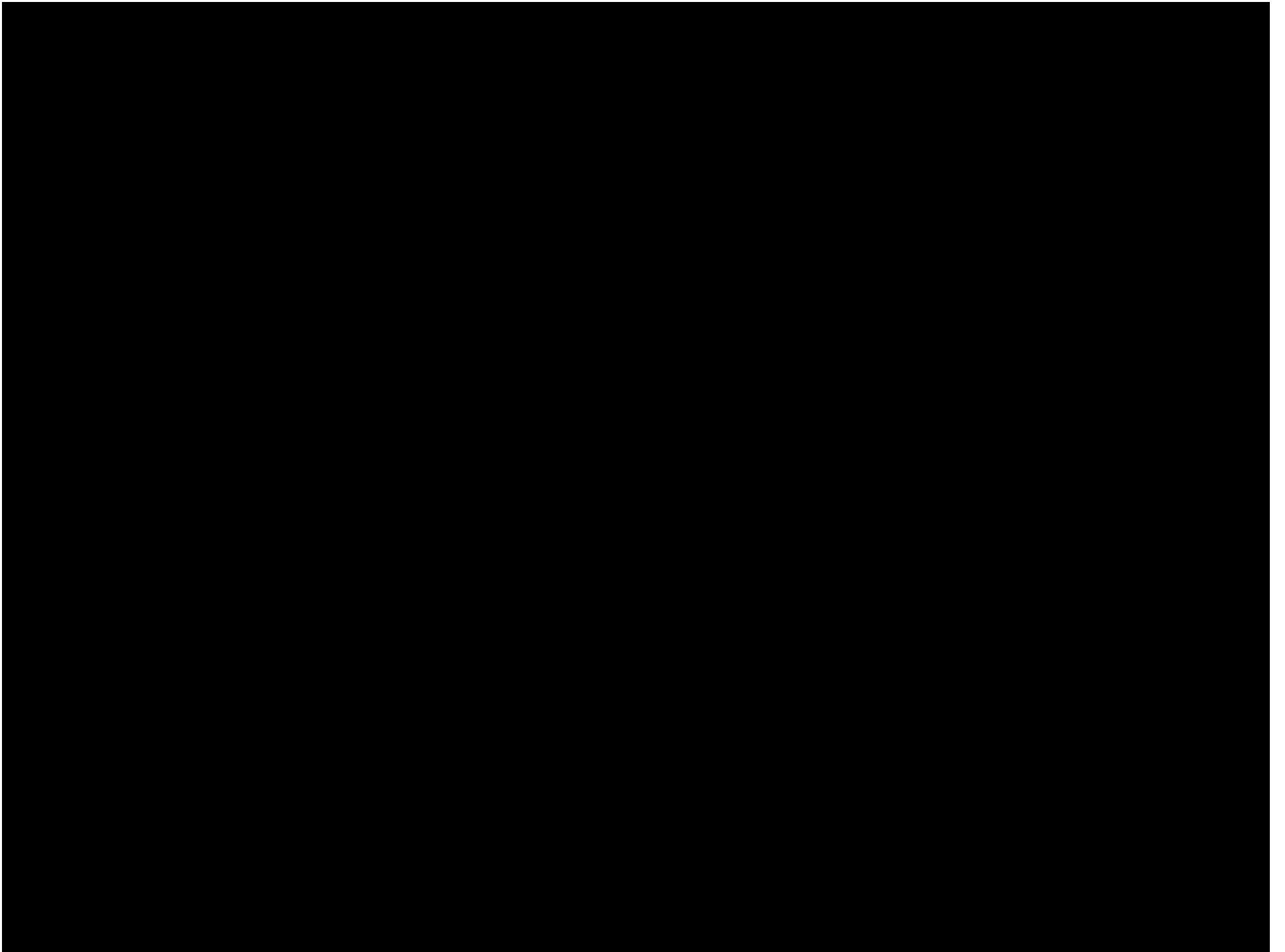




**patterns
and structures
when cold
(low energy)**



**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

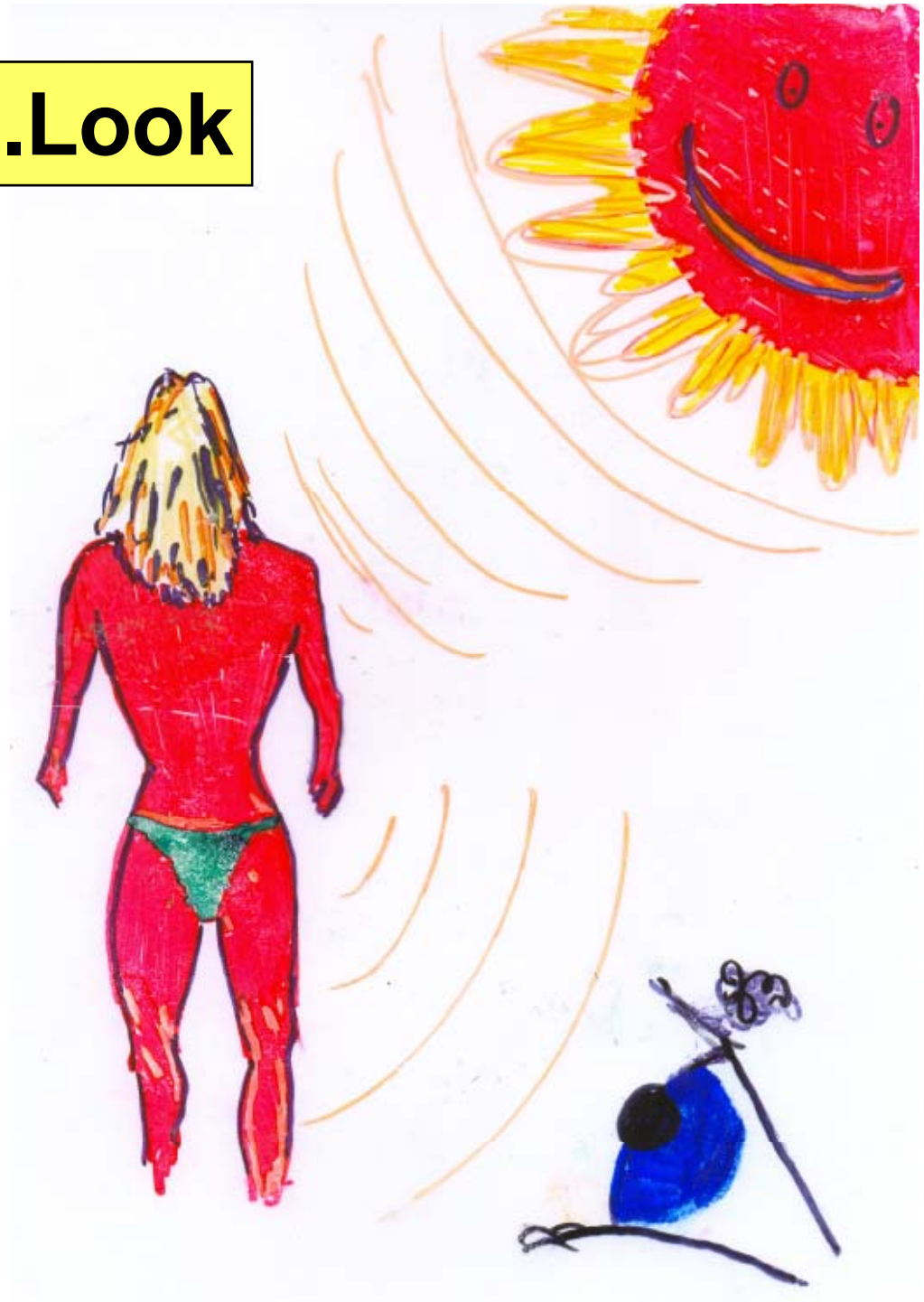


Light source

Object

Eye

1.Look



Light source

Object

Eye

1.Look



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}
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.	
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How to learn what things are made of

