

Del átomo de Demócrito a nuestros días, una mirada al mundo de las partículas

Mario Rodríguez Cahuantzi

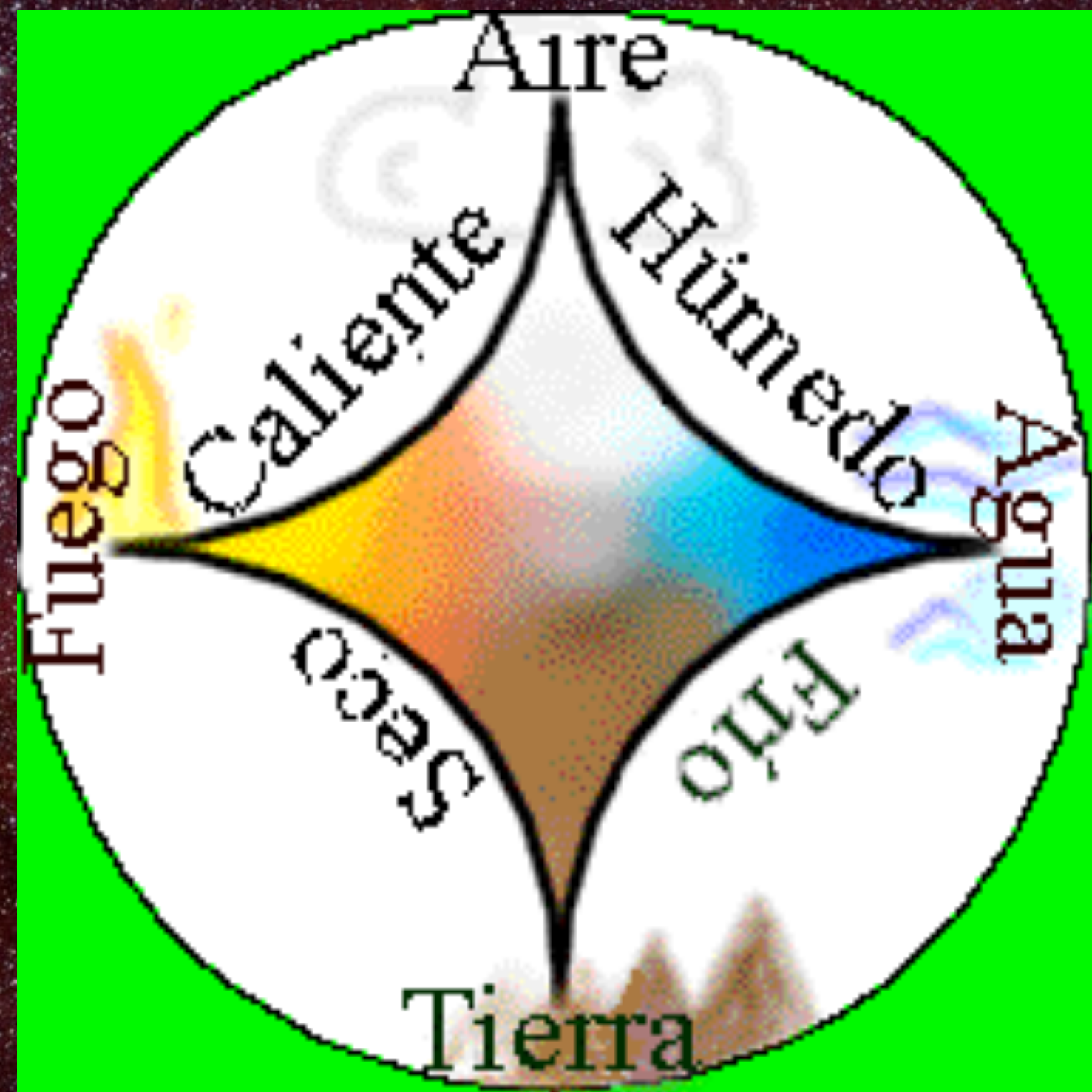
Facultad de Ciencias Físico Matemáticas,
Benemérita Universidad Autónoma de Puebla



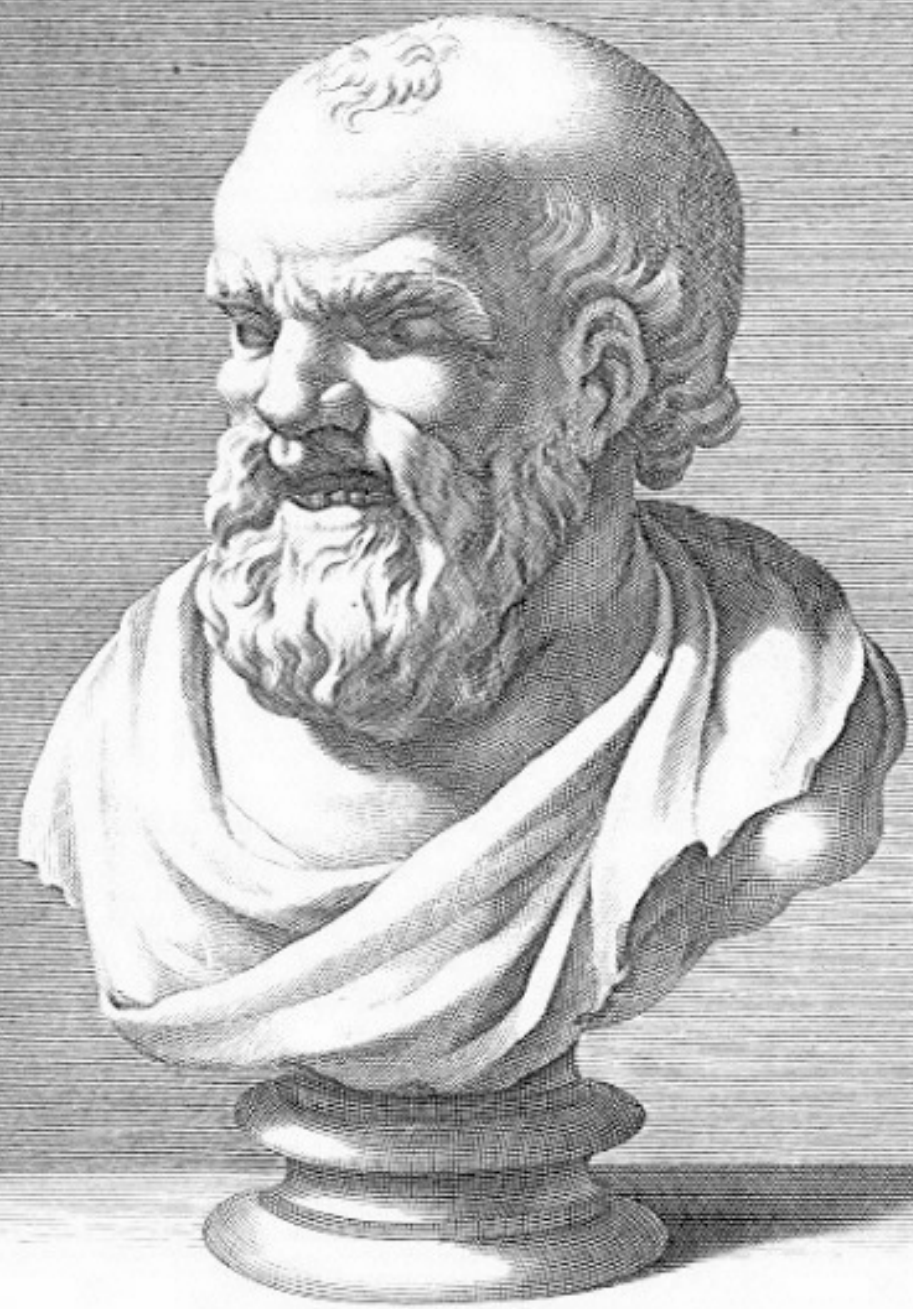
BUAP

**COLOQUIO DE DIVULGACIÓN ICN-UNAM
29 DE MARZO DE 2019**

¿DE QUÉ ESTÁ HECHO EL MUNDO?



EL FILÓSOFO GRIEGO EMPÉDOCLES EN EL SIGLO 5TO AC FUE EL PRIMERO EN CLASIFICAR COMO ELEMENTOS FUNDAMENTALES LA TIERRA, EL AIRE, EL FUEGO, Y EL AGUA.



DEMOCRITUS

Ex marmore antiquo apud J. S.

DEMÓCRITO DE ABDERA VIVIÓ
ENTRE LOS AÑOS 460 AL 370 A. C.

DEMÓCRITO DESARROLLÓ LA "TEORÍA ATÓMICA DEL
UNIVERSO":

- ★ LOS ÁTOMOS SON ETERNOS, INDIVISIBLES, HOMOGÉNEOS, INCOMPRESIBLES E INVISIBLES.
- ★ LOS ÁTOMOS SE DIFERENCIAN SOLO EN FORMA Y TAMAÑO, PERO NO POR CUALIDADES INTERNAS.
- ★ LAS PROPIEDADES DE LA MATERIA VARÍAN SEGÚN EL AGRUPAMIENTO DE LOS ÁTOMOS.

-13.819 MIL MILLONES DE AÑOS



EL PRIMER HOMINIDO (TOUMAI)

- 7 MILLONES DE AÑOS

MÁS DE 1'000 BILLONES DE GRADOS
CENTÍGRADOS

TEMPERATURA DEL SOL:
15 BILLONES DE GRADOS
CENTÍGRADOS

200 MILLONES DE TONELADAS POR cm^3



LA PIRAMIDE DEL SOL EN
LA CABEZA DE UN ALFILER

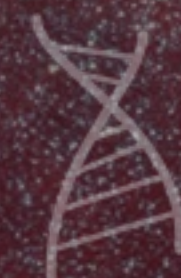
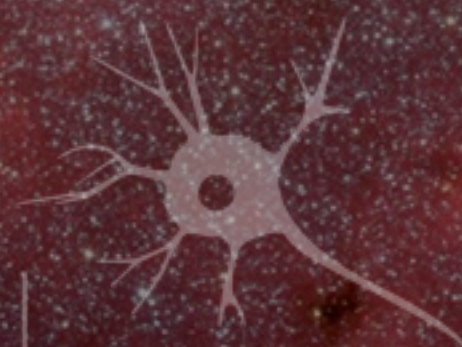
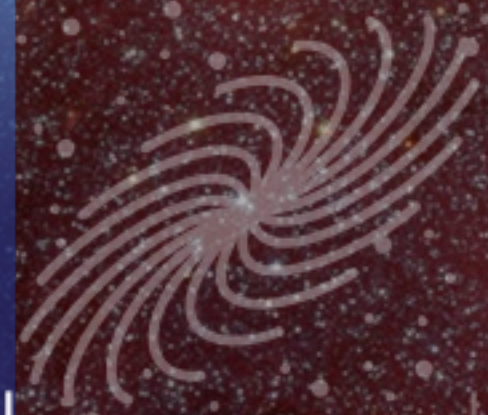


13.819 BILLONES
DE AÑOS



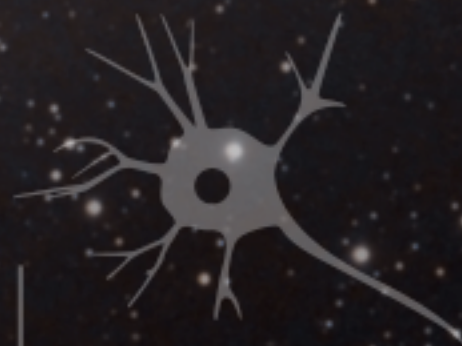
UNIVERSO

$>10^{26}\text{m}$



GALAXIAS

$\sim 10^{21}m$

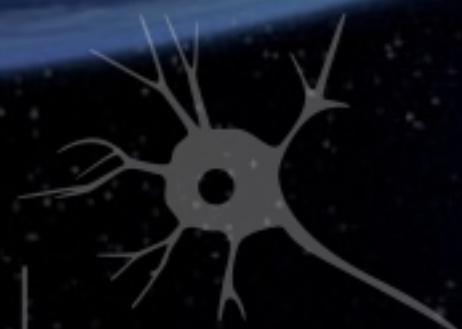


9



SISTEMA SOLAR

$\sim 10^{12}m$

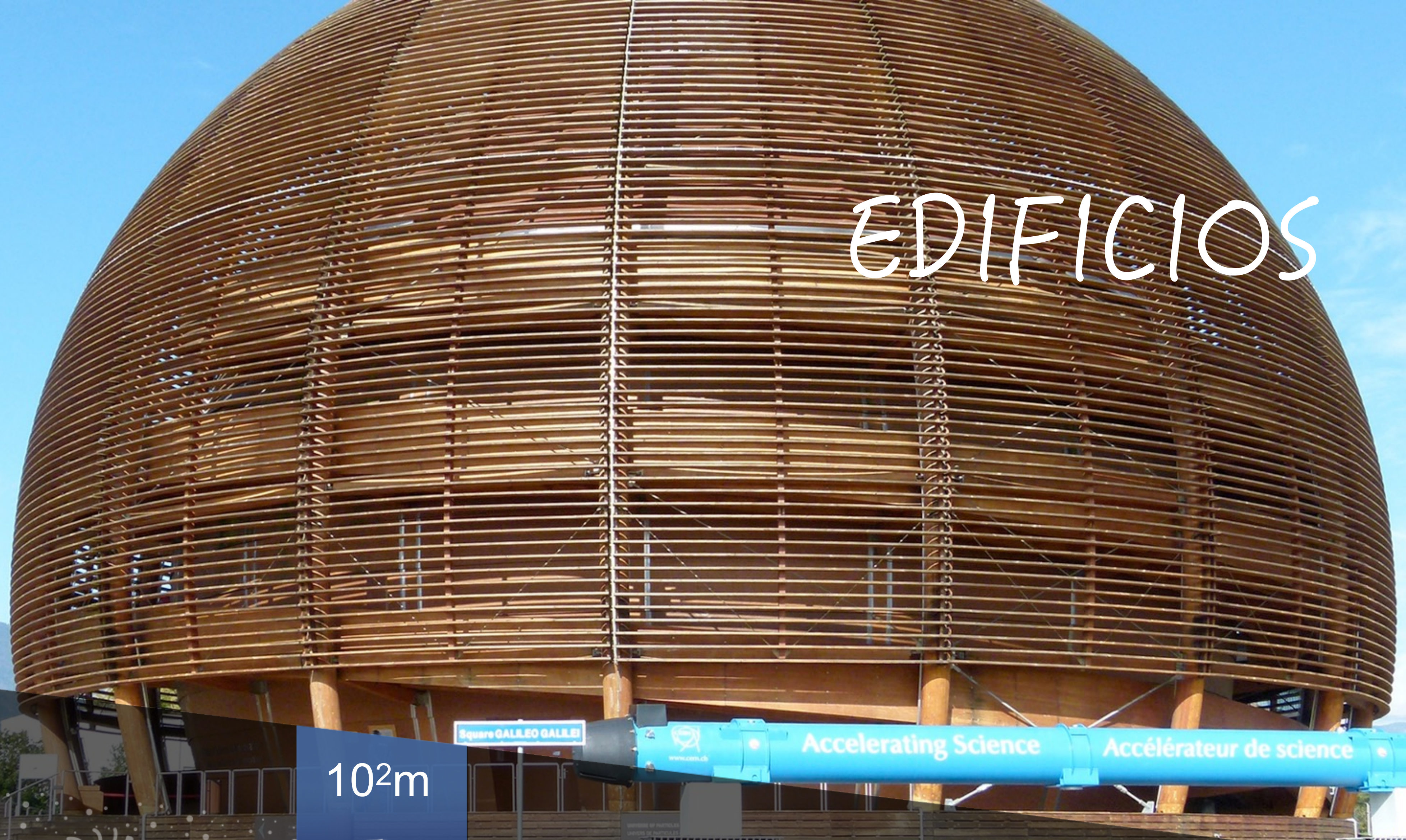


10

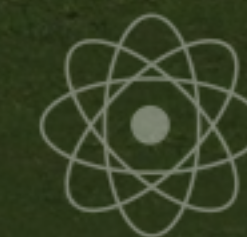
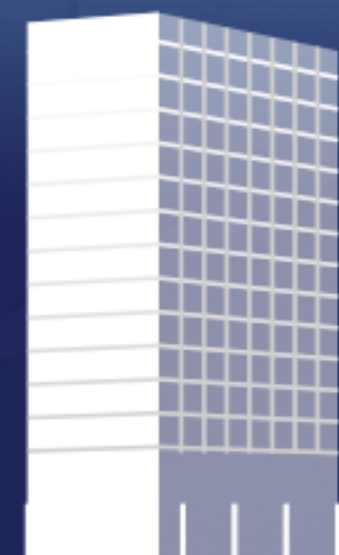


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EDIFICIOS

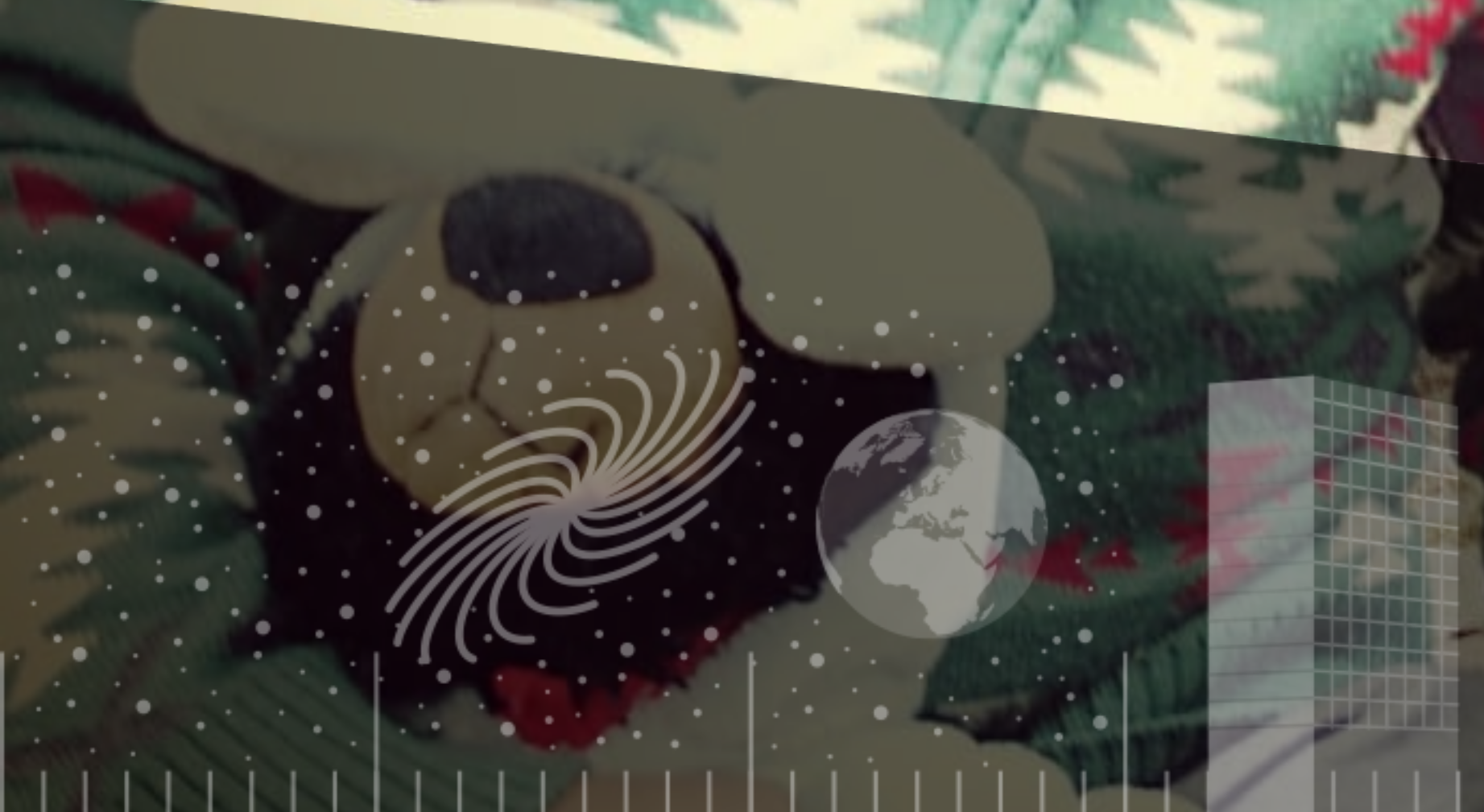


102m






EL SER HUMANO



1.74m

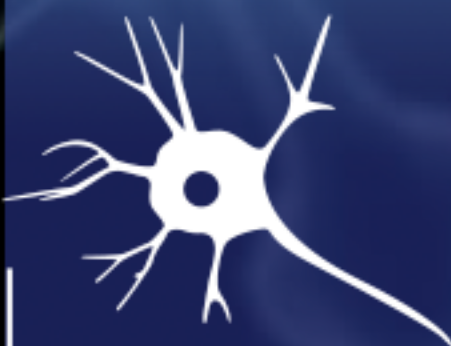


12



NEURONAS

10⁻⁵m



13



BUAP

ADN

10^{-9}m

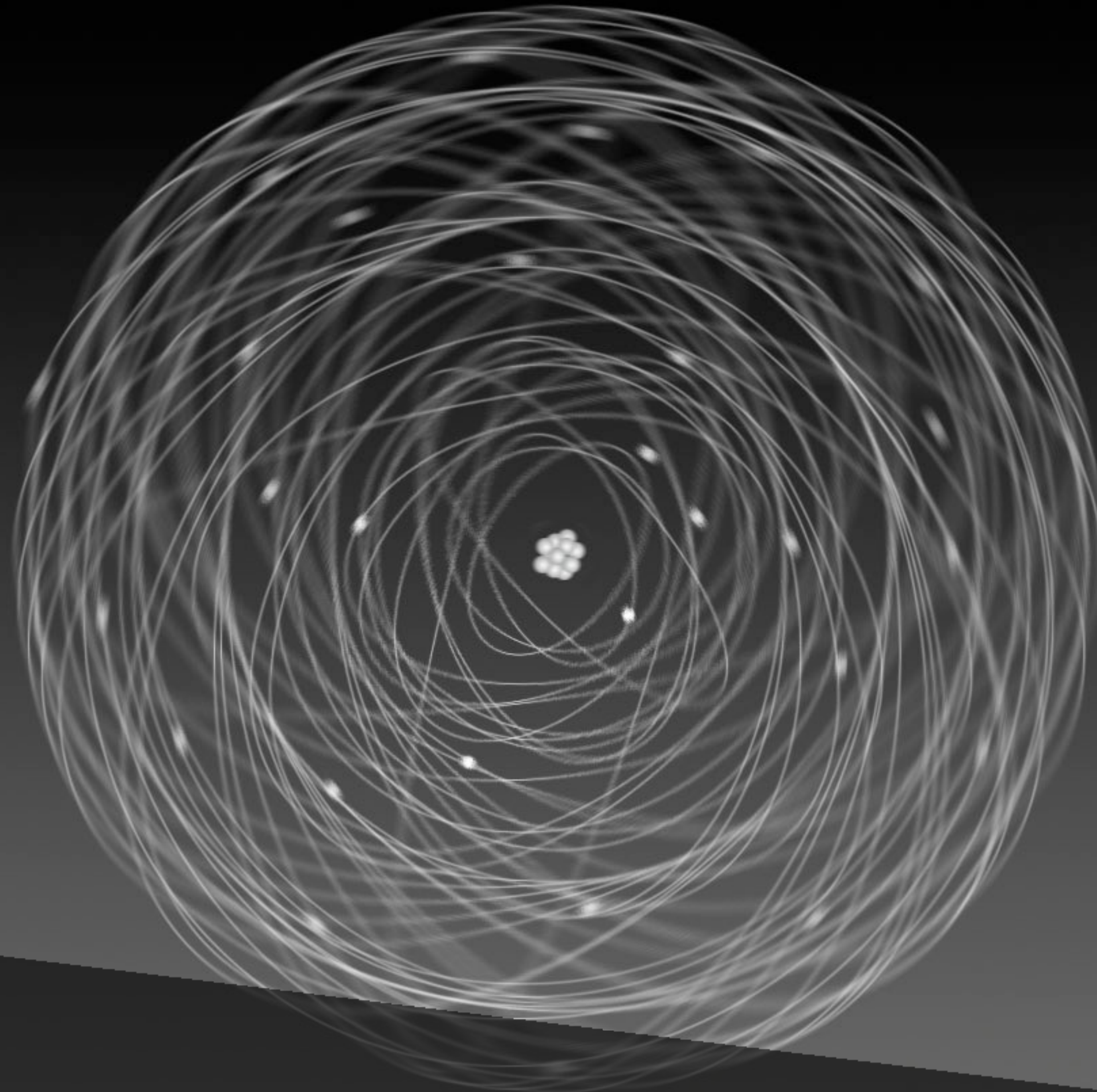


MOLÉCULAS

10^{-9}m



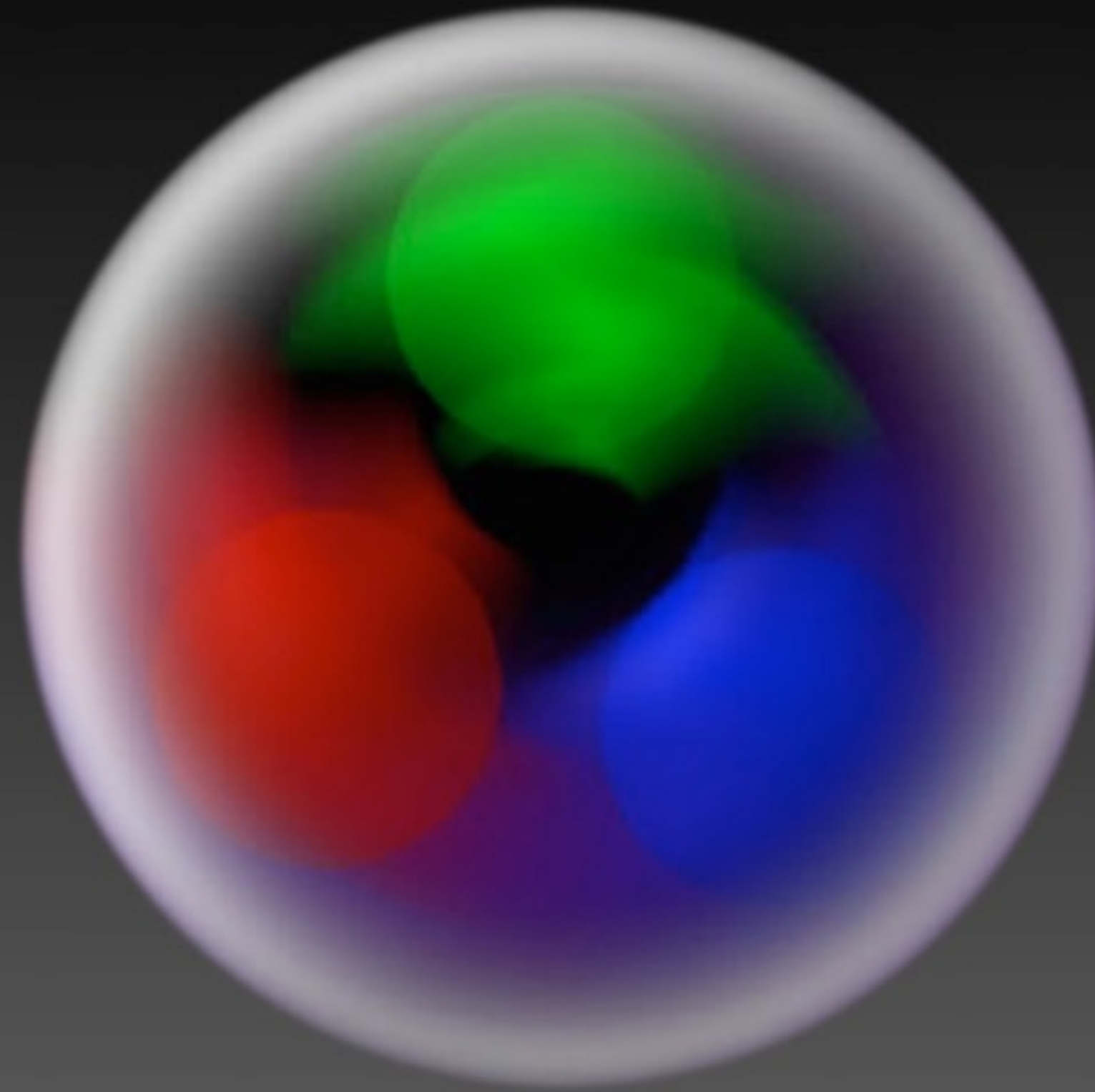
ÁTOMOS



10^{-10}m



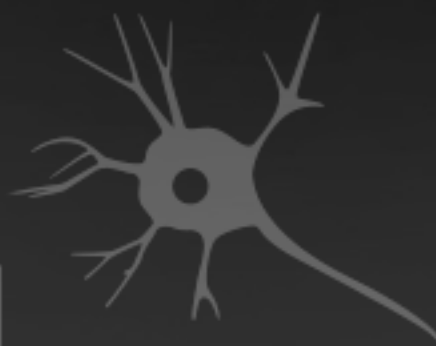
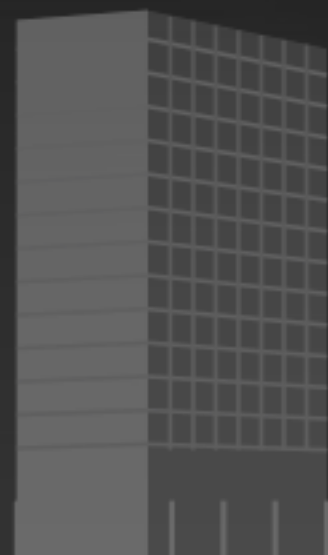
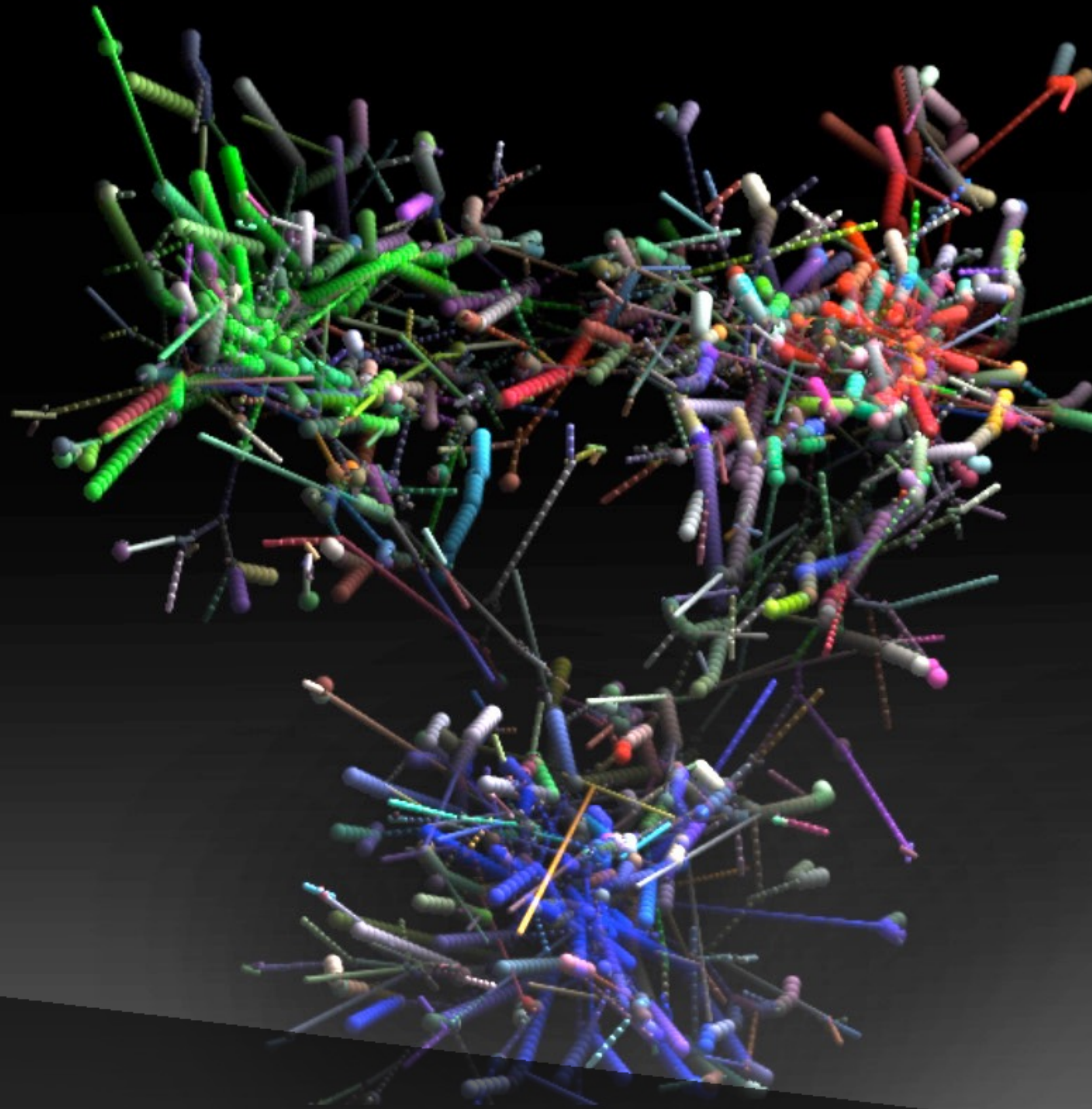
PROTONES



10⁻¹⁵m

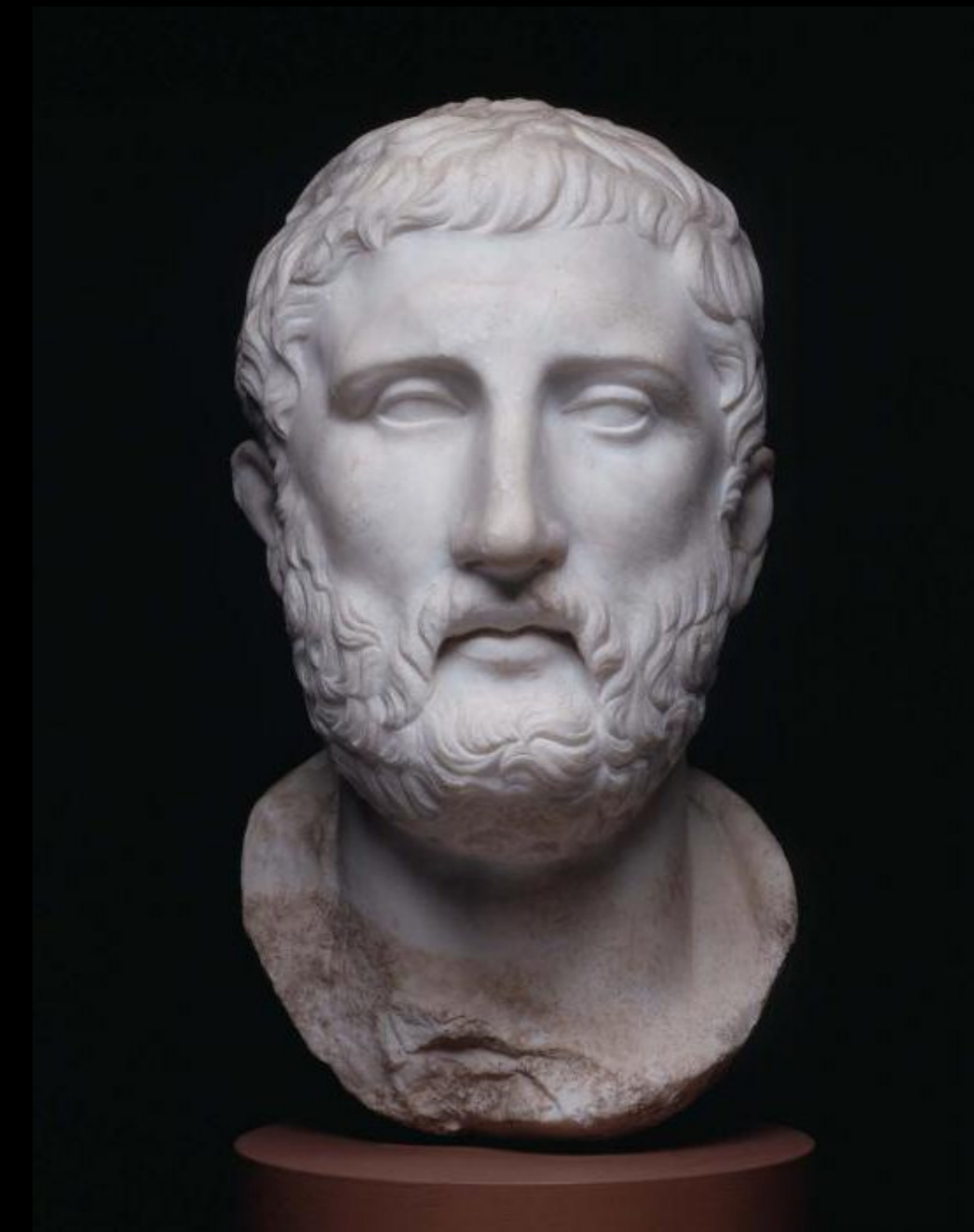


QUARKS



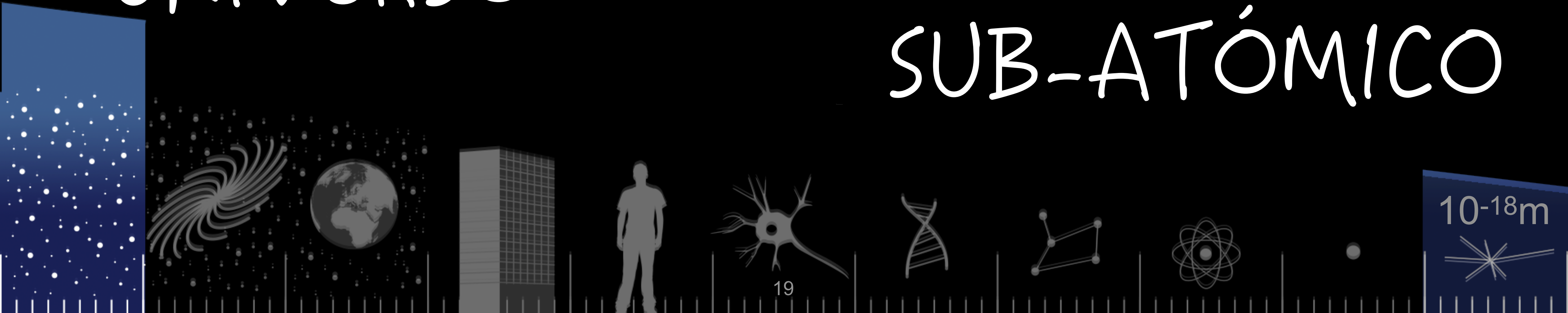
10⁻¹⁸m





UNIVERSO

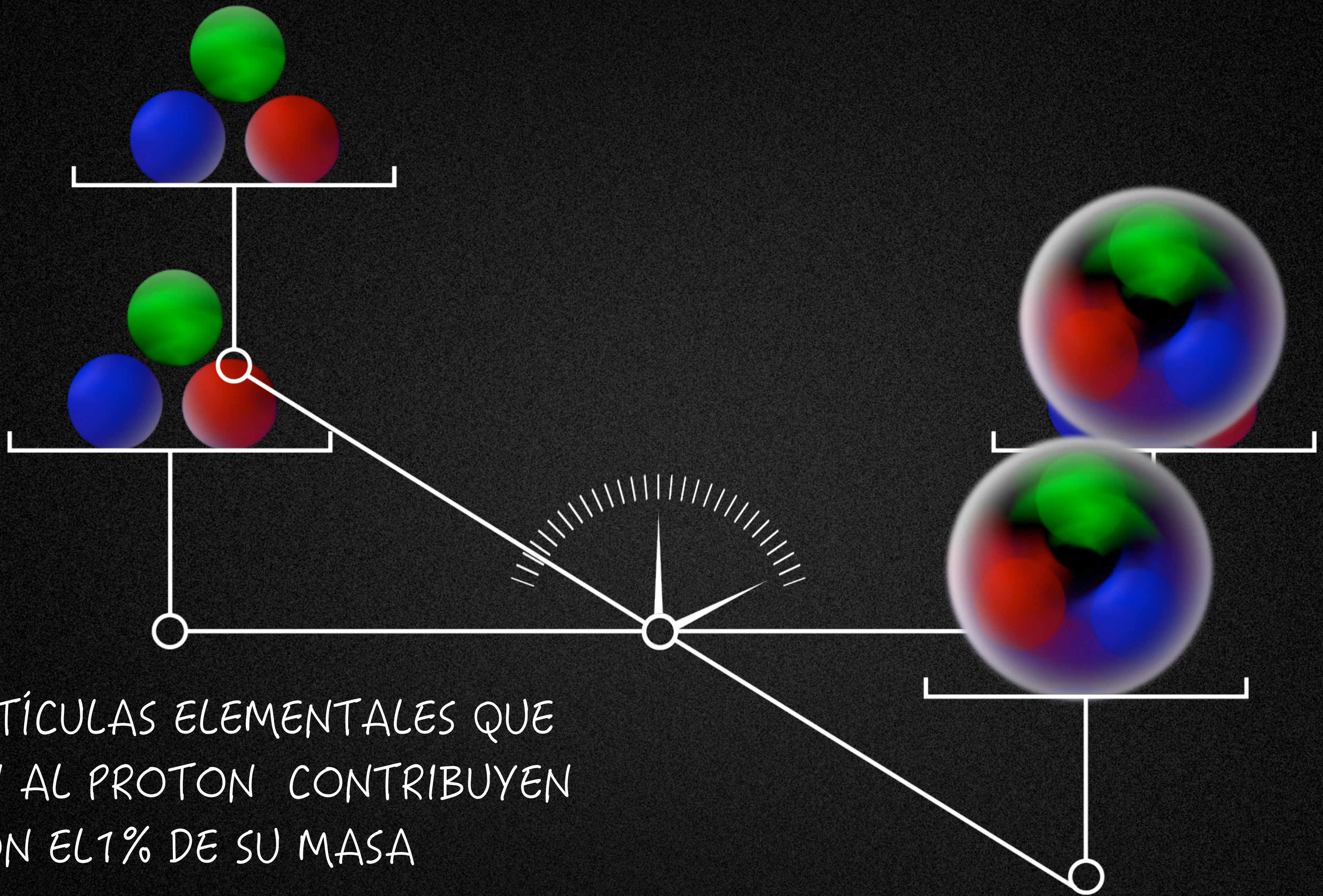
SUB-ATÓMICO



QUE SABEMOS SOBRE LA
MATERIA?