LOOK

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

SMASH

HEAT



How to learn what things are made of

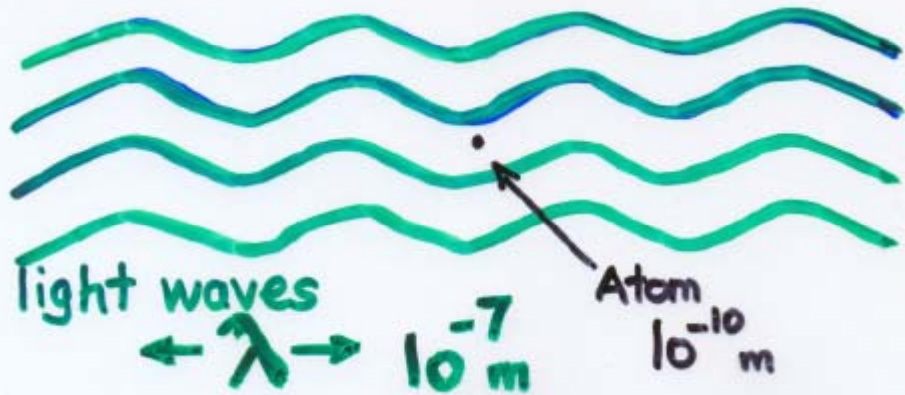
LOOK

resolution
Wave λ length

SMASH

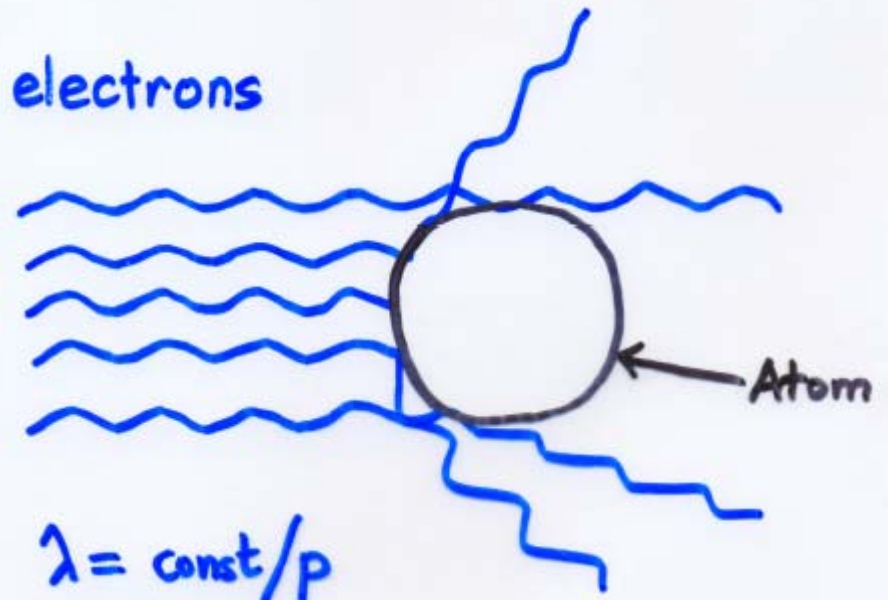
HEAT

How to see small things

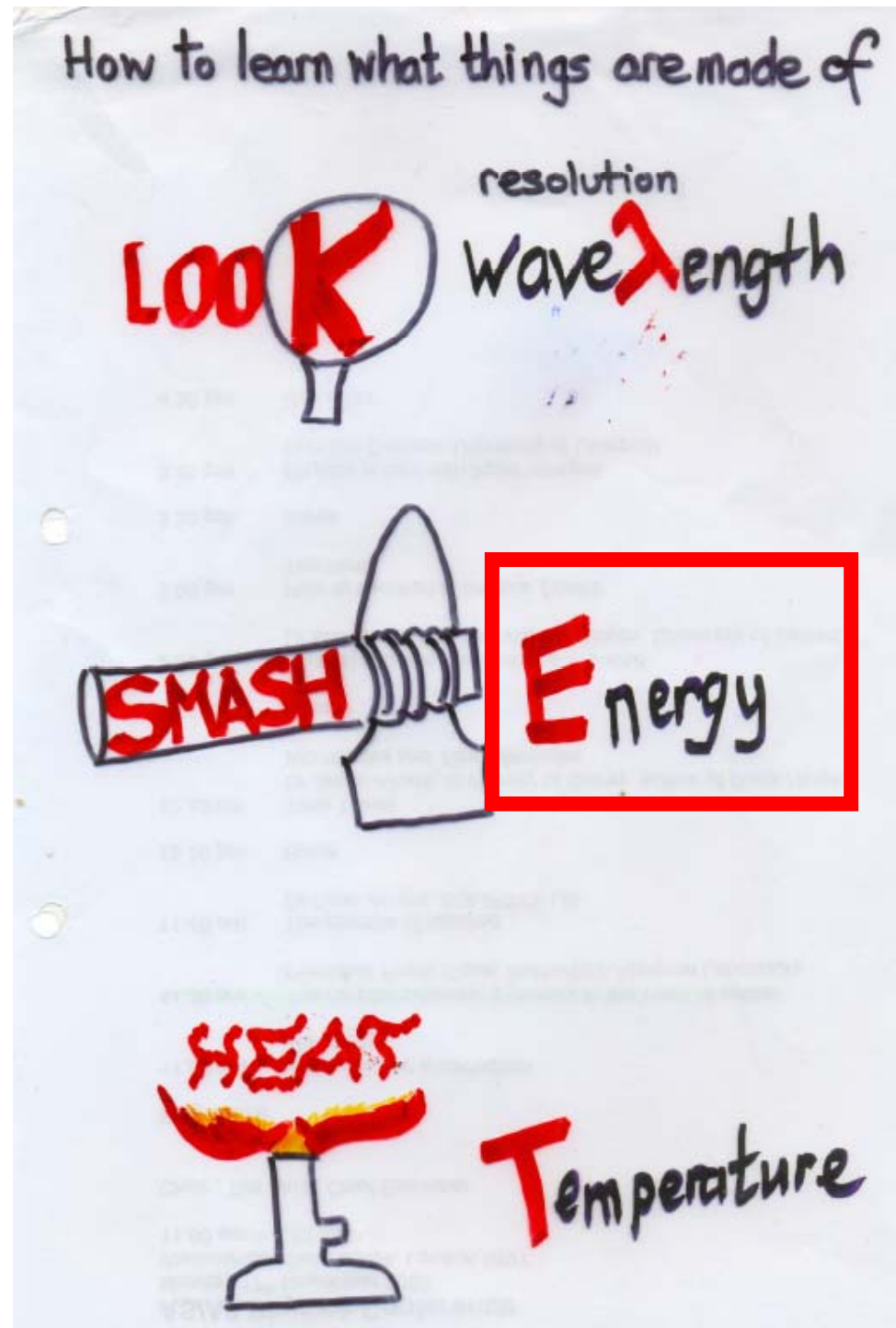


Electron microscope

electrons



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....

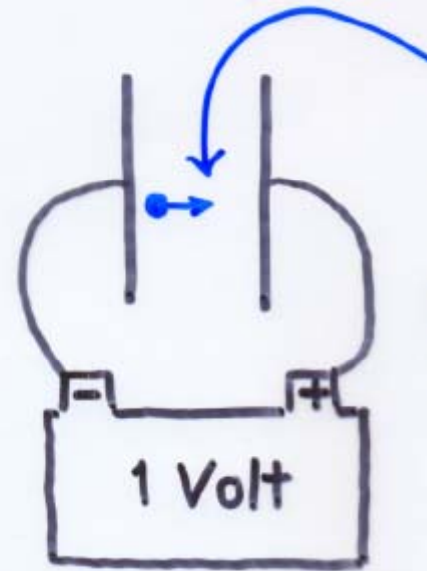
and

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**)

$$\mathbf{E} = 1 \text{ eV} \\ = 1.6 \times 10^{-19} \text{ J}$$

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

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

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

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

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

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

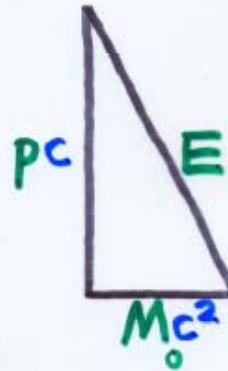
Einstein
Energy

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

$$hc/\lambda$$

$$h\nu$$

Energy

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

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



Temperature

How to learn what things are made of

resolution
LOOK **Wavelength**

SMASH **E**nergy

HEAT
Temperature

3. Heat

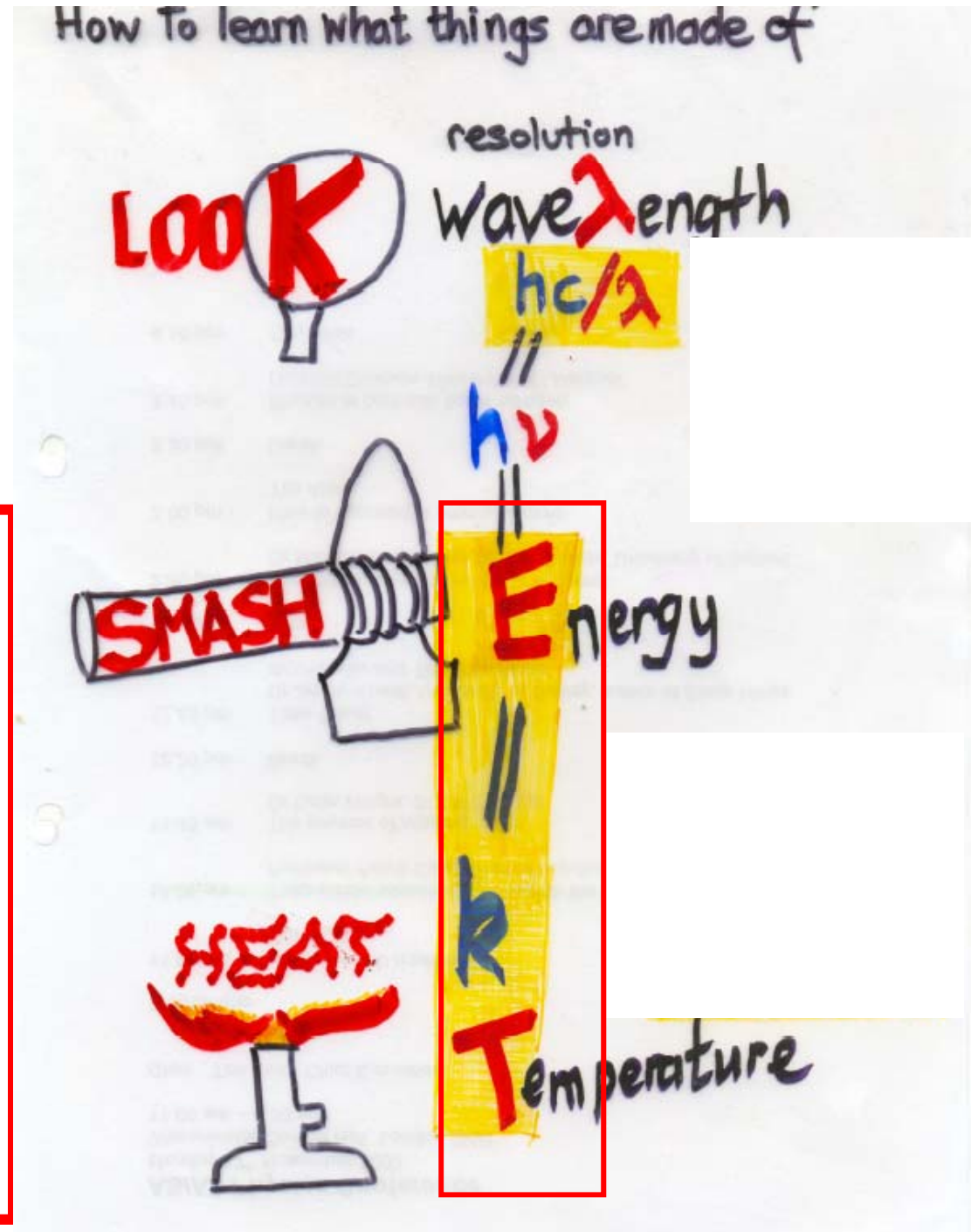
... also
profoundly
related.....