LA MATERIA ESTA VACÍA





LAS PARTÍCULAS ELEMENTALES QUE FORMAN AL PROTON CONTRIBUYEN SOLO CON EL 1% DE SU MASA



QUE SABEMOS SOBRE
LA MATERIA?

LA MATERIA
ES INMATERIAL

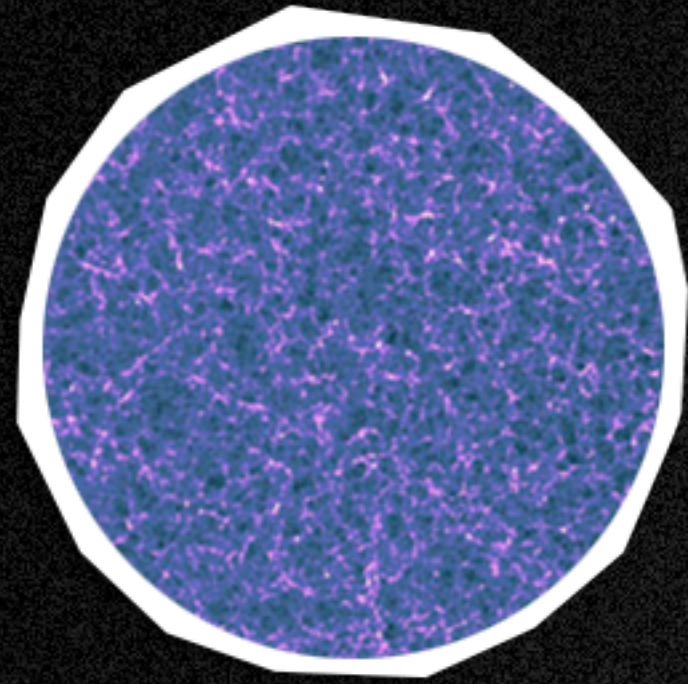
MATERIA ESTA VACIA



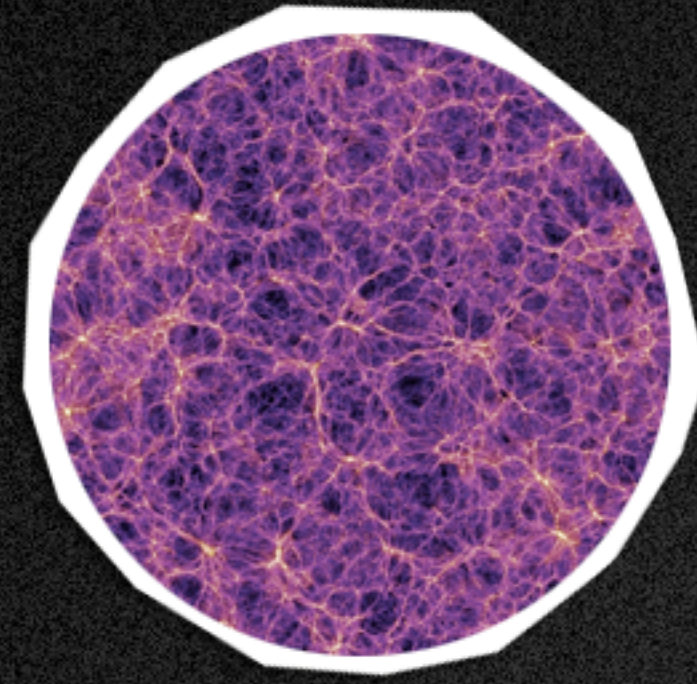
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LAS FUERZAS
DAN ESTRUCTURA A
LA MATERIA





UNIVERSO



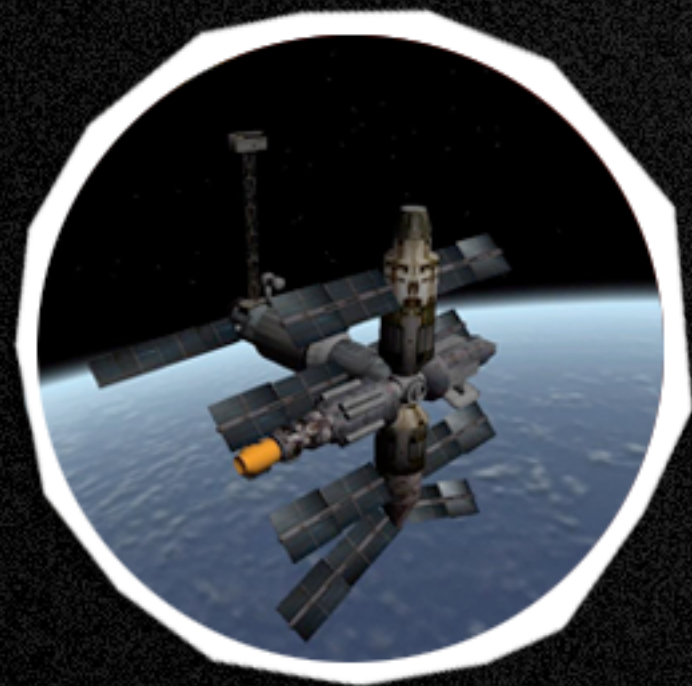
FRONTERAS
Y VACIOS



CLUSTERS -
SUPERCLUSTERS



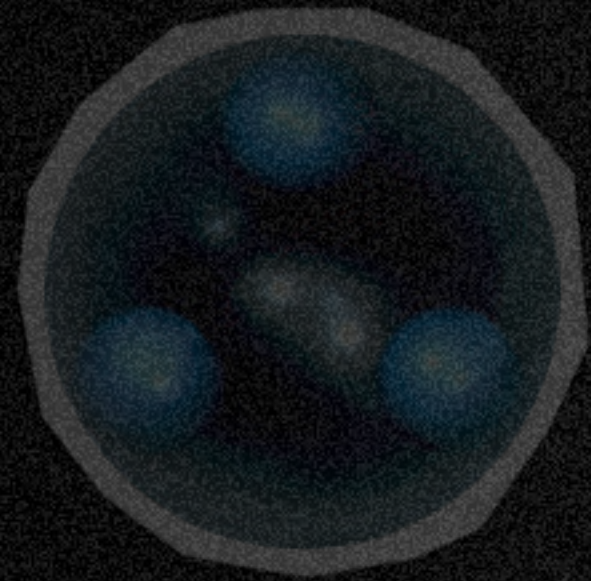
GALAXIAS



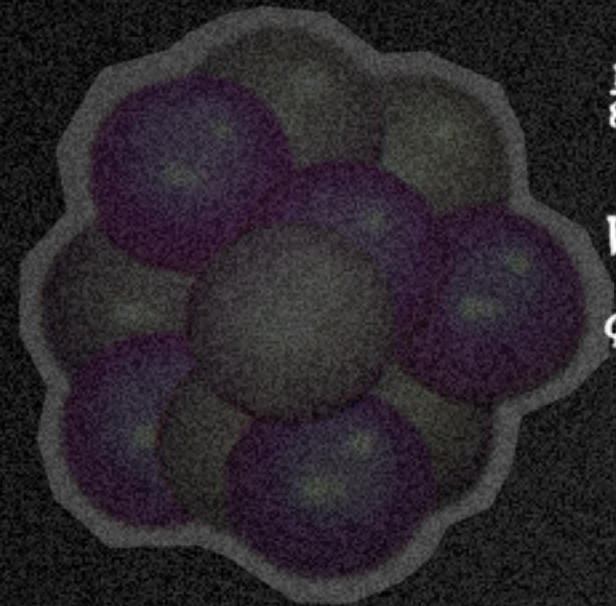
$$R_{\mu\nu} - 1/2 R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

LA FUERZA GRAVITACIONAL

THE STRONG FORCE



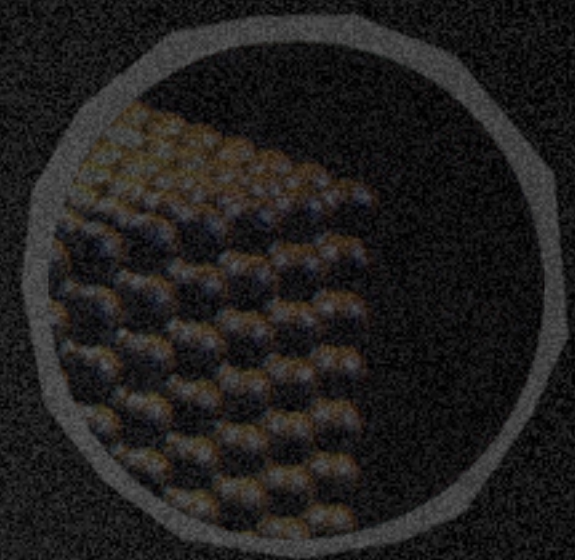
QUARKS



PROTONS AND NEUTRONS

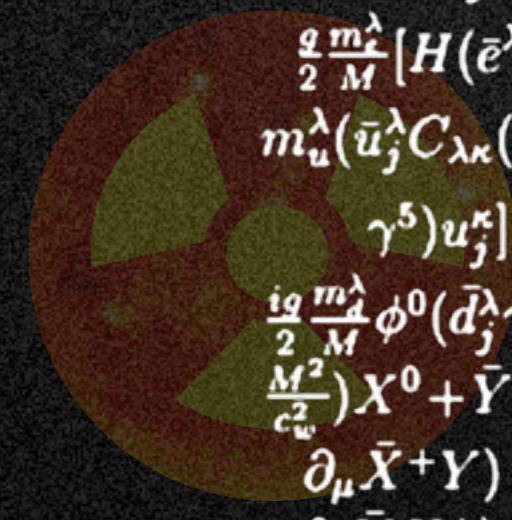
$$\begin{aligned}
 & -\frac{1}{2}\partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \\
 & \frac{1}{2}ig_s^2 (\bar{q}_i^\sigma \gamma^\mu q_j^\sigma) g_\mu^a + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - \\
 & M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_w^2} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \\
 & \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2} M \phi^0 \phi^0 - \beta_h \left[\frac{2M^2}{g^2} + \right. \\
 & \left. \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{g^2} \alpha_h - igc_w [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - Z_\nu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - \\
 & W_\nu^- \partial_\nu W_\mu^+)] - igs_w [\partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - A_\nu (W_\mu^+ \partial_\nu W_\mu^- - \\
 & W_\mu^- \partial_\nu W_\mu^+) + A_\mu (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+)] - \frac{1}{2}g^2 W_\mu^+ W_\mu^- W_\nu^+ W_\nu^- + \\
 & \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\mu^+ W_\nu^- + g^2 c_w^2 (Z_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + \\
 & g^2 s_w^2 (A_\mu W_\mu^+ A_\nu W_\nu^- - A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g\alpha [H^3 + H\phi^0 \phi^0 + 2H\phi^+ \phi^-] - \\
 & \frac{1}{8}g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2] - \\
 & gMW_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^0 Z_\mu^0 H - \frac{1}{2}ig [W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - \\
 & W_\mu^- (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \frac{1}{2}g [W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W_\mu^- (H \partial_\mu \phi^+ - \\
 & \phi^+ \partial_\mu H)] + \frac{1}{2}g \frac{1}{c_w} (Z_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - ig \frac{s_w^2}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
 & igs_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + \\
 & igs_w A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \frac{1}{4}g^2 W_\mu^+ W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \\
 & \frac{1}{4}g^2 \frac{1}{c_w^2} Z_\mu^0 Z_\mu^0 [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w^2}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - \\
 & g^1 s_w^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \\
 & \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + igs_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \\
 & \frac{ig}{4c_w} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_w^2 - \\
 & 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + \\
 & (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{ig}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger \gamma^\mu (1 + \\
 & \gamma^5) u_j^\lambda)] + \frac{ig}{2\sqrt{2}} \frac{m_\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \\
 & \frac{g}{2} \frac{m_\lambda}{M} [H (\bar{e}^\lambda e^\lambda) + i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}_j^\lambda C_{\lambda\kappa} (1 - \gamma^5) d_j^\kappa) + \\
 & m_u^\lambda (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \gamma^5) d_j^\kappa) + \frac{ig}{2M\sqrt{2}} \phi^- [m_d^\kappa (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\kappa) - m_u^\kappa (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 - \\
 & \gamma^5) u_j^\kappa) - \frac{g}{2} \frac{m_\lambda}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_\lambda}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_\lambda}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \\
 & \frac{ig}{2} \frac{m_\lambda}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{X}^+ (\partial^2 - M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \\
 & \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + igc_w W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + igs_w W_\mu^+ (\partial_\mu \bar{Y} X^- - \\
 & \partial_\mu \bar{X}^+ Y) + igc_w W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + igs_w W_\mu^- (\partial_\mu \bar{X}^- Y - \\
 & \partial_\mu \bar{Y} X^+) + igc_w Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + igs_w A_\mu (\partial_\mu \bar{X}^+ X^+ - \\
 & \partial_\mu \bar{X}^- X^-) - \frac{1}{2}gM [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2} \bar{X}^0 X^0 H] + \\
 & \frac{1-2c_w^2}{2c_w} igM [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \frac{1}{2c_w} igM [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \\
 & igMs_w [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \frac{1}{2} igM [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
 \end{aligned}$$

ELECTROMAGNETIC



ATOMS

THE WEAK FORCE



MATTER

QUE SABEMOS SOBRE
LA MATERIA?

LA MATERIA ES
ESTRUCTURADA
POR 4 FUERZAS

MATERIA ESTA VACIA

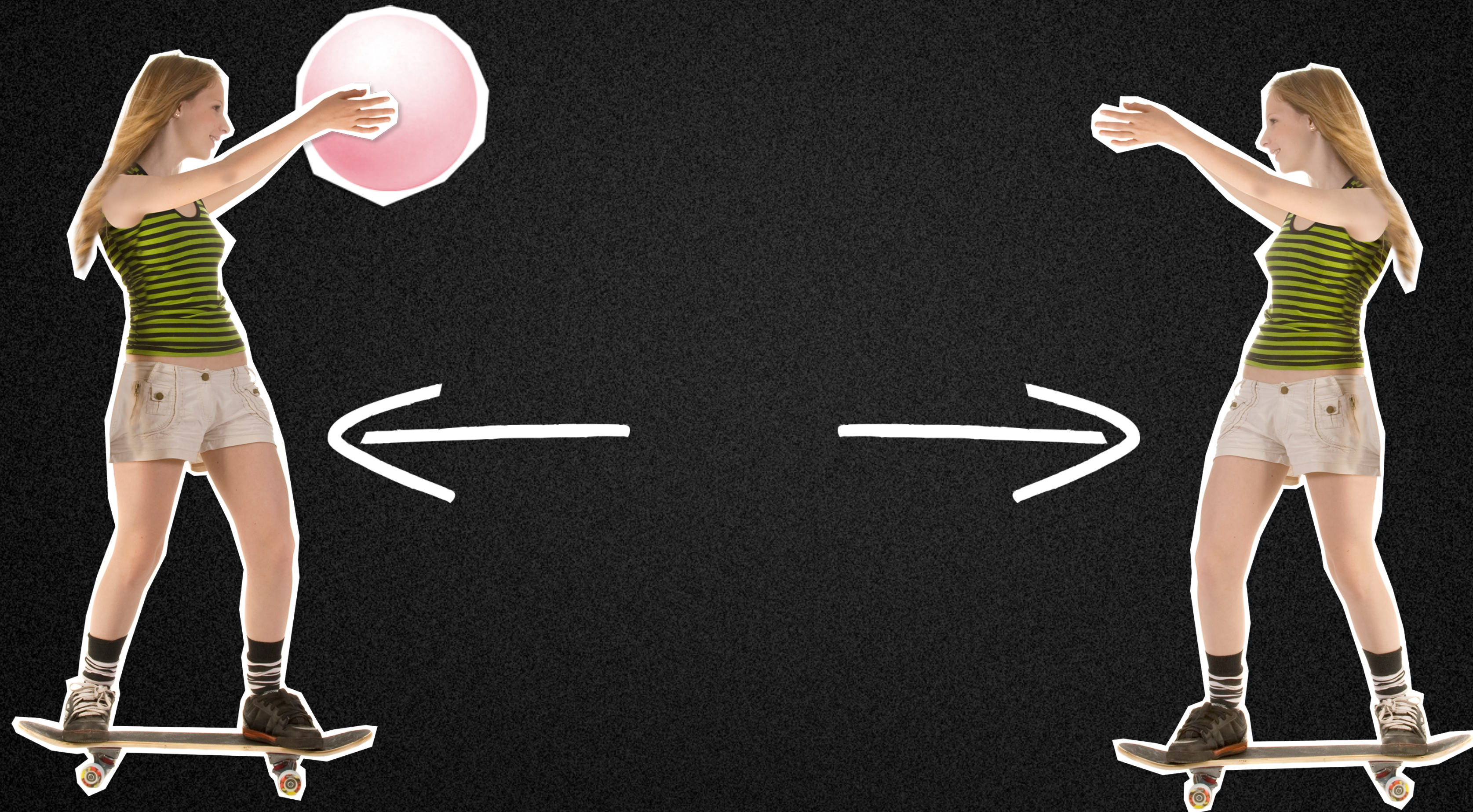
LA MATERIA ES
IMMATERIAL



LAS PARTÍCULAS
INTERACTÚAN
INTERCAMBIANDO
PARTÍCULAS
MENSAJERAS



INTERACCIONES REPULSIVAS



INTERACCIONES DE ATRACCIÓN



QUARKS

u	c	t
d	s	b

e	μ	τ
ν_e	ν_μ	ν_τ

LEPTONES

g	Z,W
γ	graviton

MENSAJEROS

QUARKS

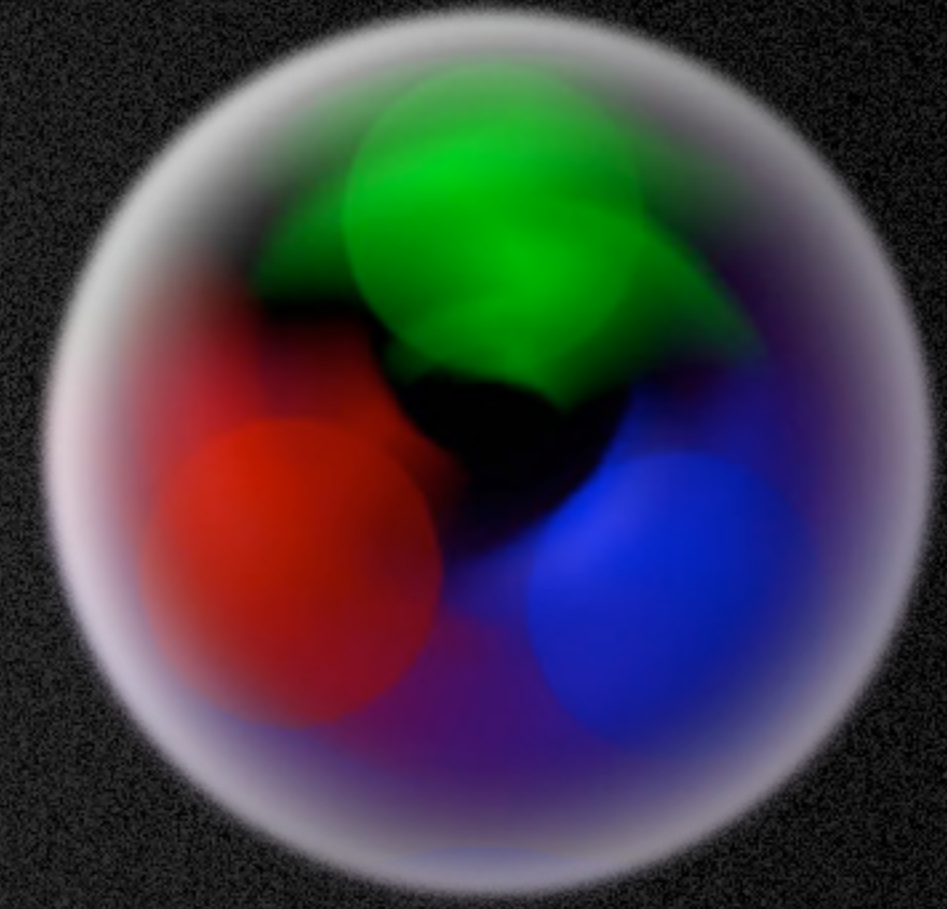
u	c	t
d	s	b

e	μ	τ
ν_e	ν_μ	ν_τ

LEPTONES

g	Z,W
γ	graviton

MENSAJEROS



HADRONES

QUARKS

u c t

d s b

e μ τ

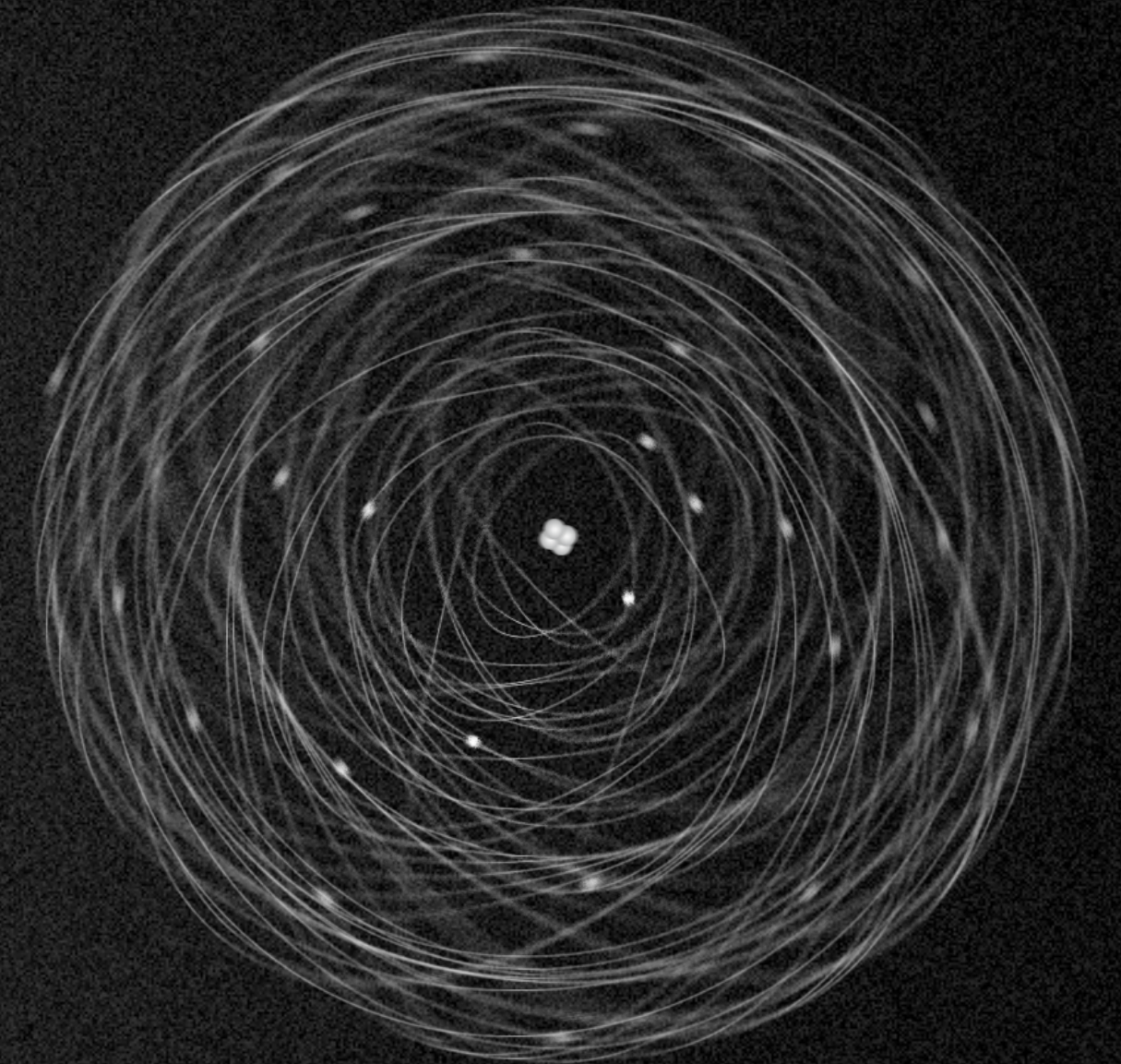
ν_e ν_μ ν_τ

LEPTONES

g Z,W

γ graviton

MENSAJEROS



QUARKS

u c t

d s b

e μ τ

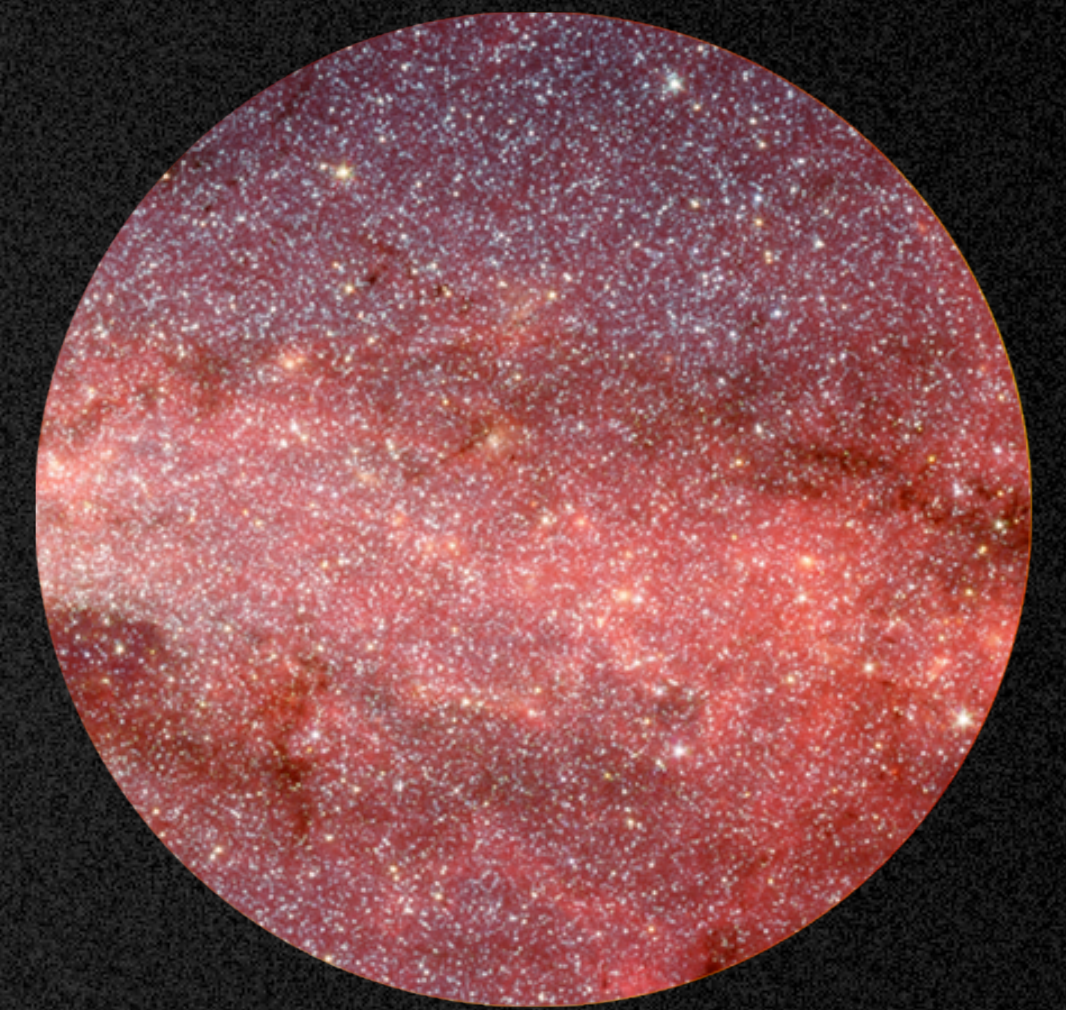
ν_e ν_μ ν_τ

LEPTONES

g Z,W

γ graviton

MENSAJEROS



QUARKS

u c t

d s b

e μ τ

ν_e ν_μ ν_τ

LEPTONES

H

g Z,W

γ graviton

MENSAJEROS

QUE SABEMOS SOBRE
LA MATERIA?

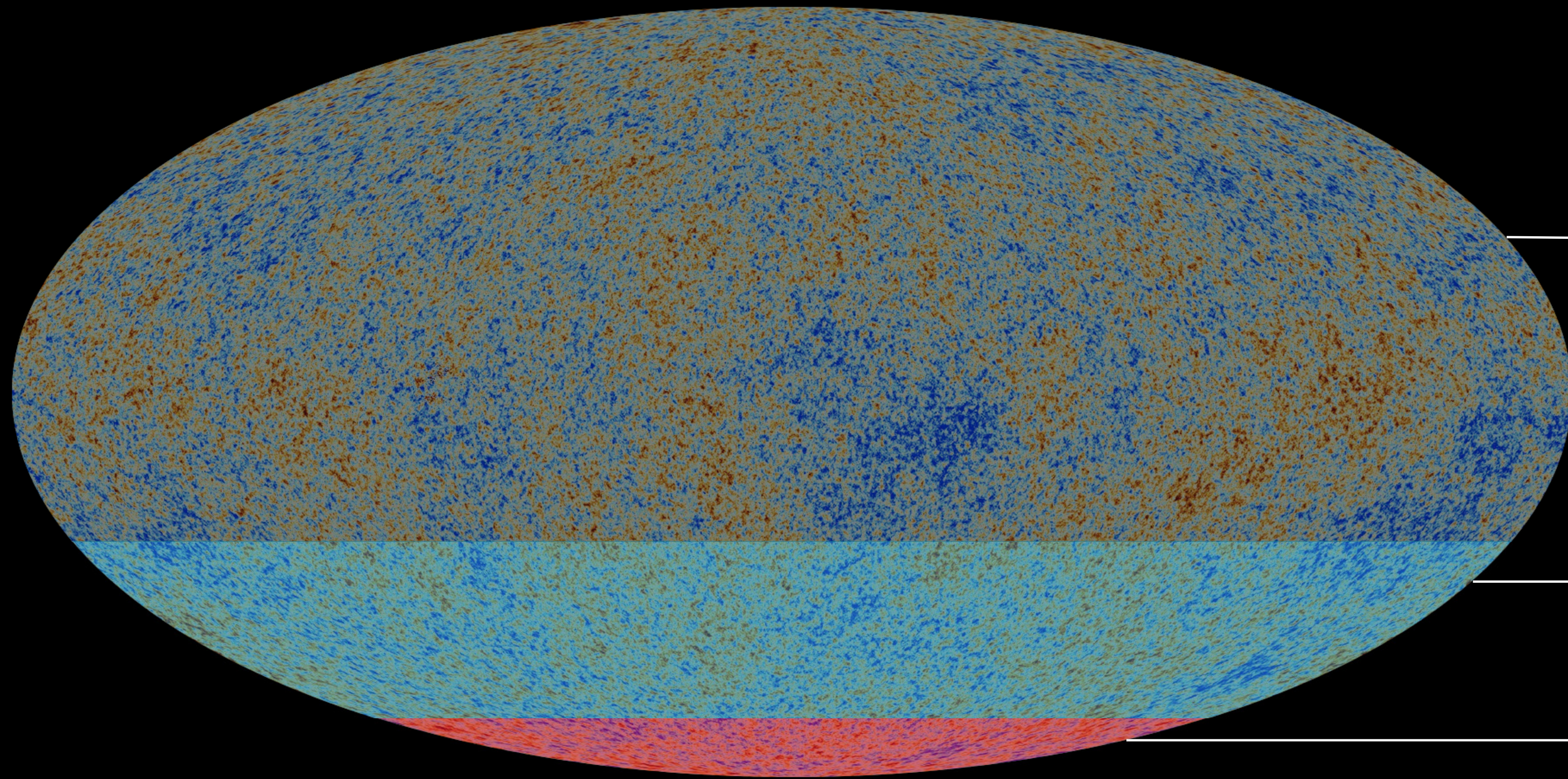
4 PARTÍCULAS ELEMENTALES
CONSTITUYEN LA MATERIA
ORDINARIA....

MATERIA ESTA VACIA

LA MATERIA ES
IMATERIAL

LA MATERIA ES ESTRUCTURADA
POR 4 FUERZAS

LA FOTO MAS ANTIGUA DEL UNIVERSO:
380'000 AÑOS DESPUÉS DEL BIG-BANG, TIBIO ... 2700°C,
FORMACIÓN DEL PRIMER ÁTOMO



69,4%
ENERGIA
OSCURA

25,8%
MATERIA
OSCURA

4,8%
MATERIA
VISIBLE

QUE SABEMOS ACERCA
DE LA MATERIA?

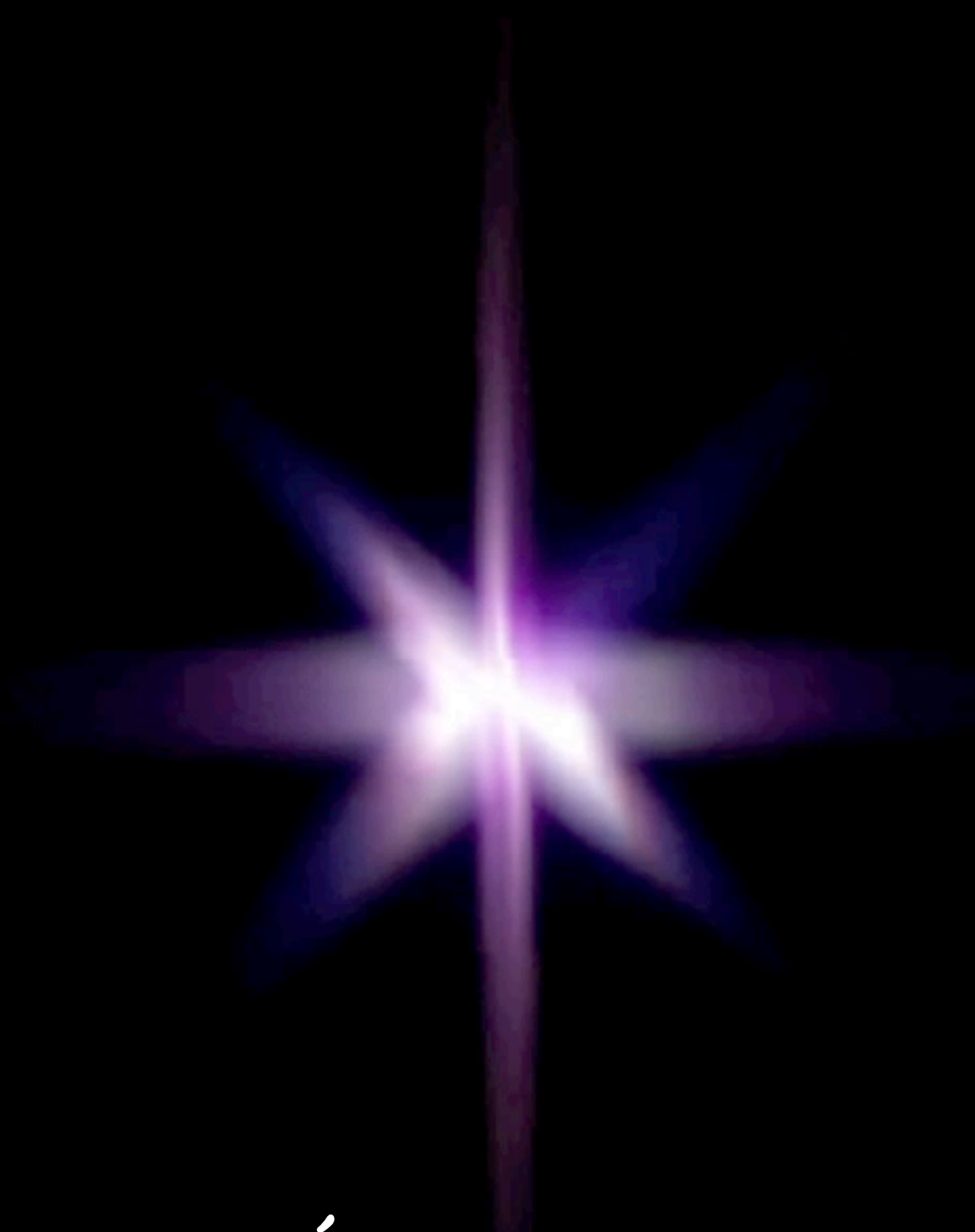
LA MATERIA ORDINARIA
REPRESENTA
4.8% DEL UNIVERSO

MATERIA ESTA VACIA

LA MATERIAL ES IMMATERIAL


LA MATERIA ES ESTRUCTURADA POR
4 FUERZAS

4 PARTÍCULAS CONSTITUYEN LA
MATERIA ORDINARIA...



DE LA COSMOLOGÍA SABEMOS QUE EL
UNIVERSO EXISTE DESDE HACE
-13.819 BILLONES DE AÑOS

3 MINUTOS DESPUÉS 99 % LA MATERIAL ORDINARIA SE
CREO DE PARTÍCULAS ELEMENTALES (NUCLEO-SÍNTESIS
PRIMORDIAL)



100 MILLONES DE AÑOS DESPUÉS, ELEMENTOS PESADOS (C, O, FE,...) SE CREARON EN LOS NÚCLEOS DE LAS PRIMERAS ESTRELLAS

QUE SABEMOS DE LA
MATERIA?

99% DE LA MATERIA PRESENTE
SE CREO EN TRES MINUTOS

MATERIA ESTA VACIA

LA MATERIA ES INMATERIAL

LA MATERIA ES ESTRUCTURADA POR
4 FUERZAS

4 PARTÍCULAS ELEMENTALES
CONSTITUYEN LA MATERIA
ORDINARIA...

LA MATERIA ORDINARIA FORMA
4,8% DEL UNIVERSO

LA MATERIA EN TODOS SUS ESTADOS



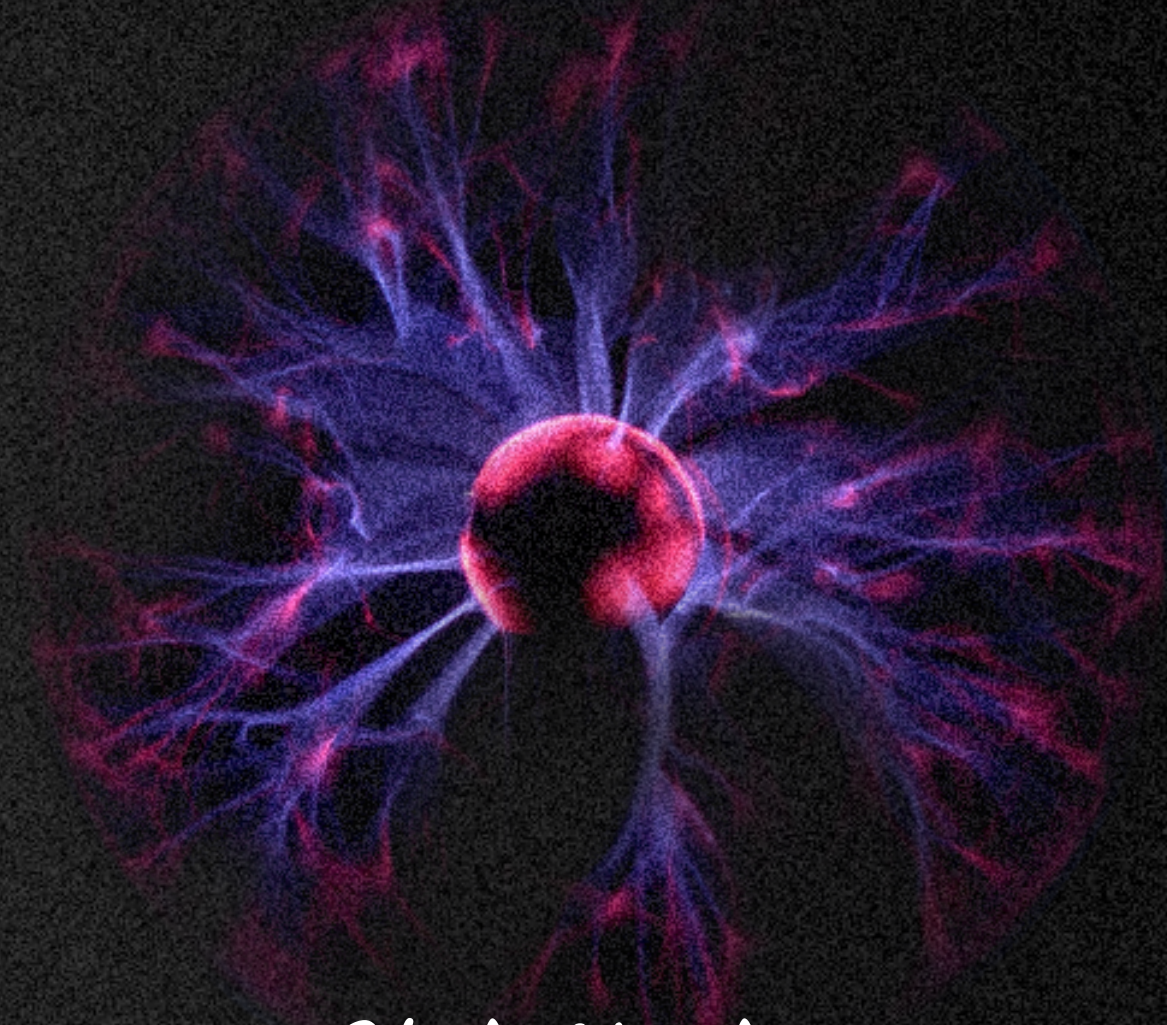
SOLIDO



LIQUIDO



VAPOR



PLASMA

LA MATERIA SE PUEDE TRANSFORMAR

QUE SABEMOS ACERCA
DE LA MATERIA?