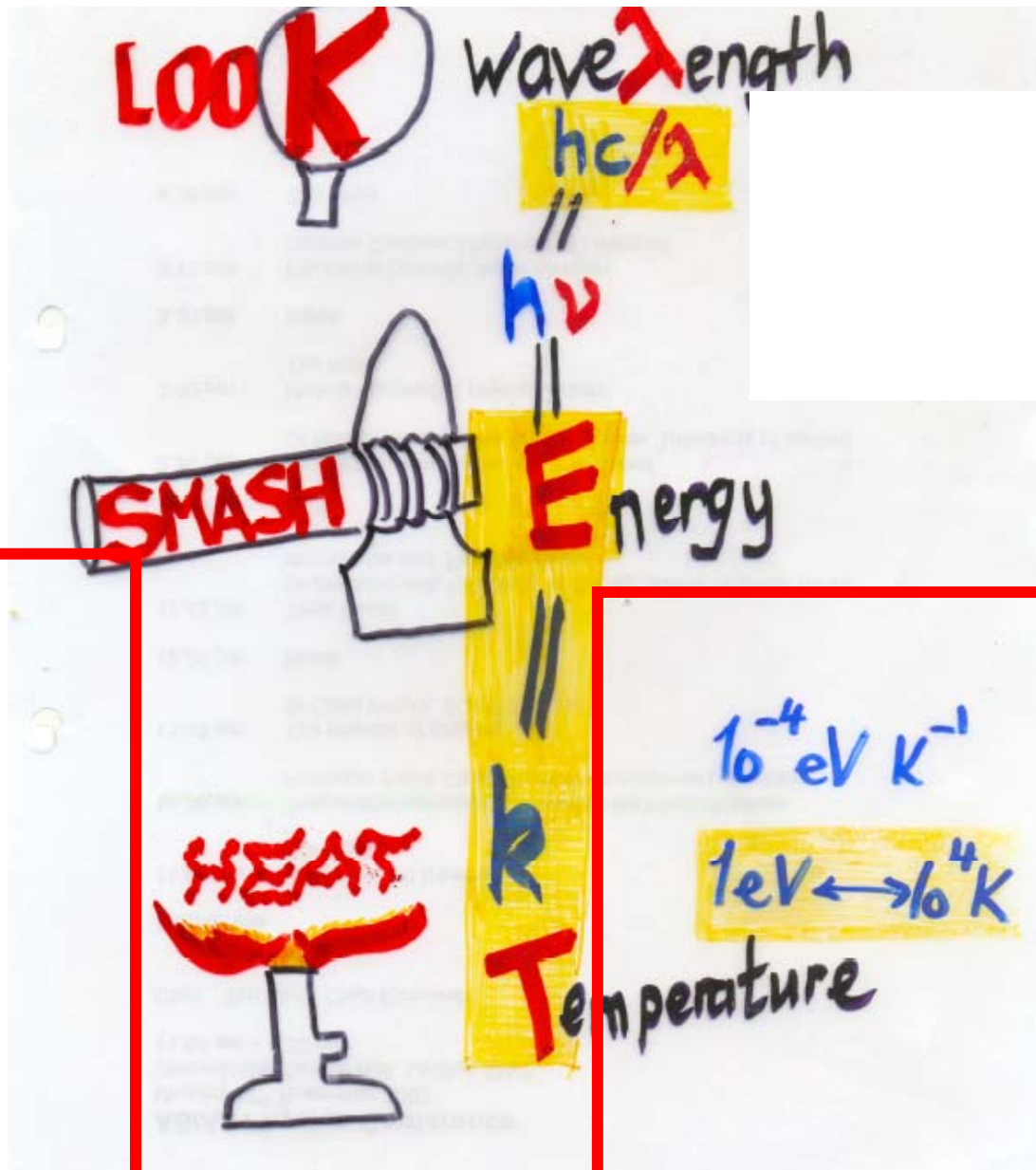
SMASH or HEAT

Energy

and

Temperature





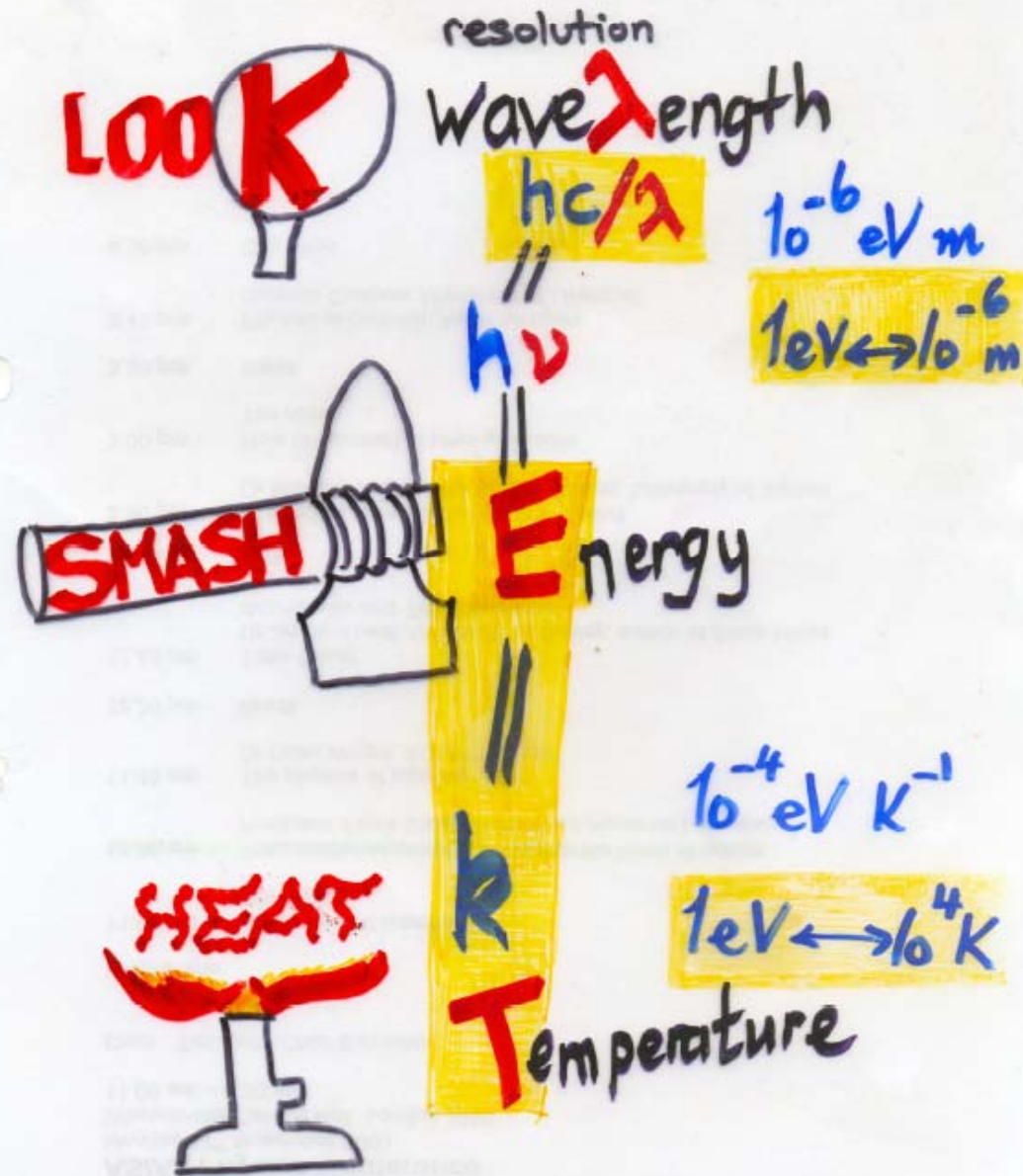
SMASH or HEAT

Energy

and

Temperature

How to learn what things are made of



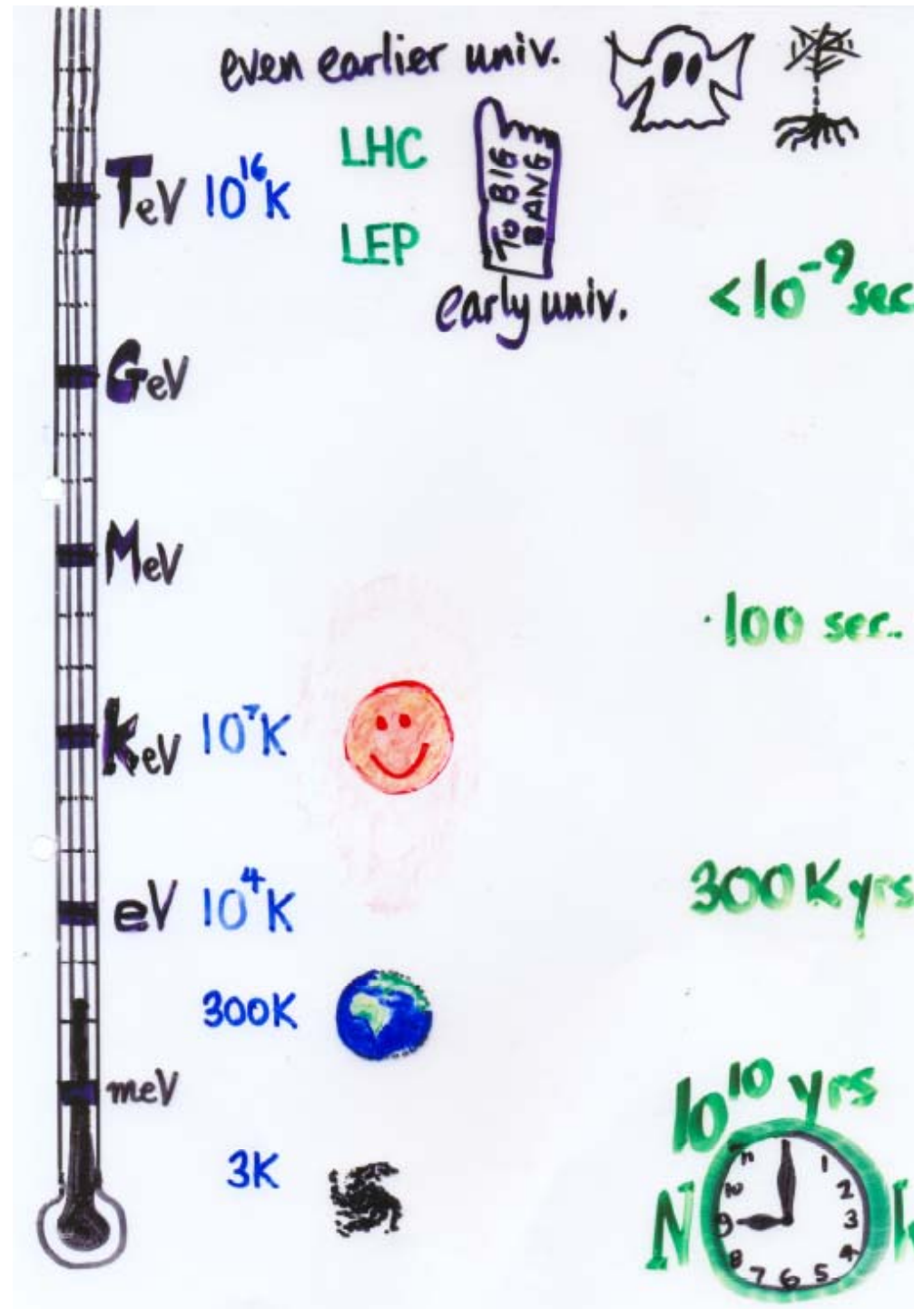
Beyond (normal) vision

	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 $\sqrt{\frac{Gh}{c^3}}$	10^{20} GeV	10^{-35}