LA MATERIA HA ADQUIRIDO
ESTRUCTURA, INICIANDO DE
UN PLASMA DE QUARKS Y
GLUONES

MATERIA ESTA VACIA

LA MATERIA ES
INMATERIAL

LA MATERIA TOMA SU ESTRUCTURA
DE 4 FUERZAS

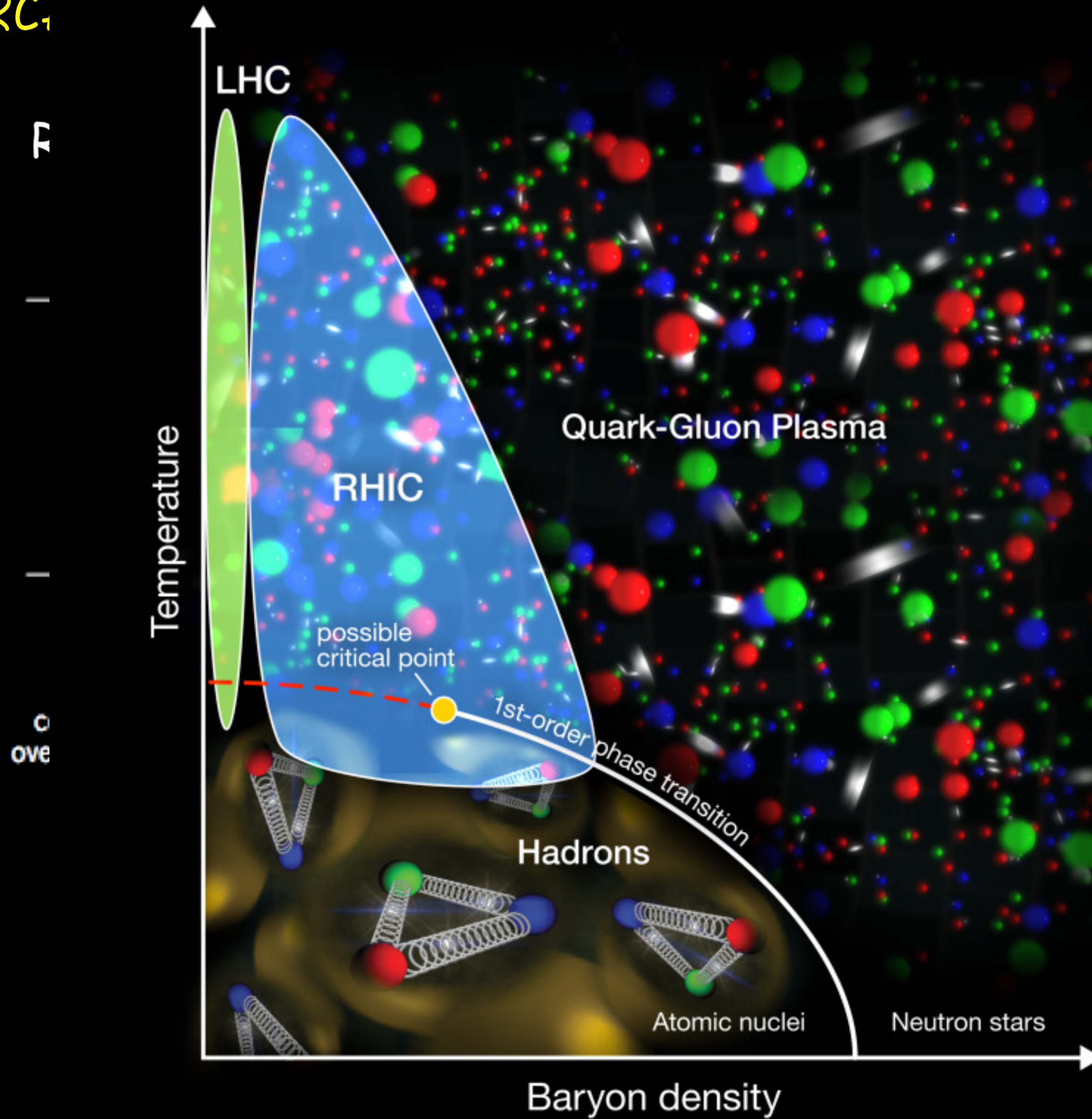
4 PARTÍCULAS ELEMENTALES
CONSTITUYEN LA MATERIA
ORDINARIA...

LA MATERIA ORDENADA
REPRESENTA

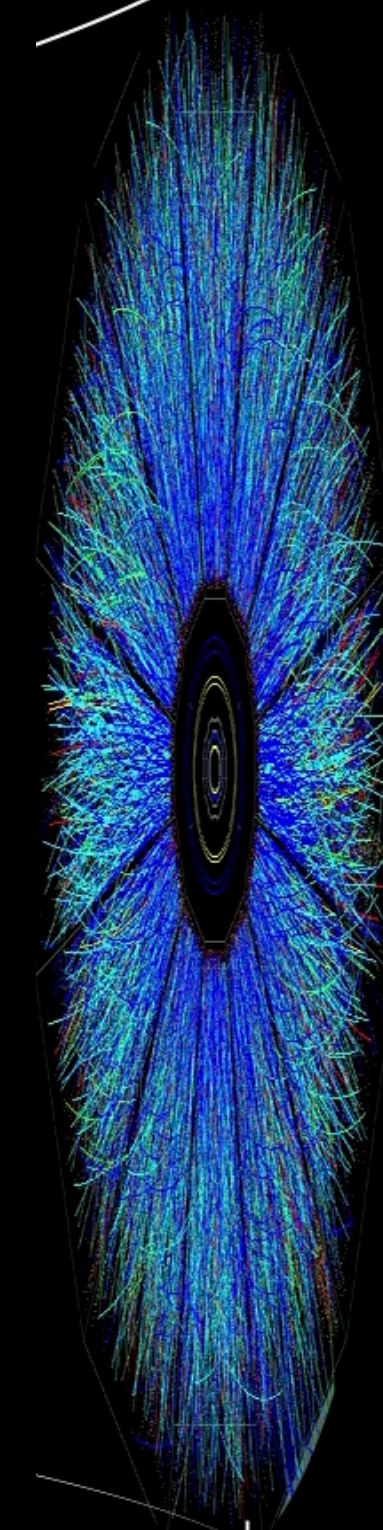
4,8% DEL UNIVERSO

99% DE LA MATERIA SE FORMO EN
LOS PRIMEROS 3 MINUTOS

QUE SABEMOS ACERCA DE LA MATERIA?



final detected
particle distributions

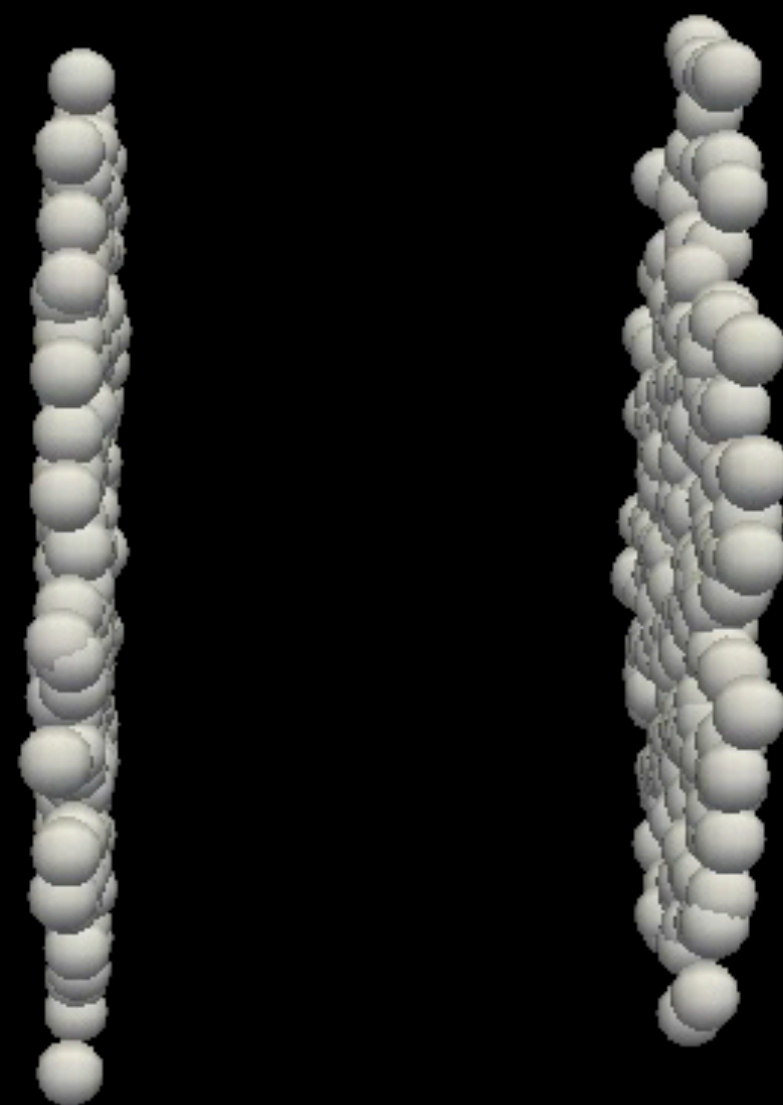


ng
 $\sim 10^{15} \text{ fm}/c$

¿CÓMO PODEMOS RECREAR LA
MATERIA PRIMITIVA?

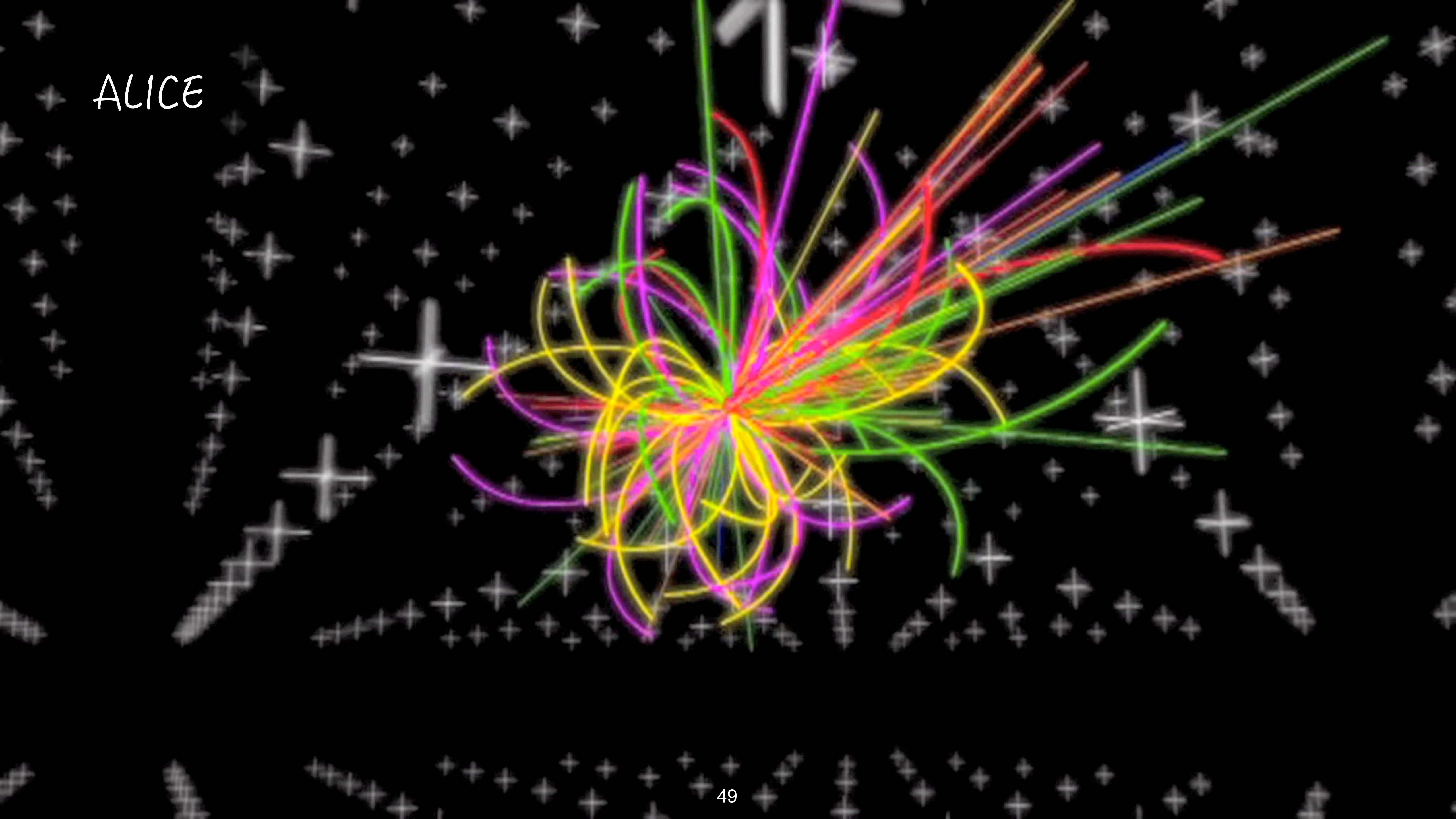
An aerial photograph of a large dam structure, likely the Jinping II Dam, situated in a deep valley. The dam is a long, narrow concrete structure with several towers. The surrounding area is a mix of green vegetation and brownish soil. The sky is a clear, pale blue.

ACELERAR NÚCLEOS DE PLOMO A 99.99999997%
DE LA VEL. DE LA LUZ



CUANDO DOS NÚCLEOS DE PLOMO COLISIONAN

ALICE



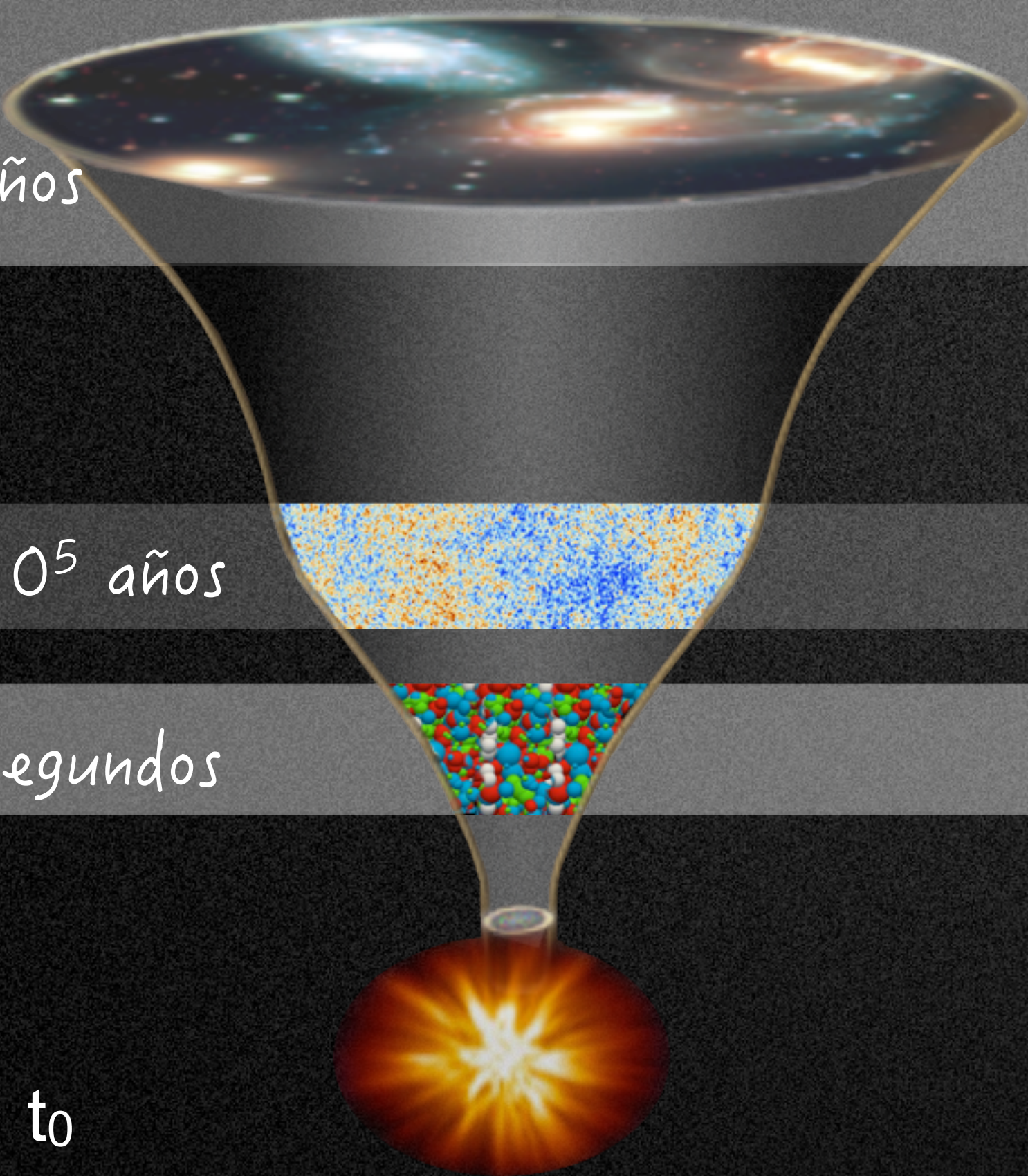
BIG BANG

MICRO BIG BANG

$t_0 + 13.8 \times 10^9$ años

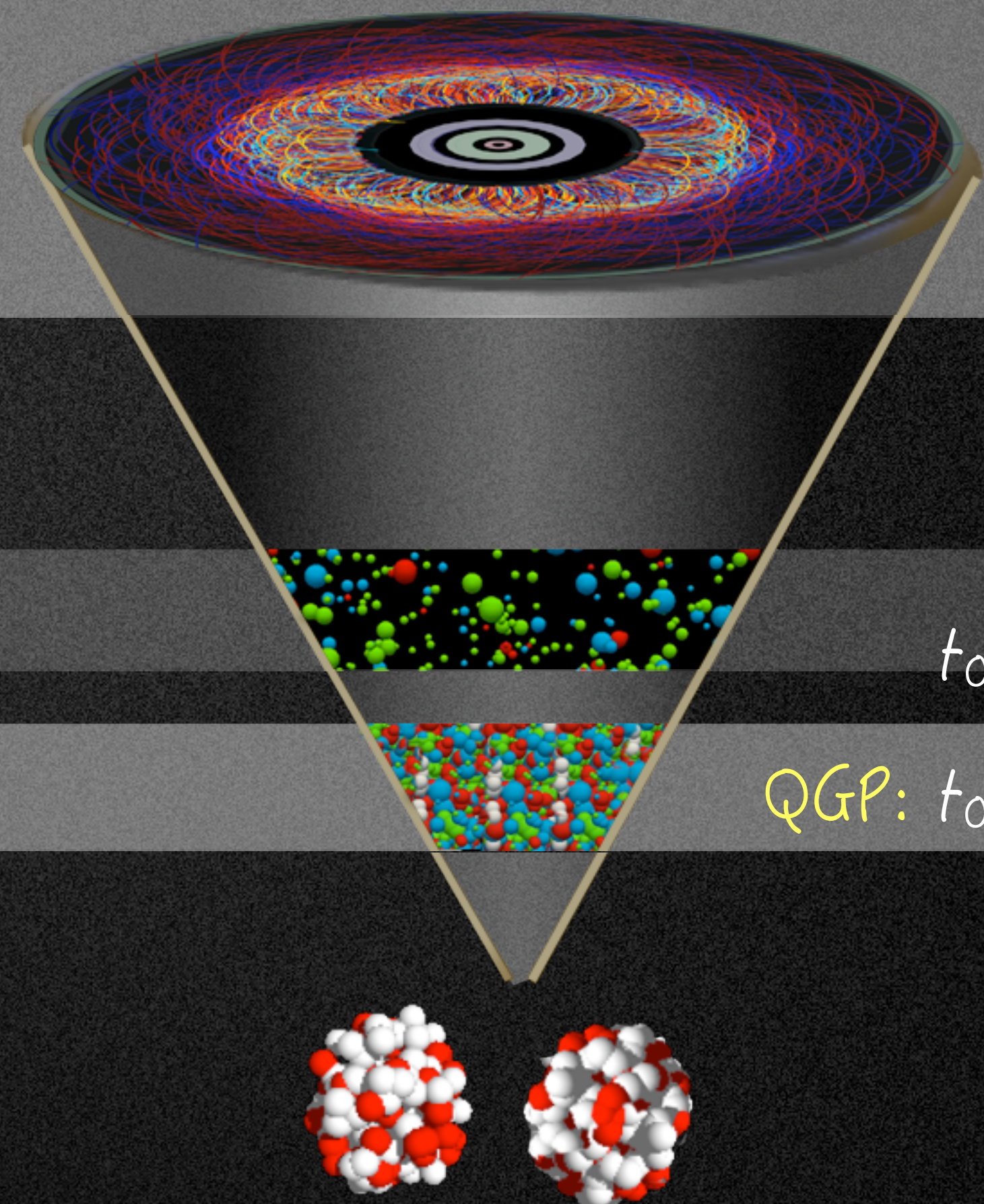
CMB: $t_0 + 3.8 \times 10^5$ años

QGP: $t_0 + 10^{-6}$ segundos



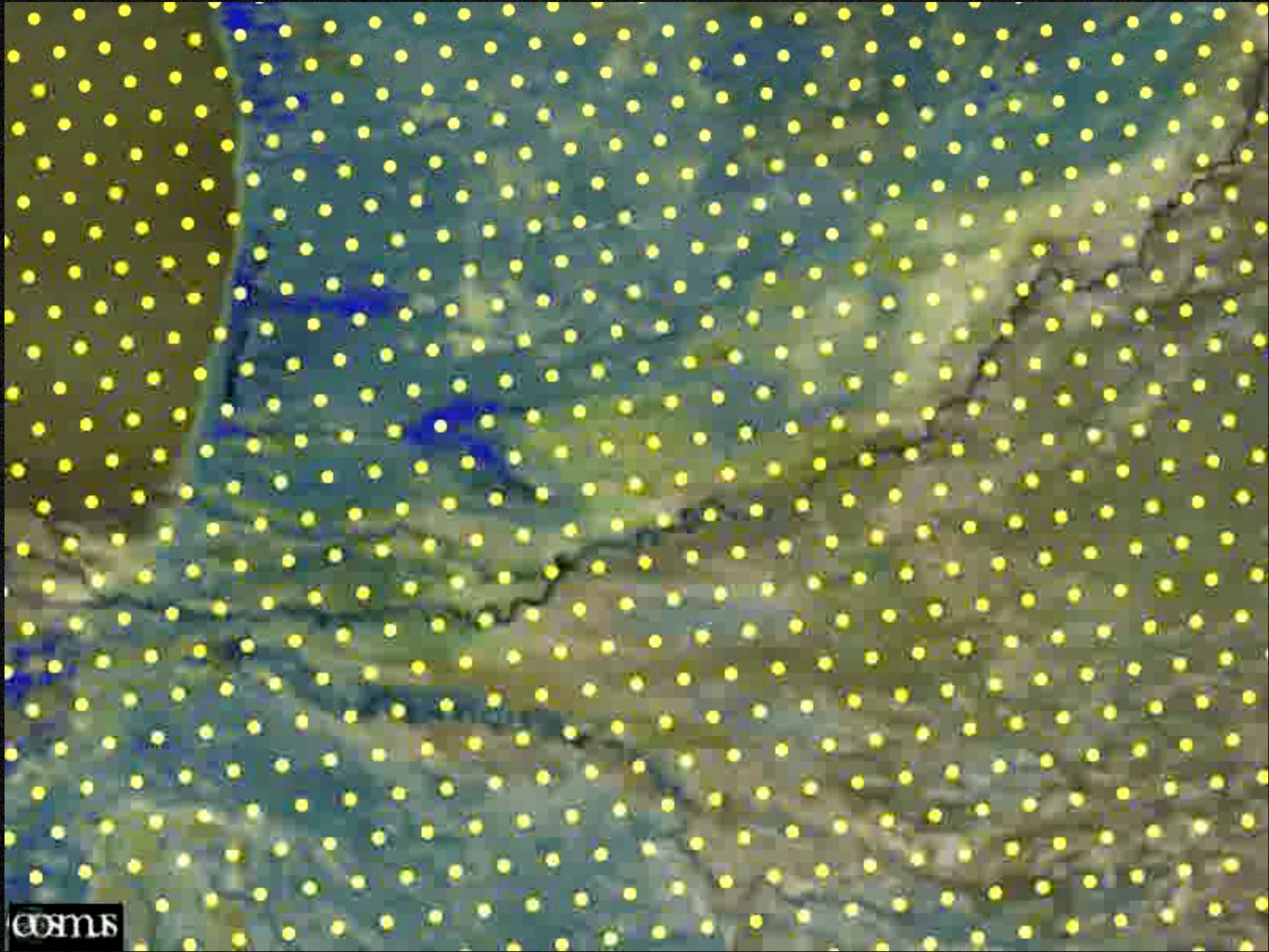
gas de hadrones
 $t_0 + 10^{-23}$ segundos


QGP: $t_0 + 10^{-24}$ segundos



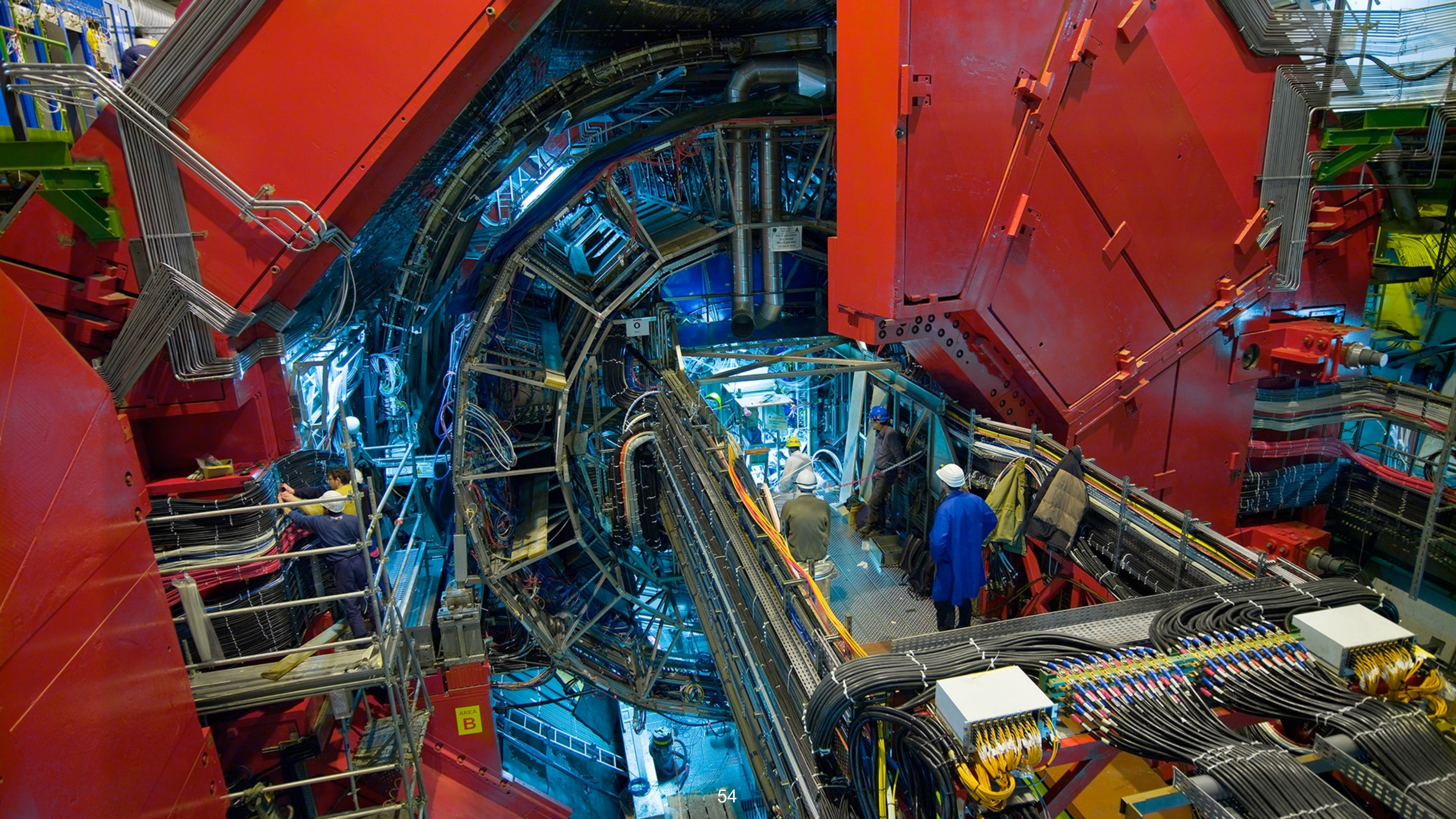
RESULTA QUE ESTUDIANDO
RAYOS CÓSMICOS TAMBIÉN
PODEMOS ESTUDIAR
PROPIEDADES DE LA MATERIA







DETECTAMOS RADIACIÓN CÓSMICA (LUZ
CÓSMICA) CON DISPOSITIVOS ALTAMENTE
SENSIBLES A ESTE TIPO DE RADIACIÓN



Algunos comentarios

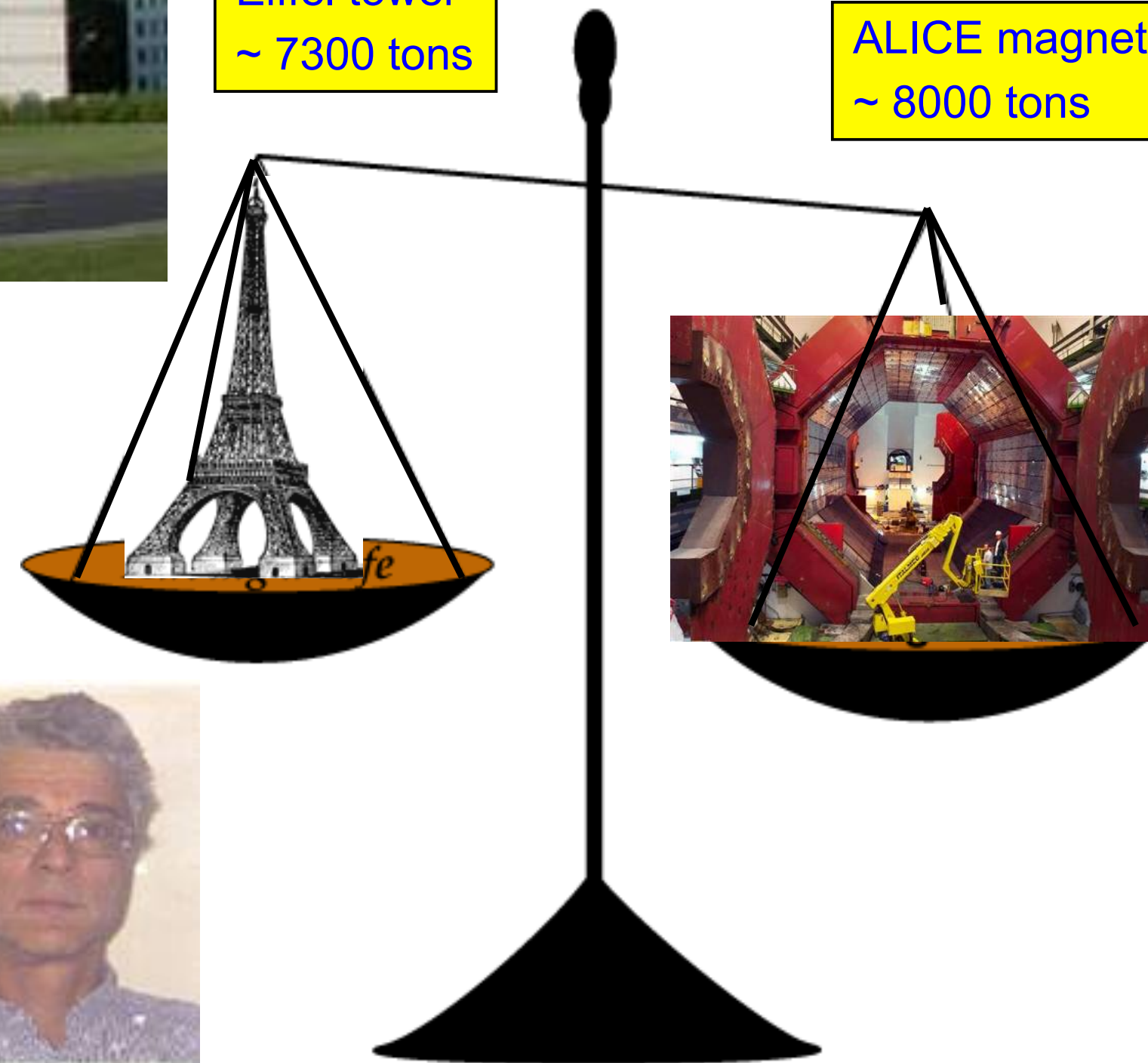


- Experiments at LHC are

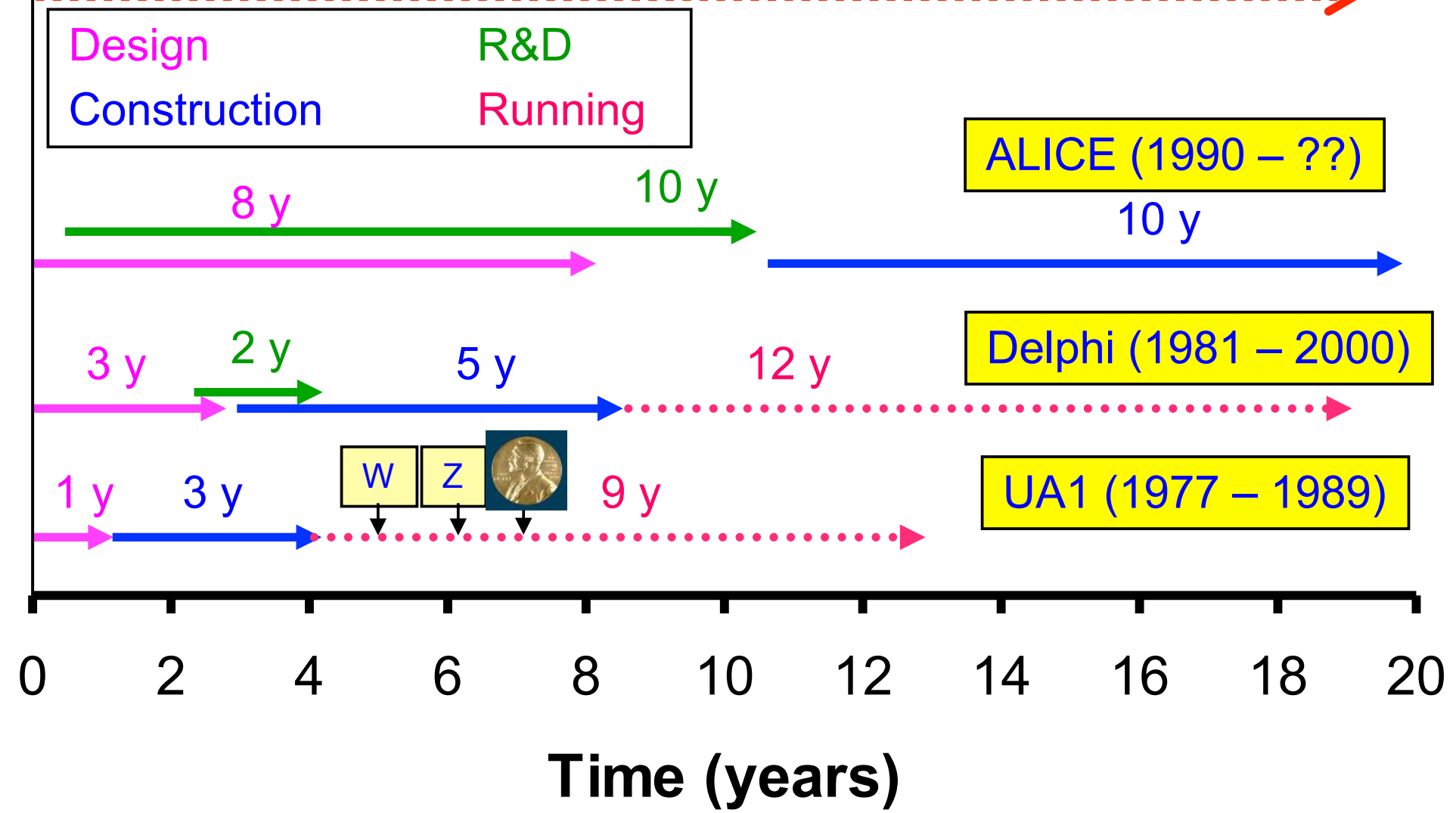
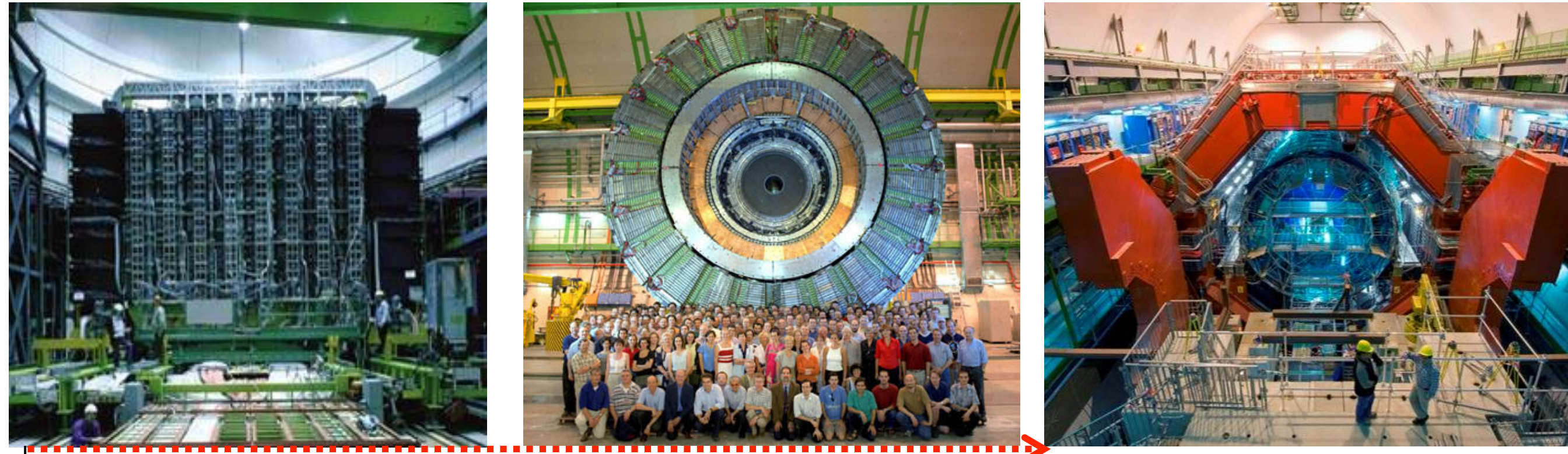
- ⇒ Big
- ⇒ Heavy
- ⇒ and took a loong time ...