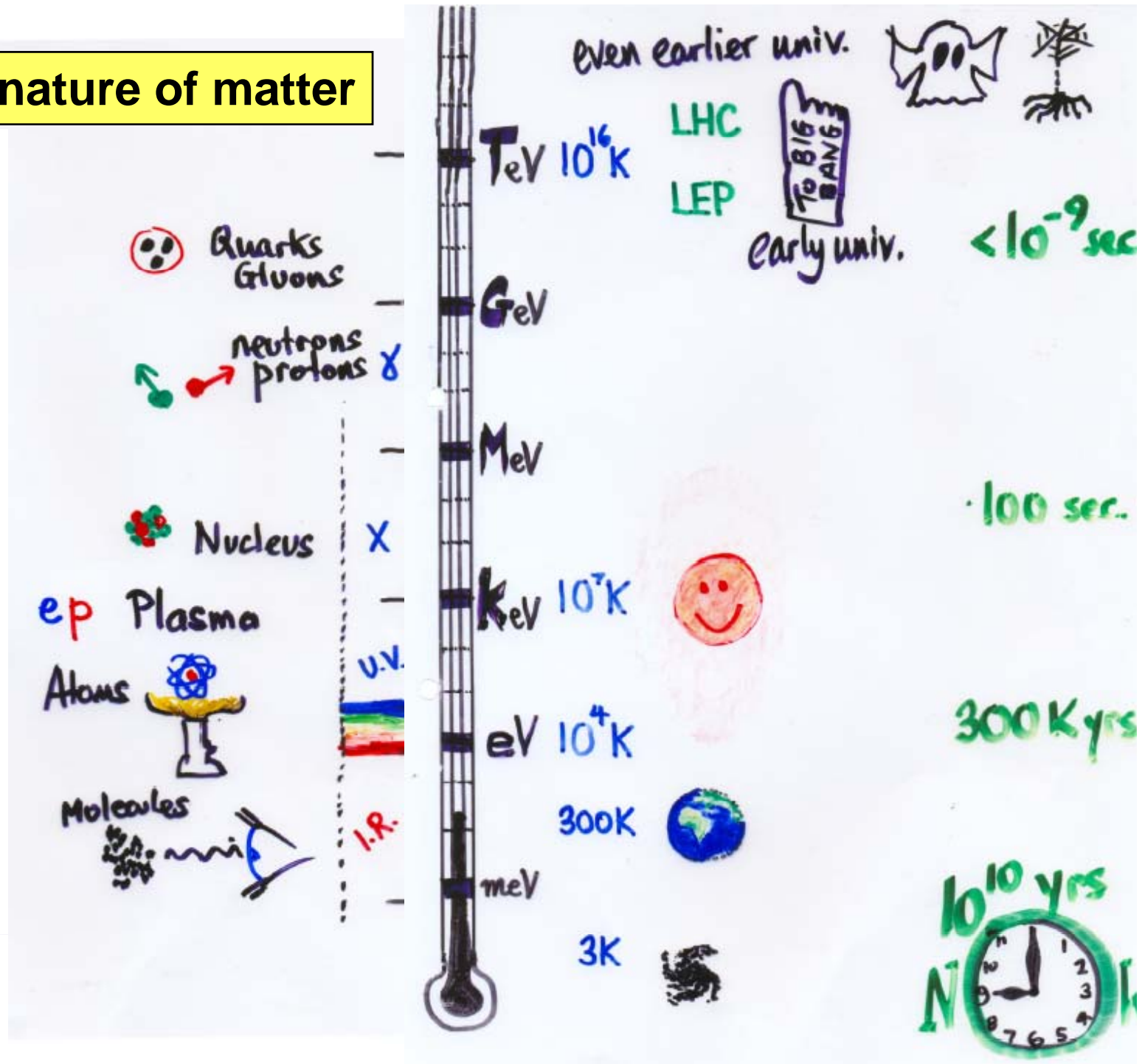
The Universe

in

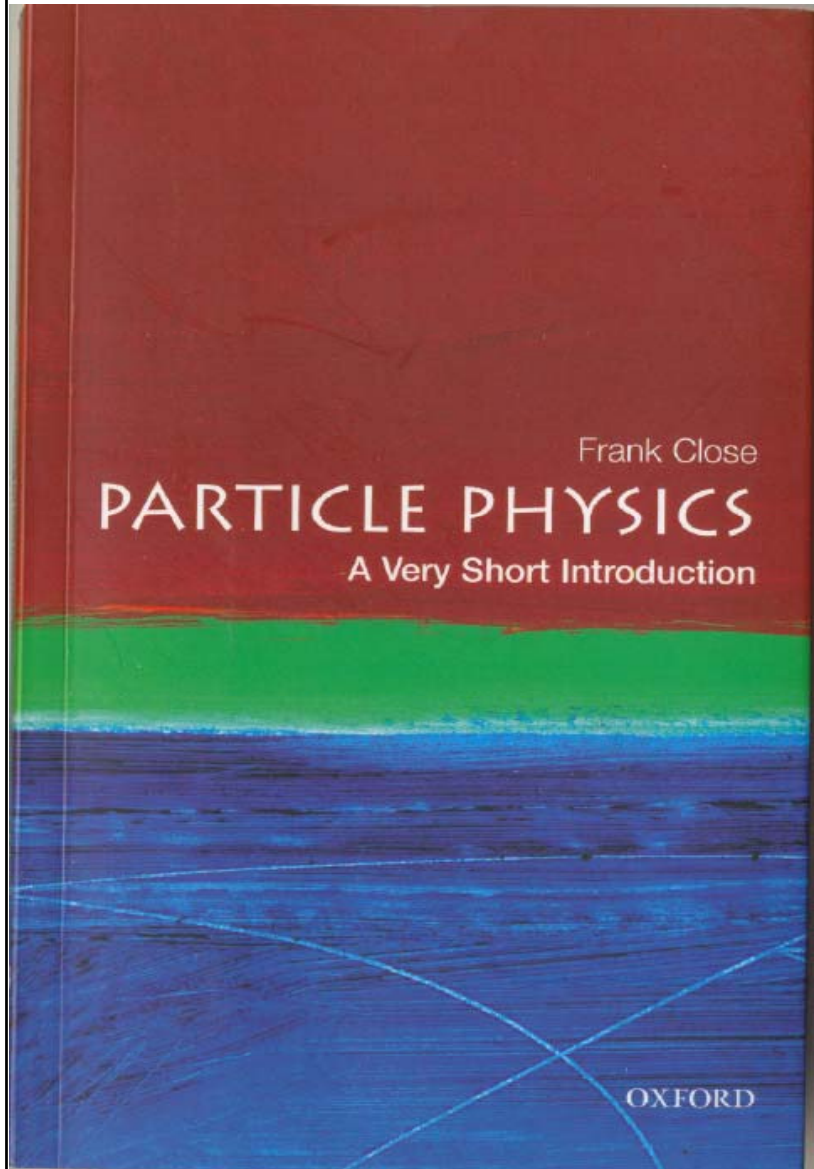
Temperature
Energy and
Time



...and the nature of matter



A Very Short Introduction



Coming out in December

NEW

THE COSMIC ONION

Quarks and the Nature of the Universe

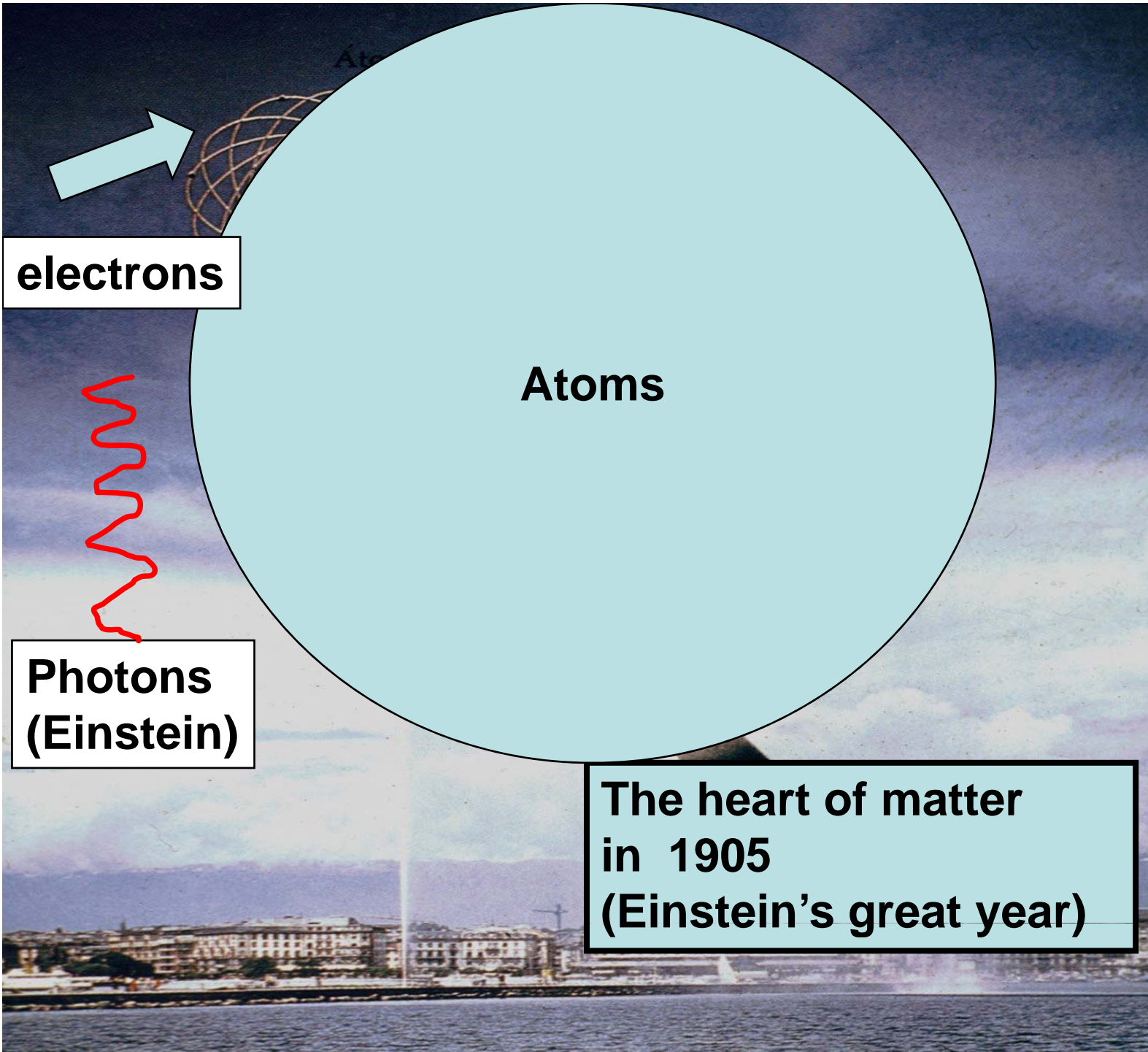


Frank Close

Particles in Three Minutes

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