Eiffel tower
~ 7300 tons

ALICE magnet
~ 8000 tons



Algunos comentarios



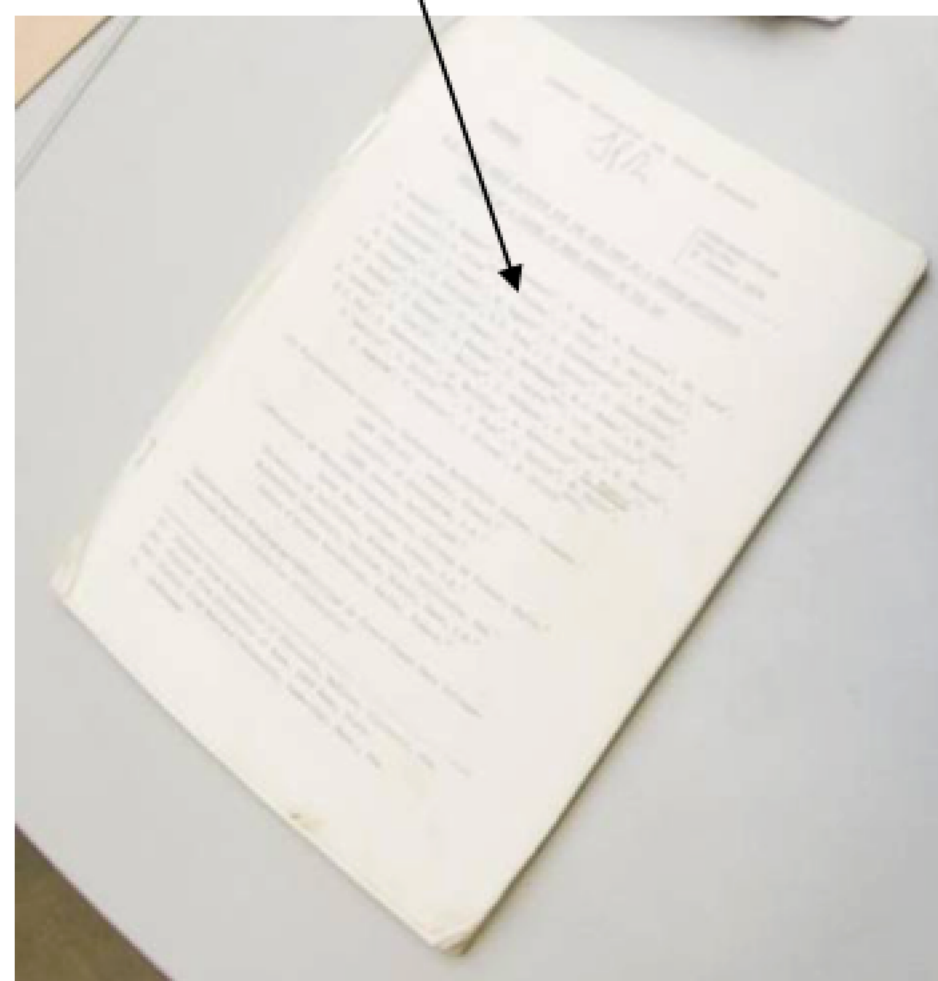
Algunos comentarios



Paper and Committee work..



UA1 proposal (154 p.)
sub. Jan '78, approved June '78



Algunos comentarios

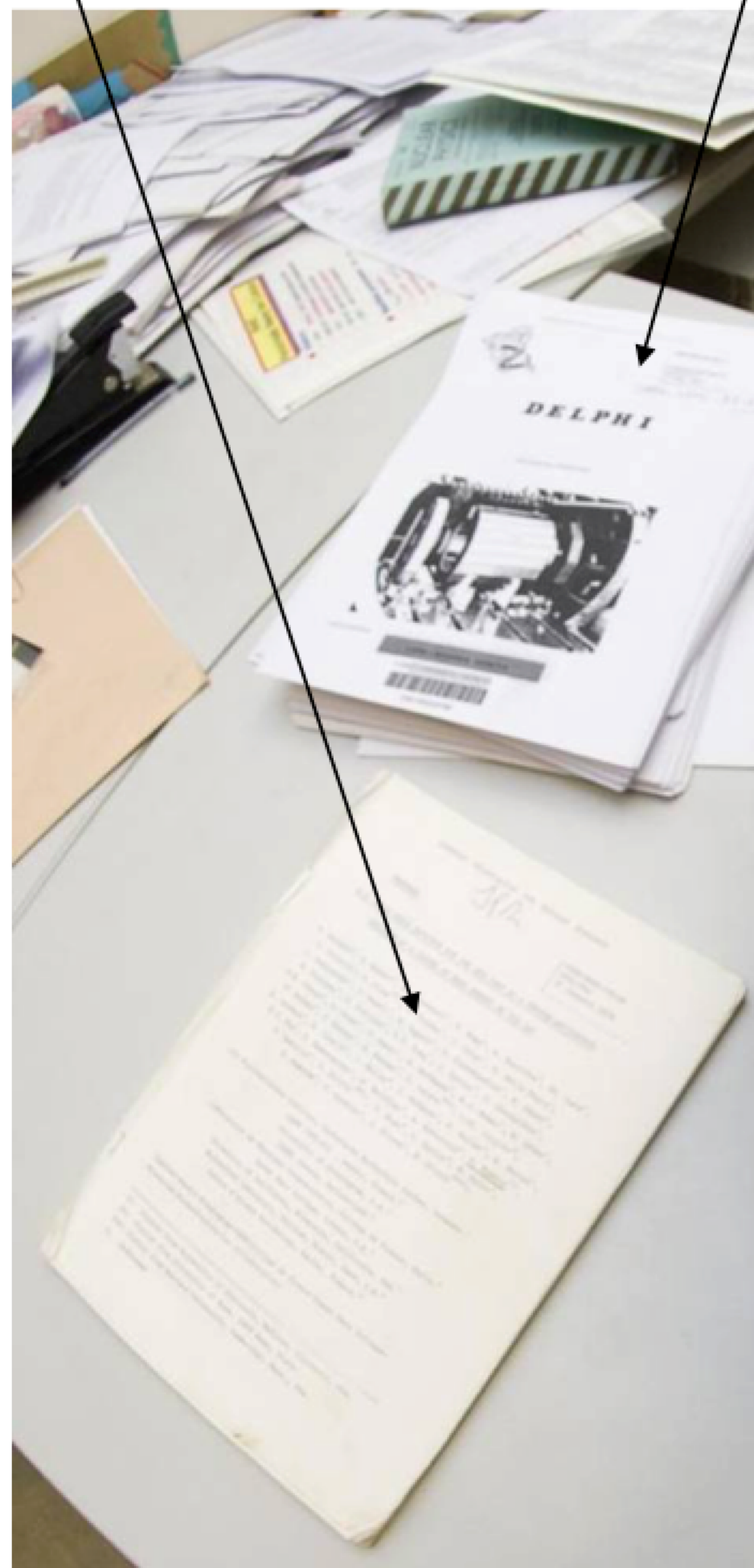


Paper and Committee work..



UA1 proposal (154 p.)
sub. Jan '78, approved June '78

Delphi Lol, TP, 7 Addenda (500 p.)



Algunos comentarios



Paper and Committee work..



UA1 proposal (154 p.)
sub. Jan '78, approved June '78

Delphi Lol, TP, 7 Addenda (500 p.)



Alice:

Eol

Lol + 1 Add

TP + 3 Add

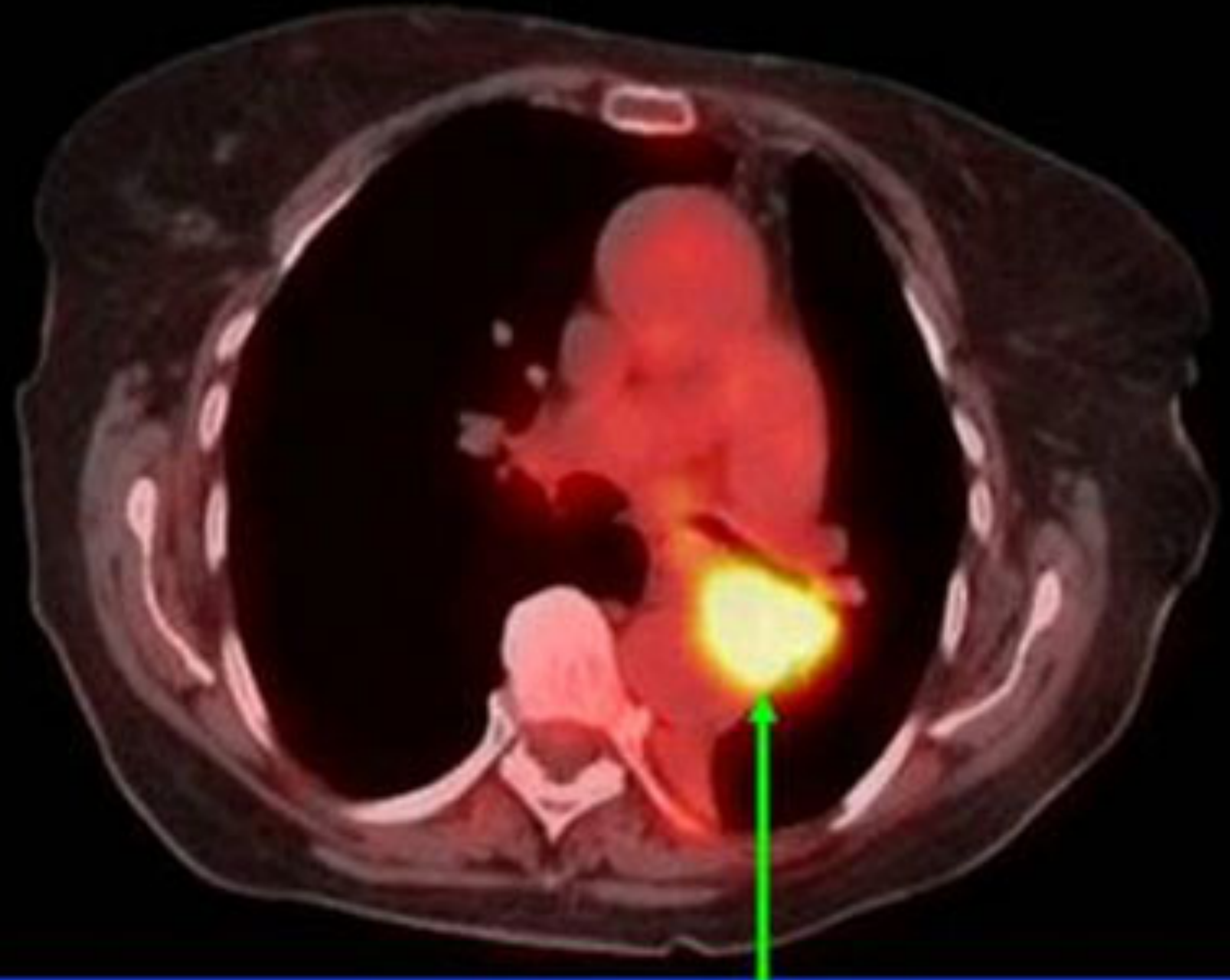
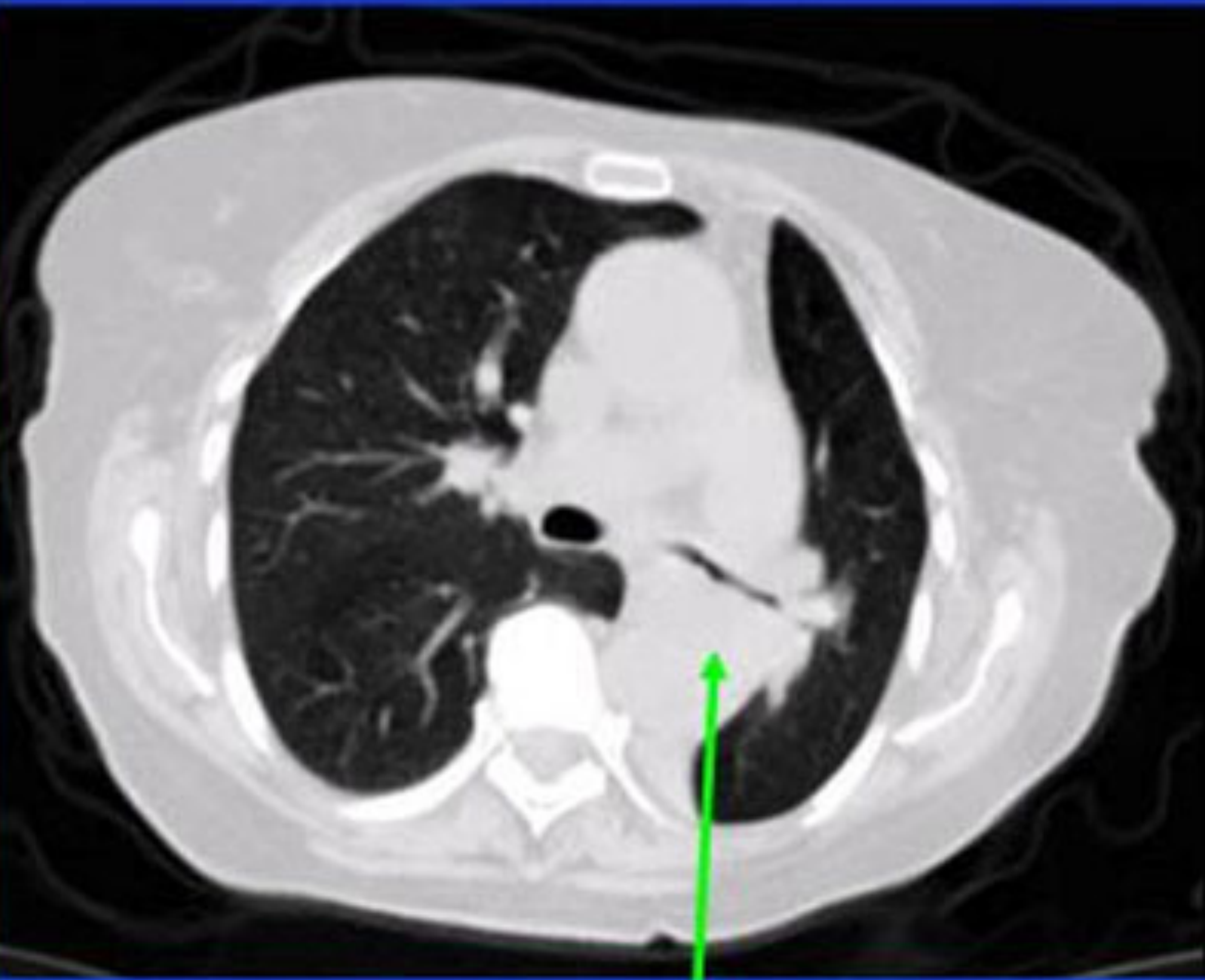
12 TDR's + 3 Add

3 Vol PPR

4422 p.

CT Image

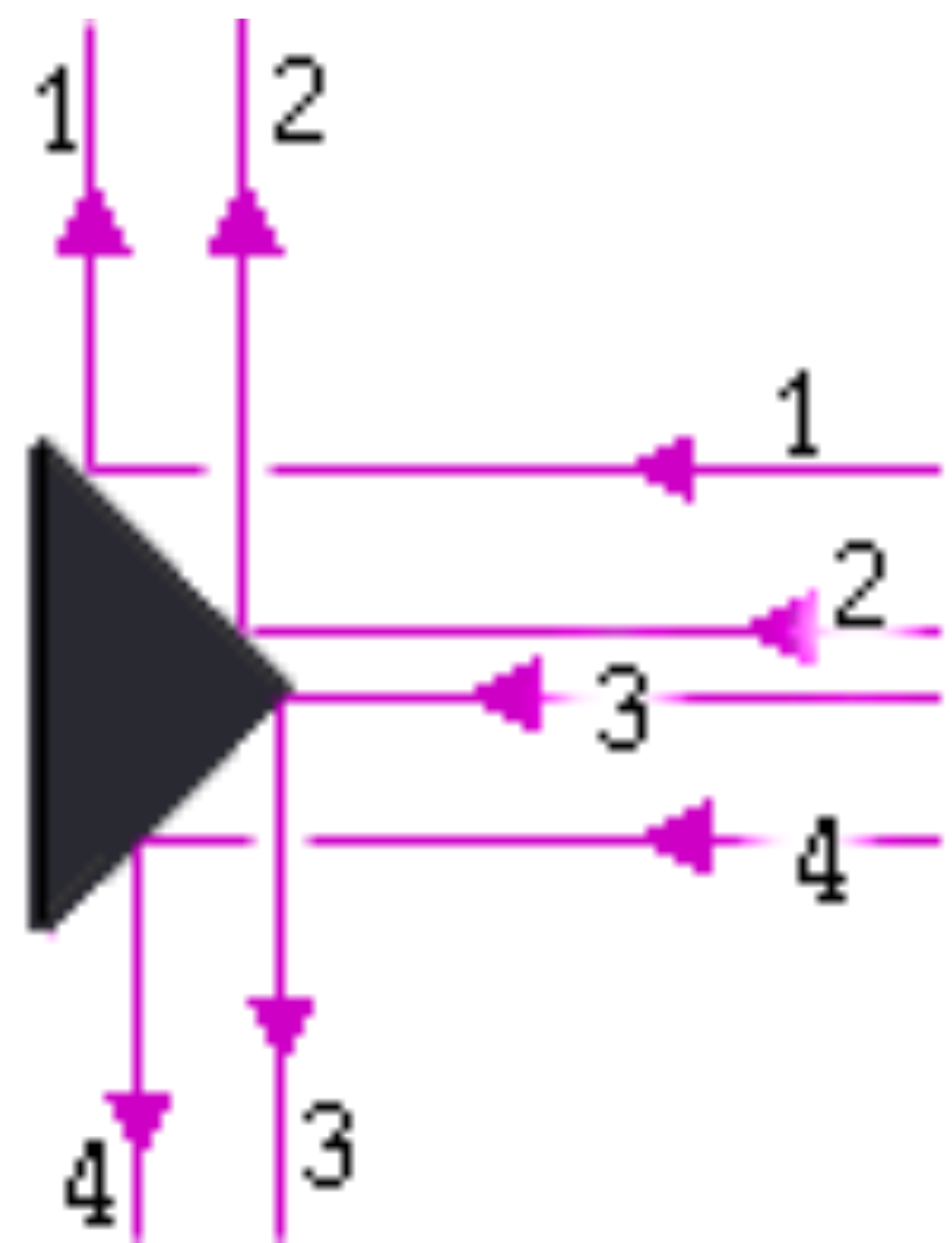
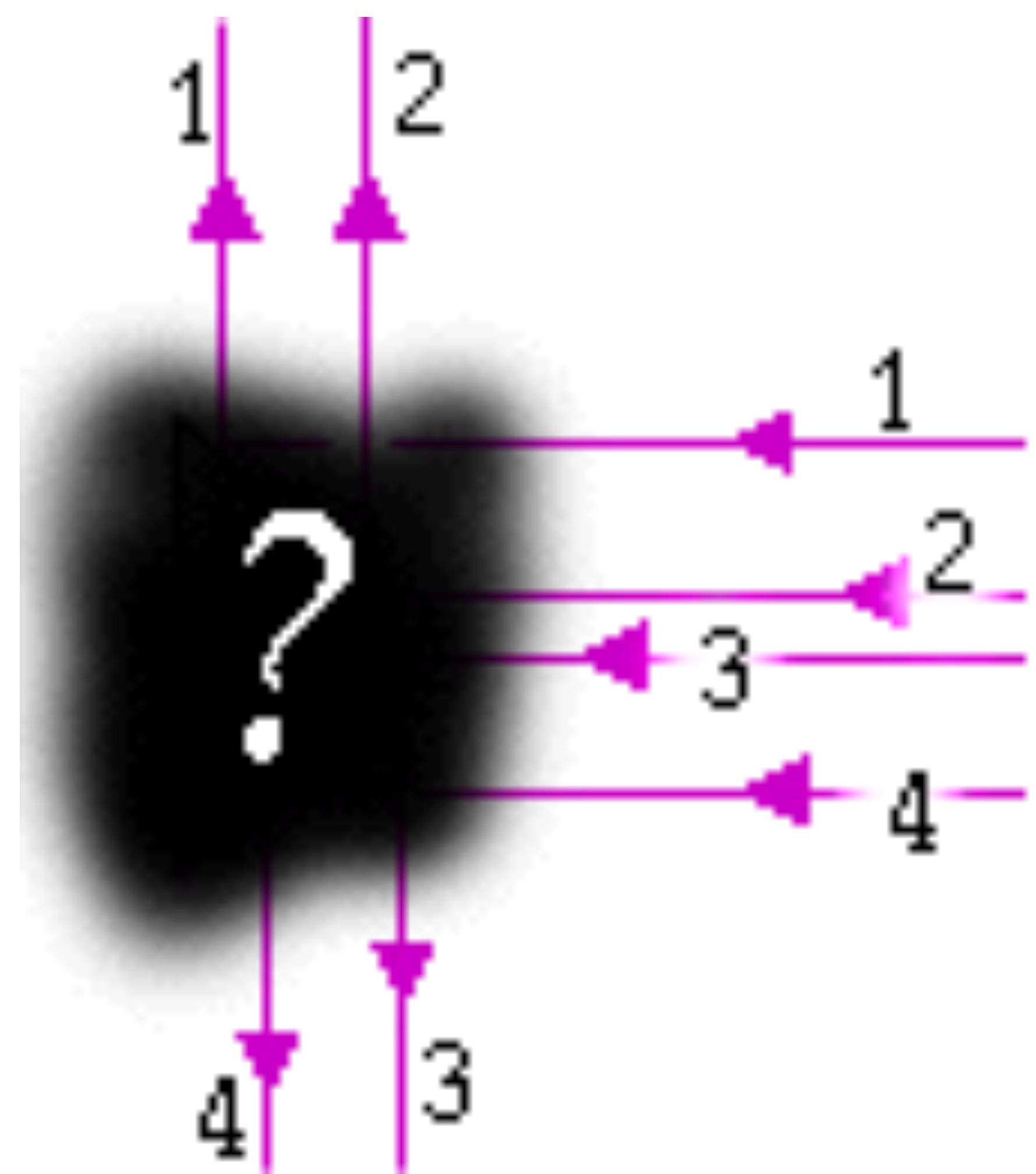
Fused CT-PET Image