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

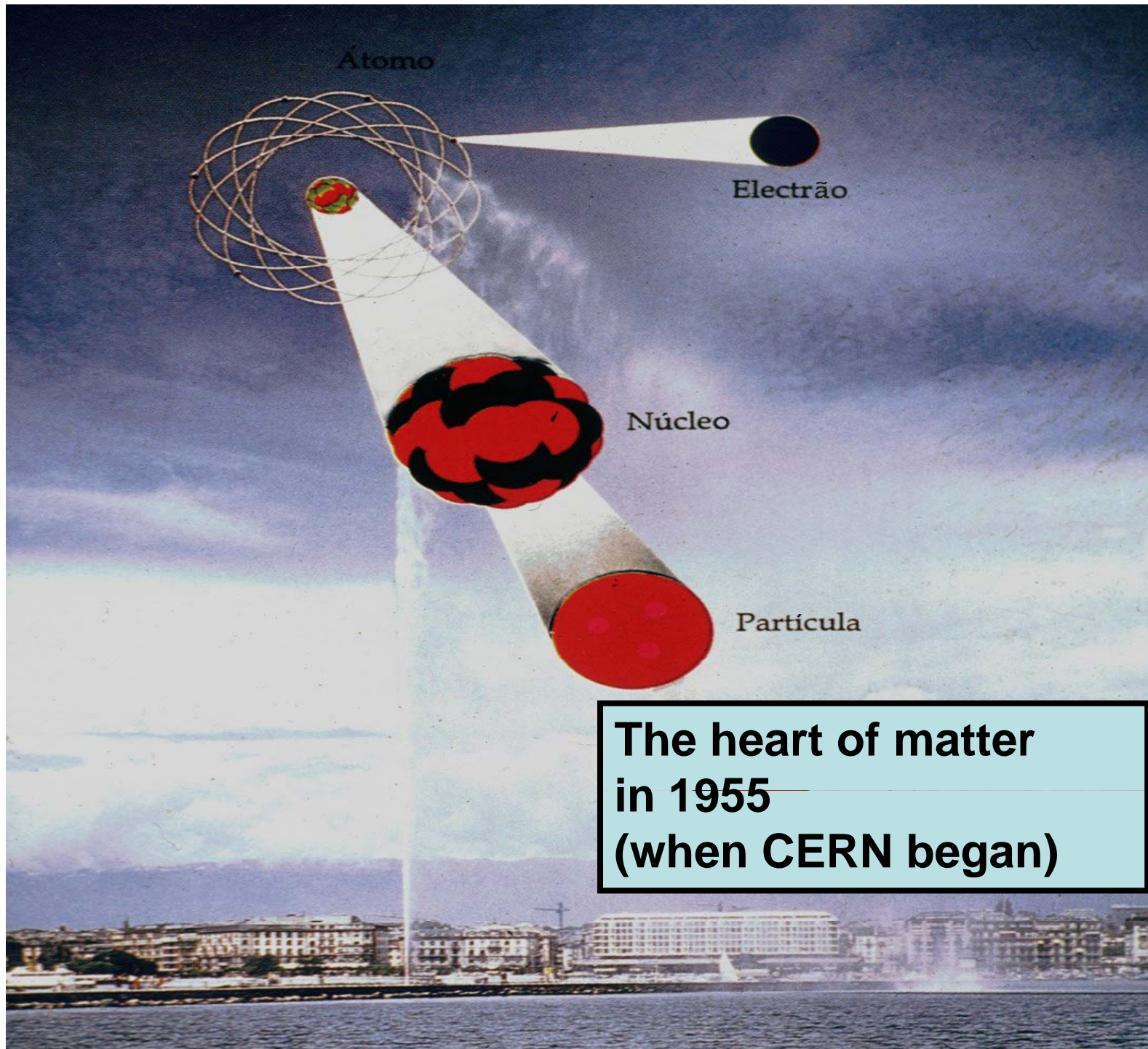


electrons

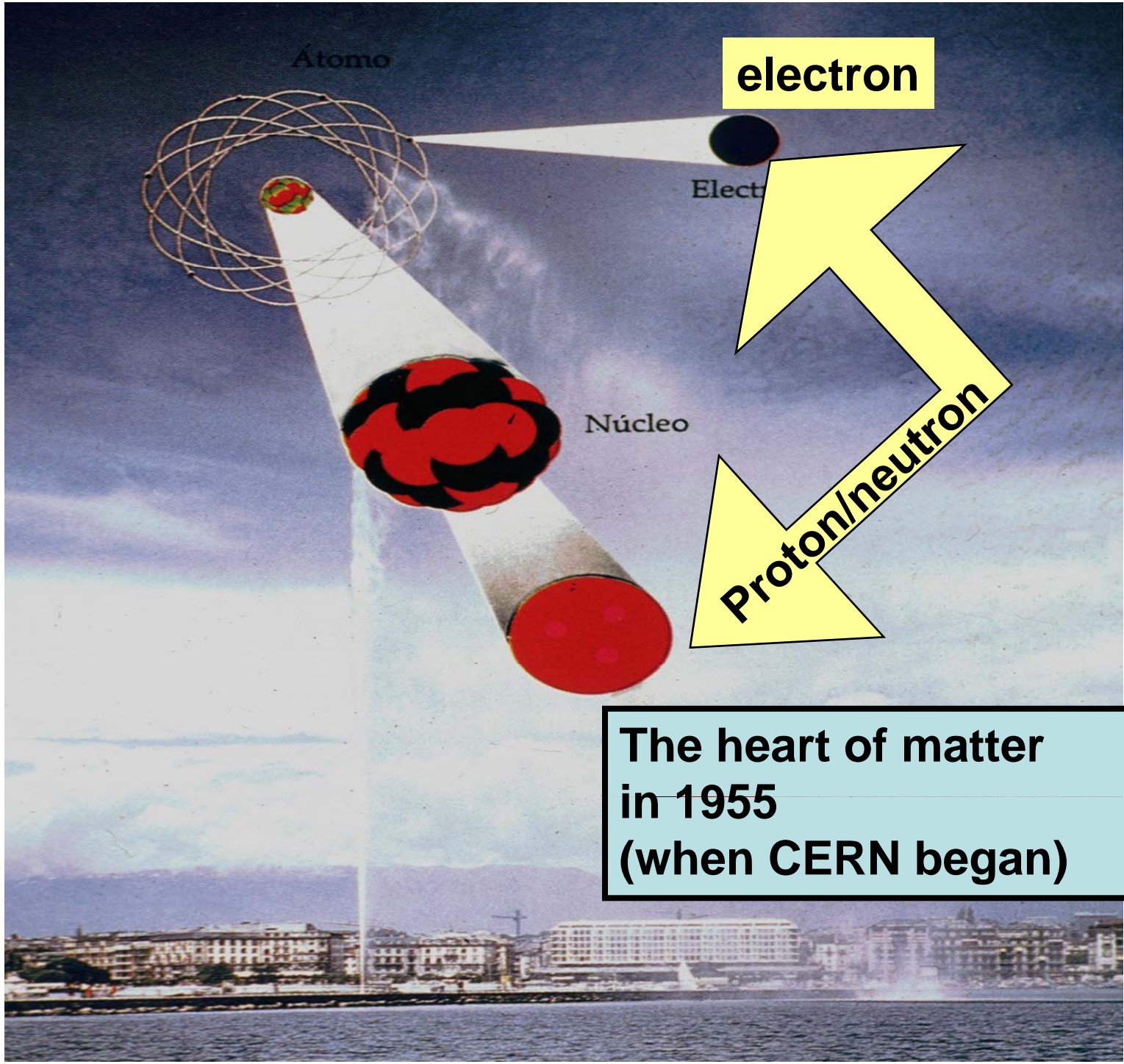
**Photons
(Einstein)**

Atoms

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



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



electron

Electrón

Núcleo

Proton/neutron

The heart of matter
in 1955
(when CERN began)

Electron
and
Proton
utterly
different.

proton
2000
times
heavier

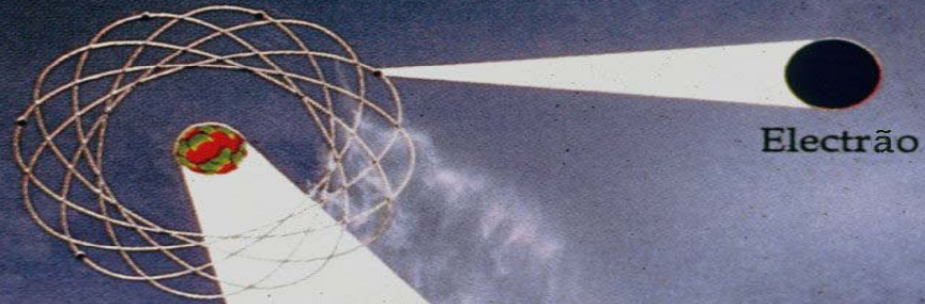
10000
times
bigger

1955

ELECTROMAGNETIC force binds electrons

FORCES

in the
atom



Electrão



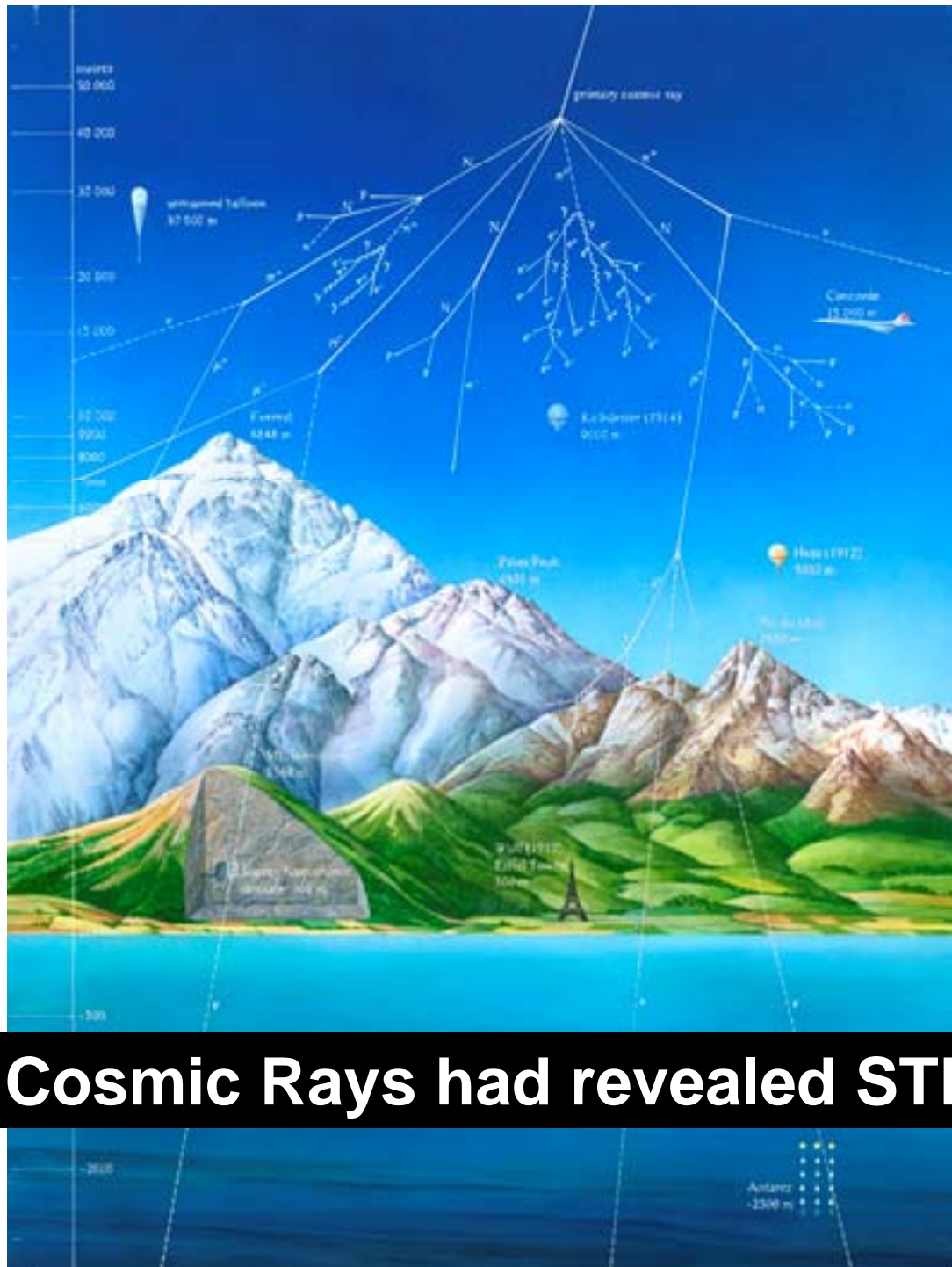
Núcleo

Partícula

STRONG force binds nucleus

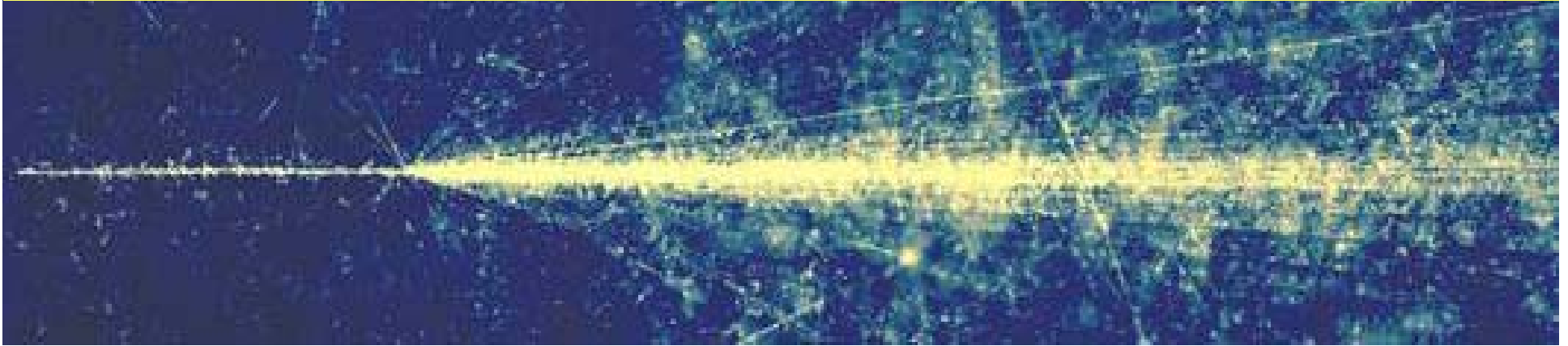
WEAK force = radioactivity



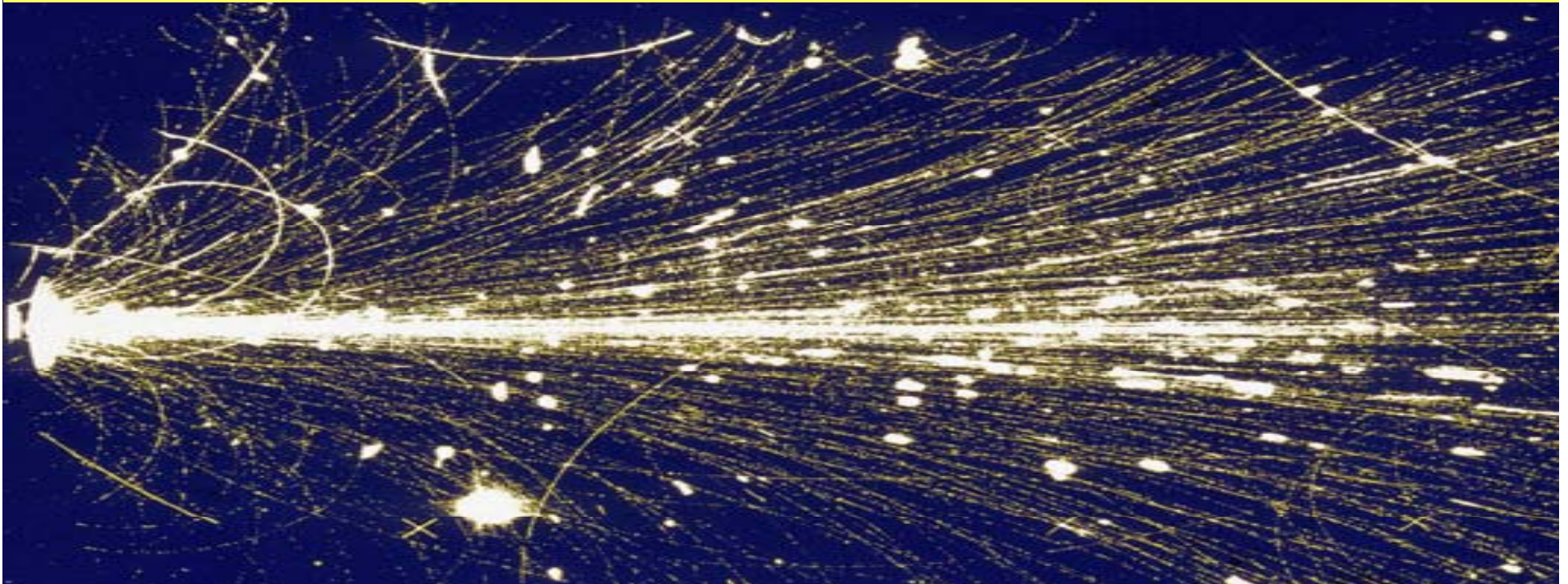


Cosmic Rays had revealed STRANGE particles

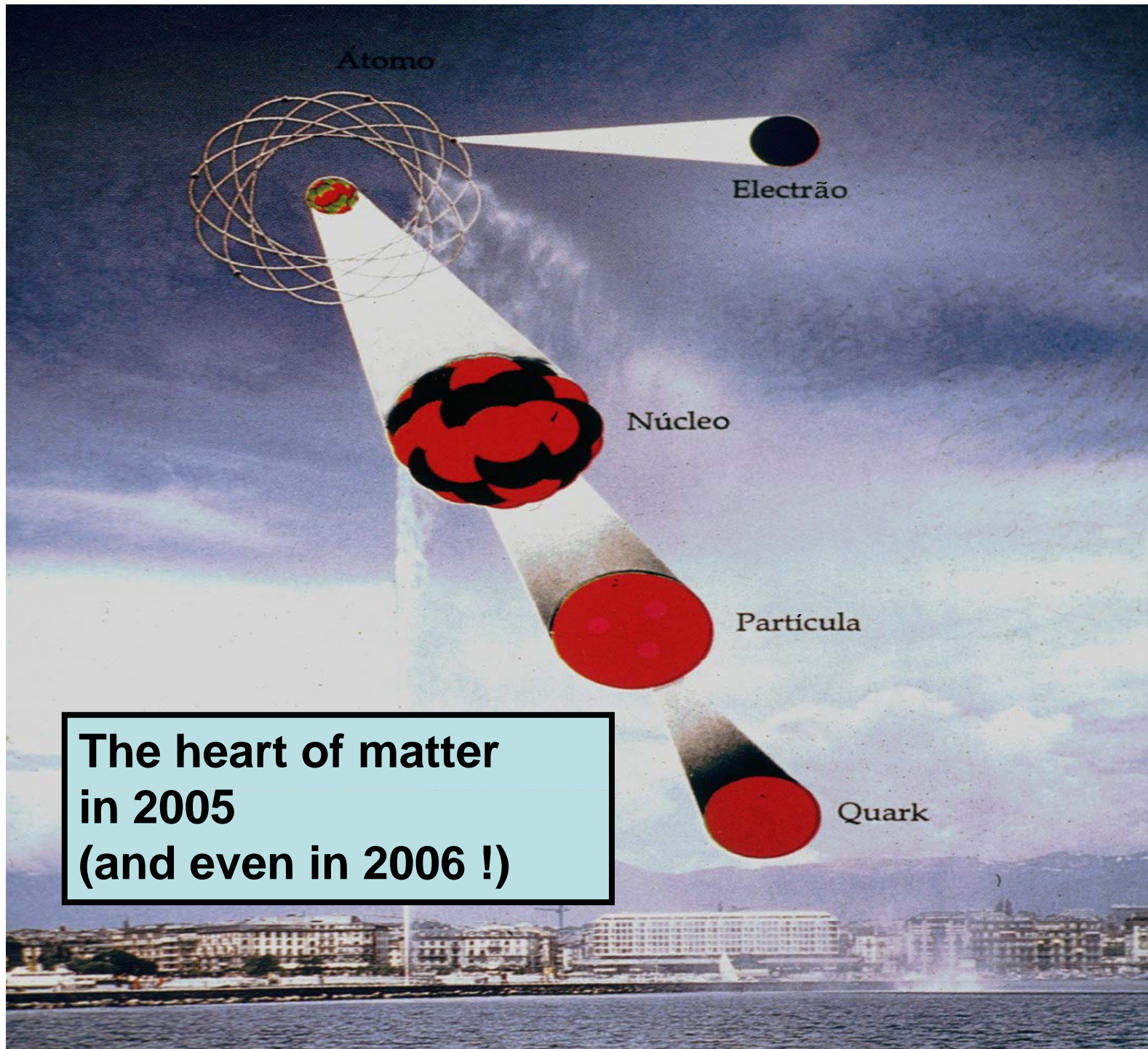
1955 CERN accelerators replicate cosmic rays on Earth...



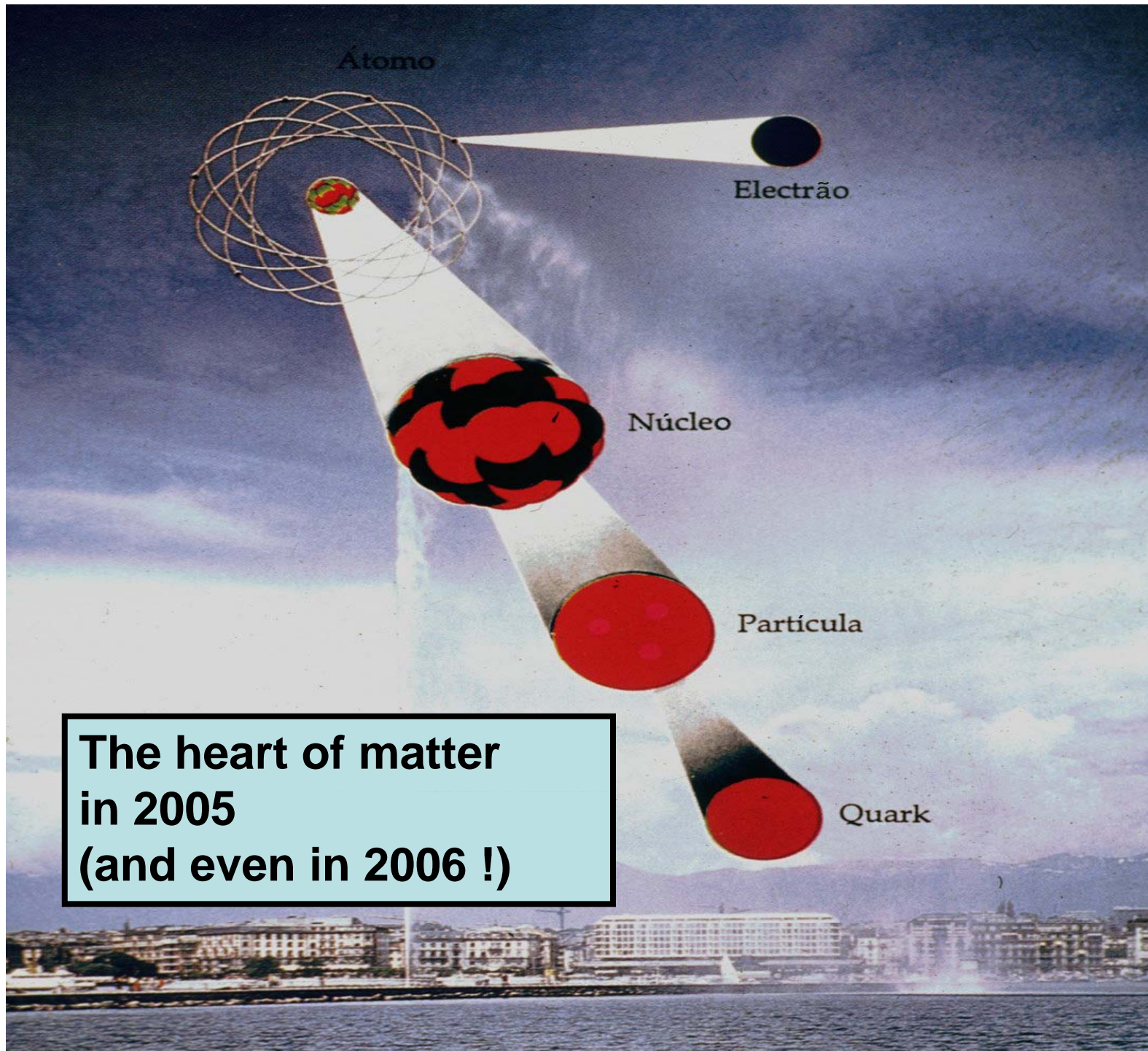
..record the images and reveal the real heart of matter....



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



**The heart of matter
in 2005
(and even in 2006 !)**



The heart of matter
in 2005
(and even in 2006 !)

Electron
and
quark
very
similar
in

Mass
Size
Spin

and in
how
they
respond
to the
FORCES

2005

ELECTROweak force binds electrons

FORCES

in the
atom

United
electroweak/QCD



Electrão

Núcleo

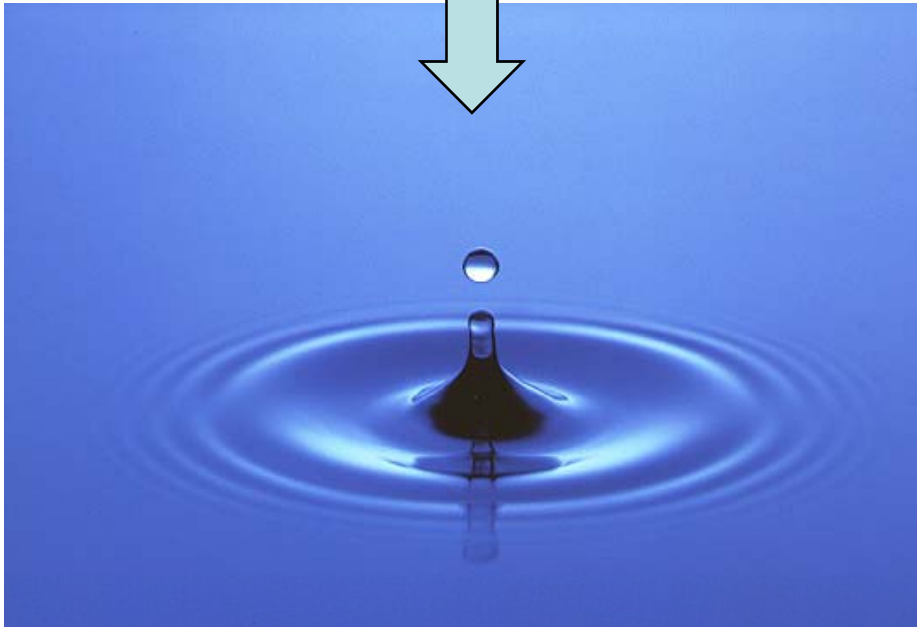
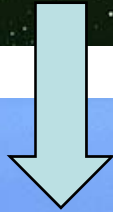
Partícula

Quark

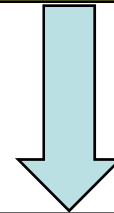
electroWEAK force = radioactivity

Colour QCD force binds quarks

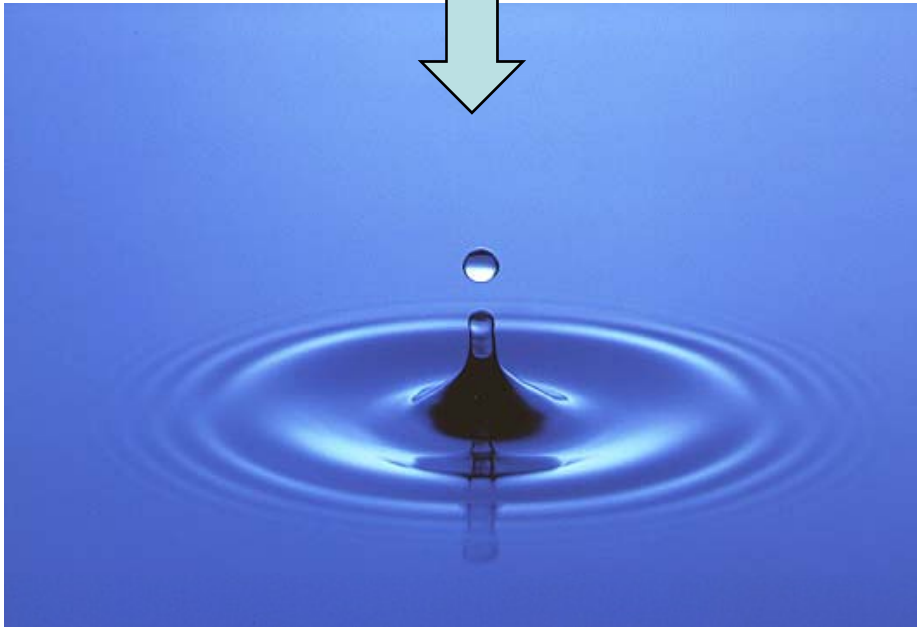
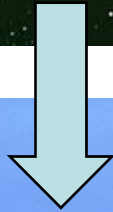




**patterns
and structures
when cold
(low energy)**



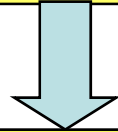
**Symmetry
when warm
(high
energy)**



FORCES 1955-2005

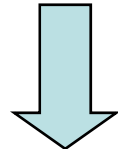
COLD

**Electromagnetic
Weak
Strong**



WARM

**ElectroWeak
Strong (QCD)**



HOT

**GrandUnified
Force**

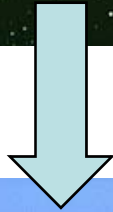


Standard Model of Quarks Leptons and forces

= **pattern** based on **mass**

“**cold**” = “low” energy

= **below 1 TeV**



Standard Model of Quarks Leptons and forces

= **pattern** based on **mass**

“**cold**” = “low” energy

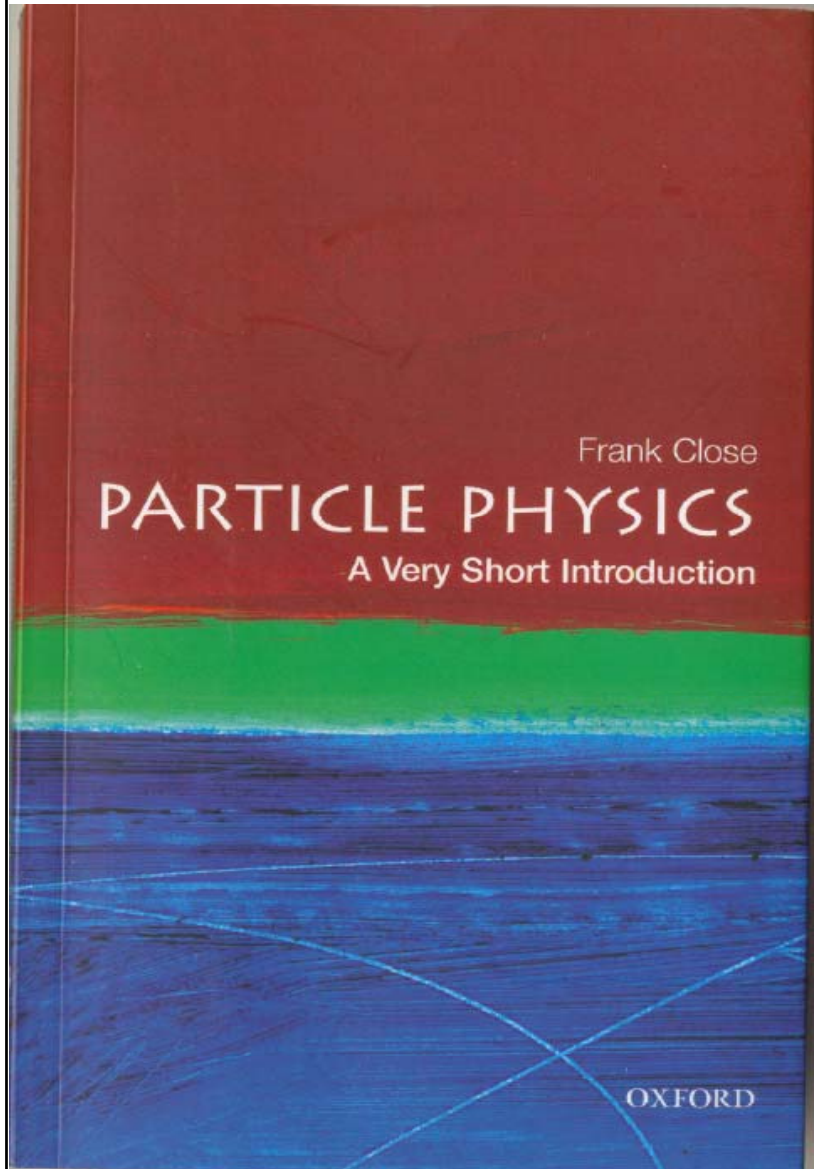
= **below 1 TeV**



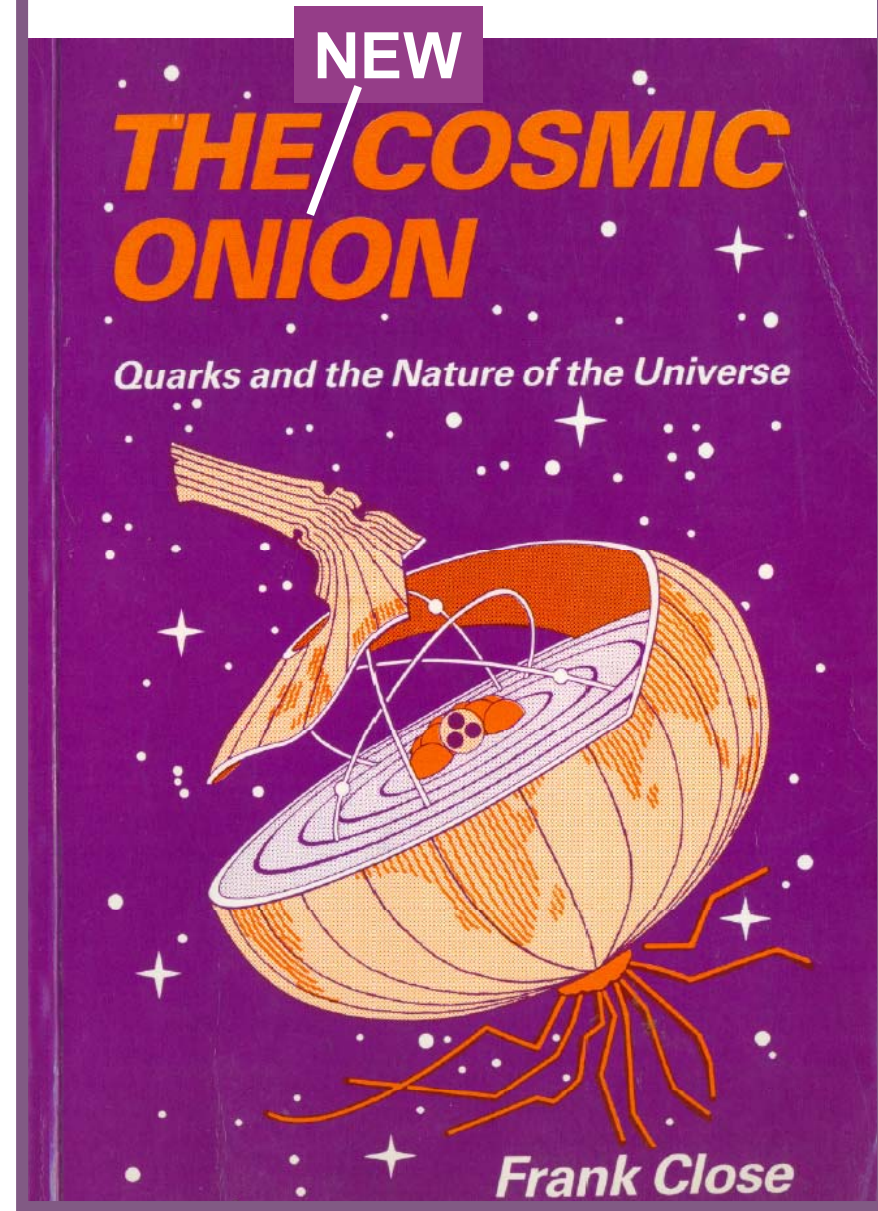
superSymmetry
when “**warm**”
(= high energy $> 1\text{TeV}$)

Higgs Boson
Supersymmetry
Nature of Reality

A Very Short Introduction



Coming out in December



...and patterns (that change)

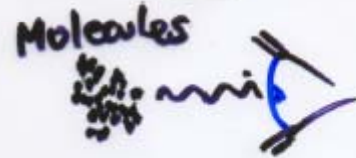
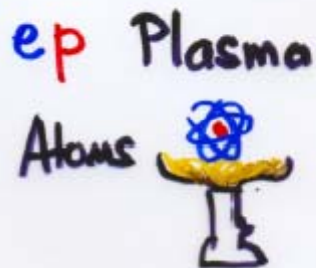
QG Plasma



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
MASS

t	b	τ	ν	W
c	s	μ	ν	Z
u	d	e	ν	γ

Nuclear Isotopes



Mendeleev



Snowflake pattern



even earlier univ.



TeV 10^{16} K

LHC

LEP



early univ.

$< 10^{-9}$ sec

GeV

MeV

100 sec.

KeV 10^7 K



eV 10^4 K

300K yrs

300K



meV

3K



10^{10} yrs
NO