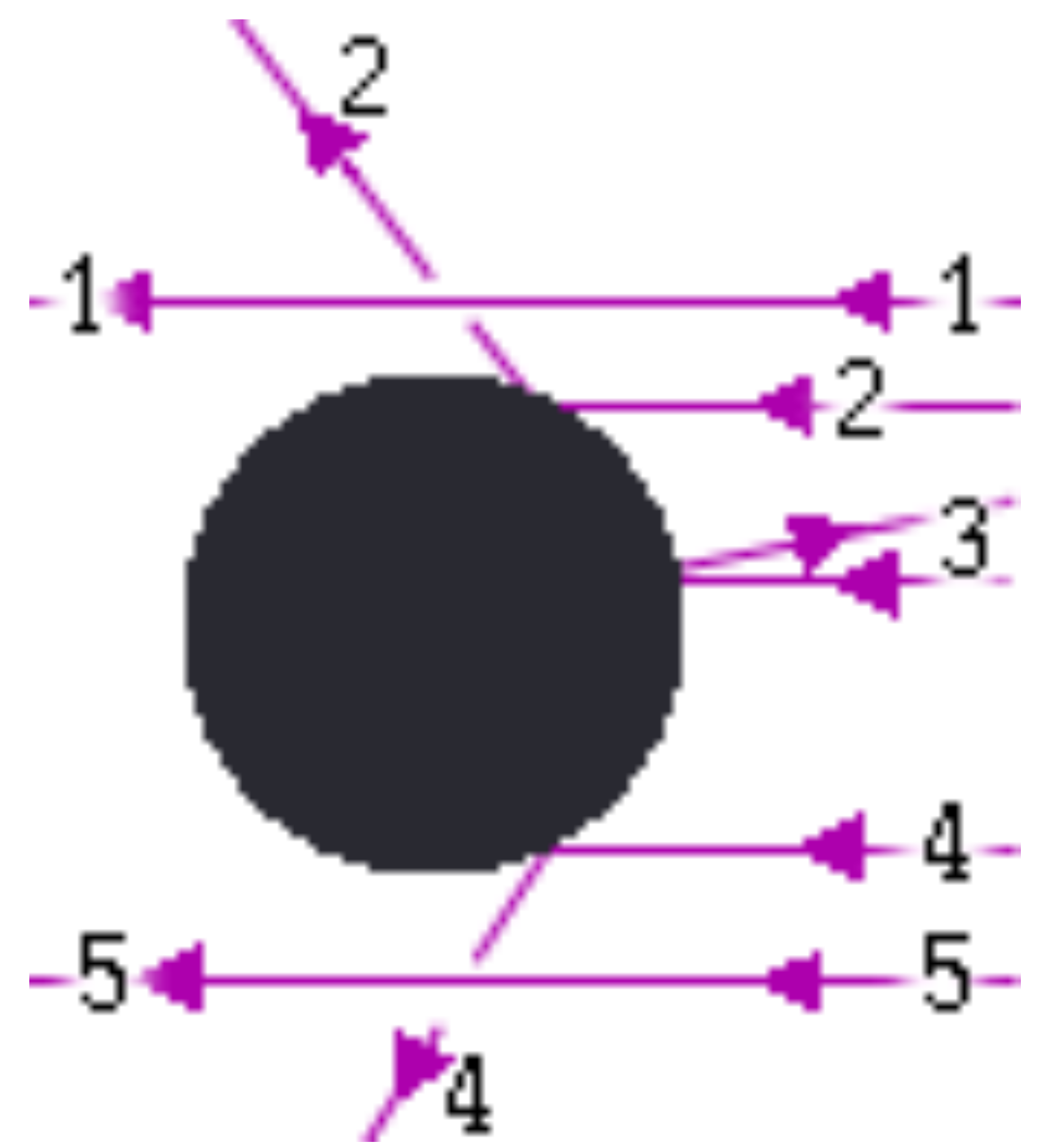
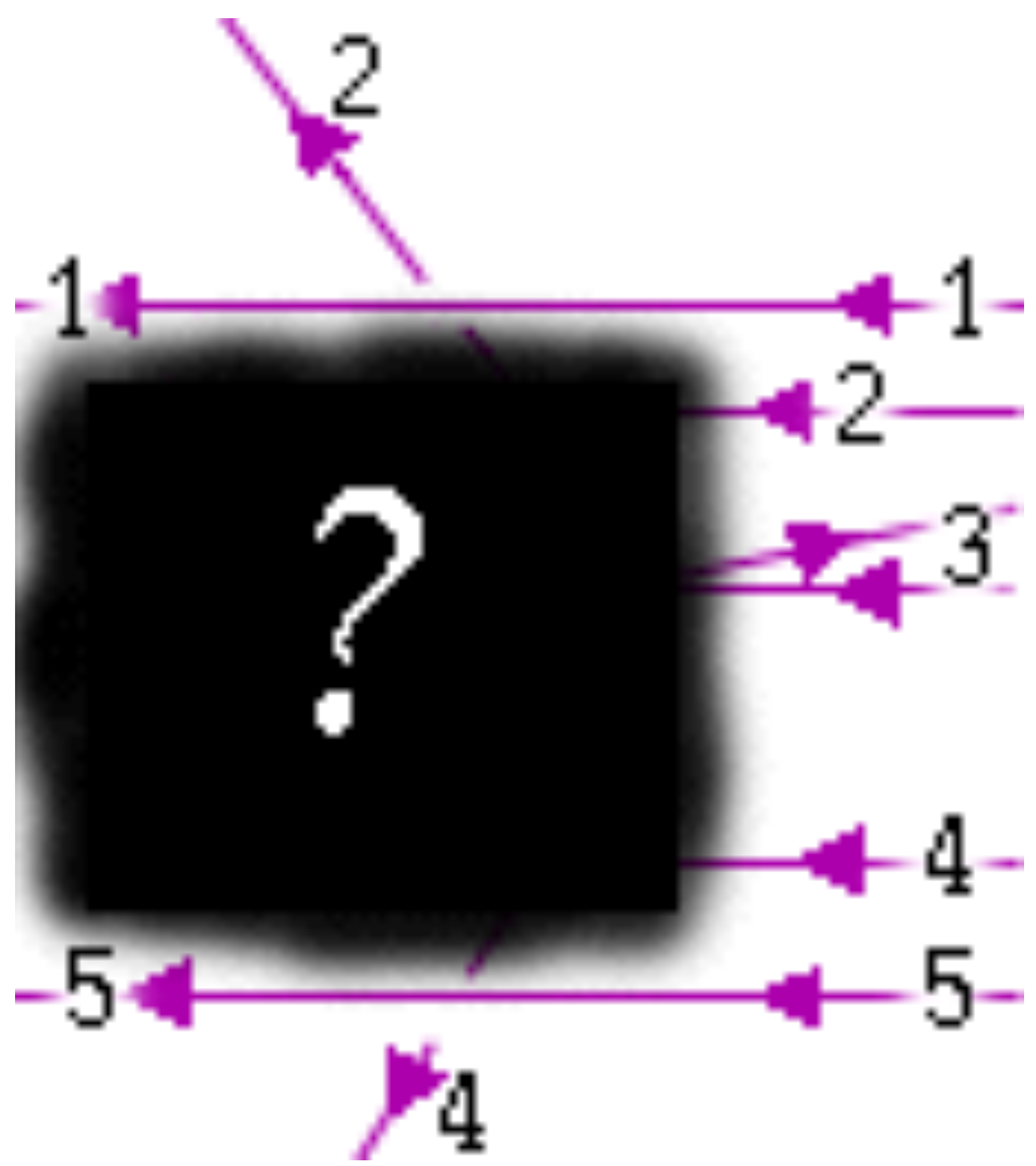


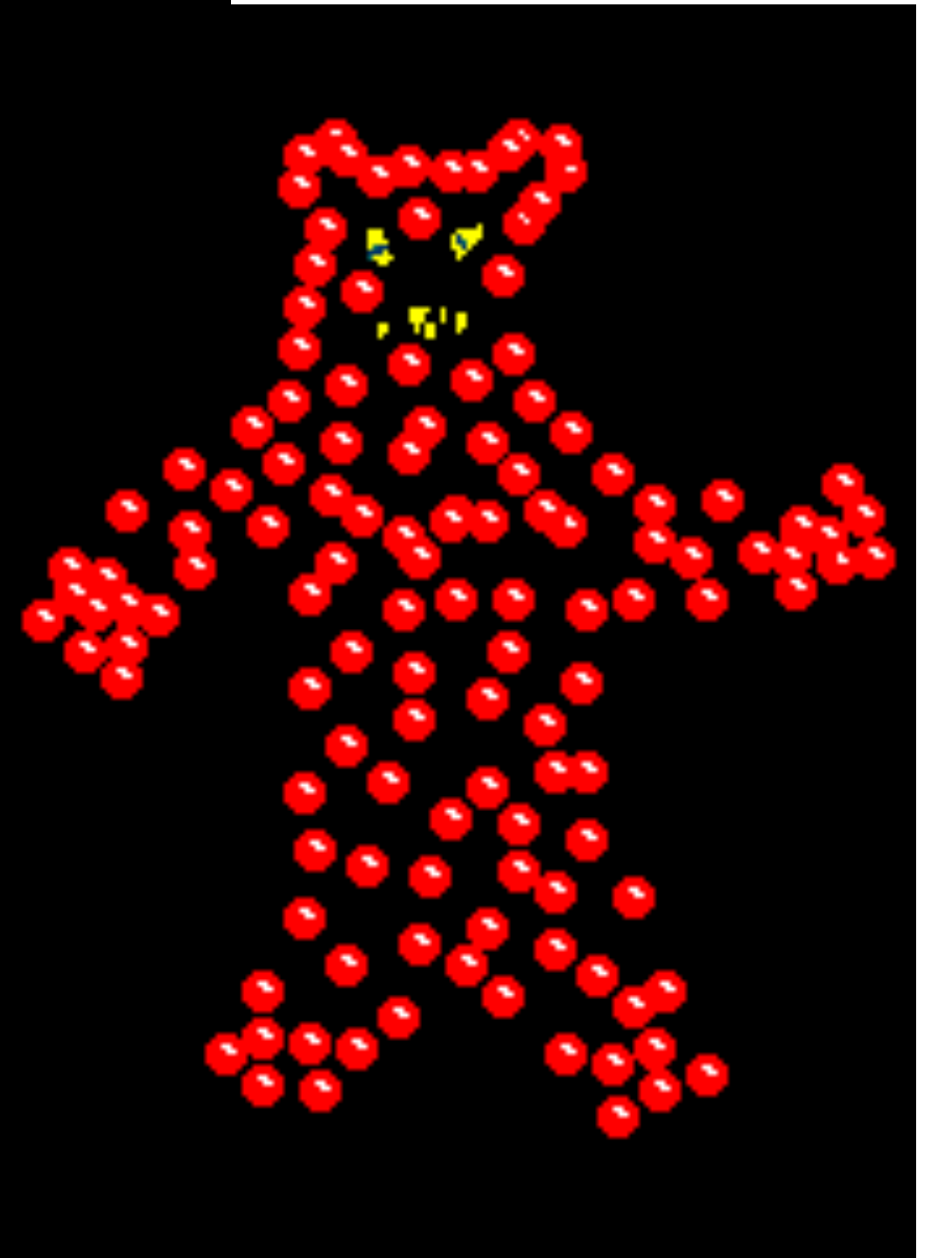
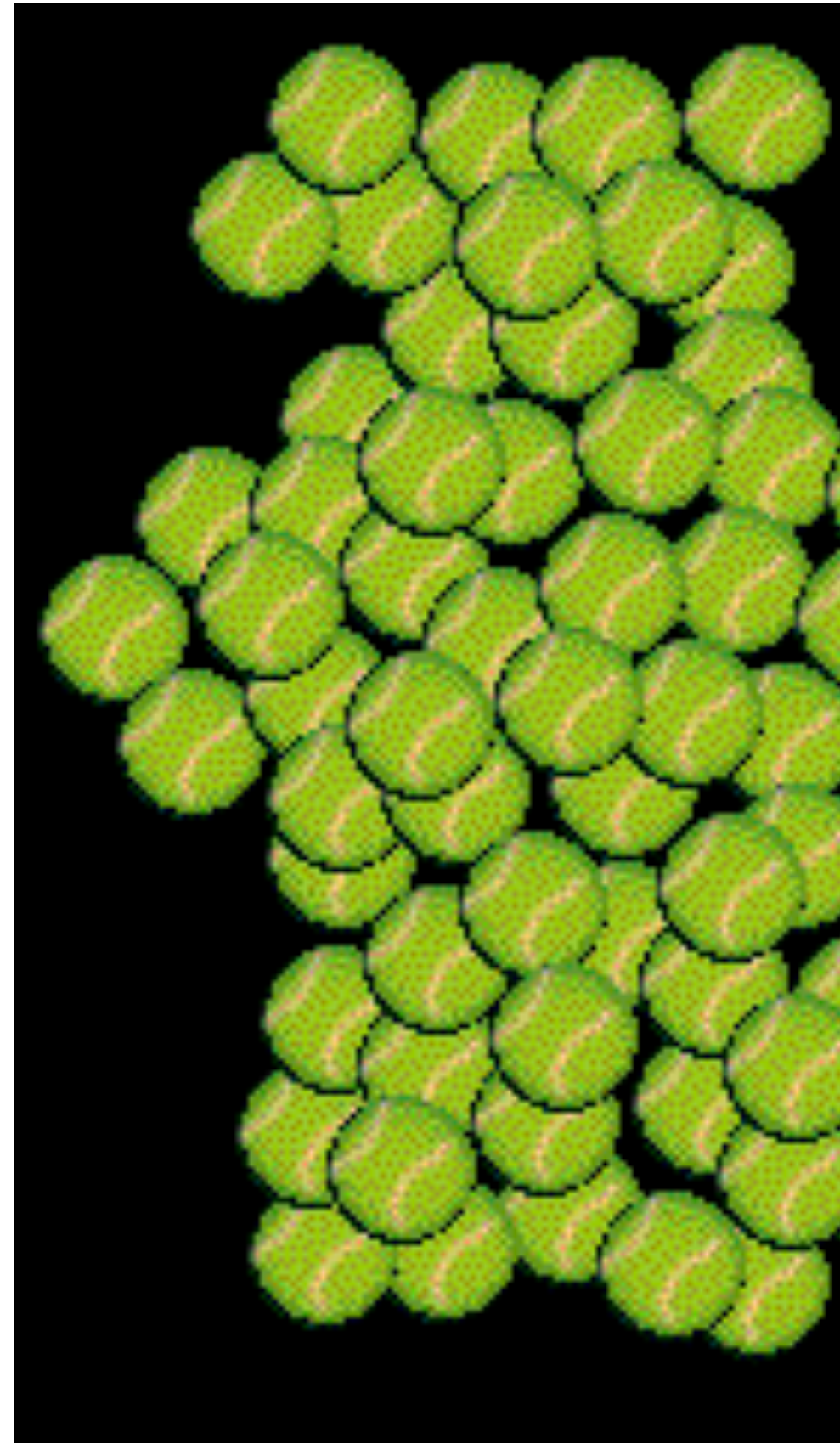
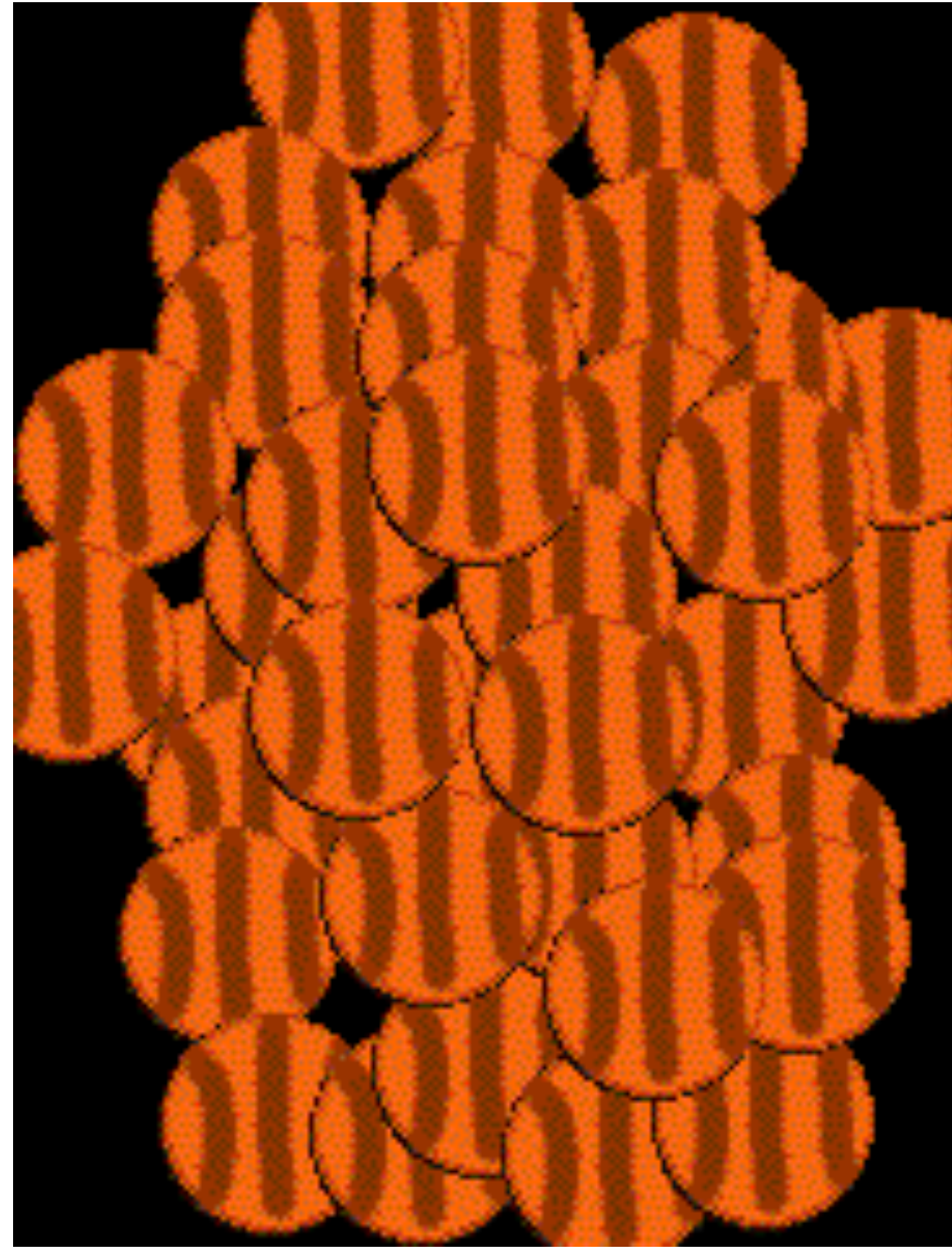
Poorly Defined Tumor Margins

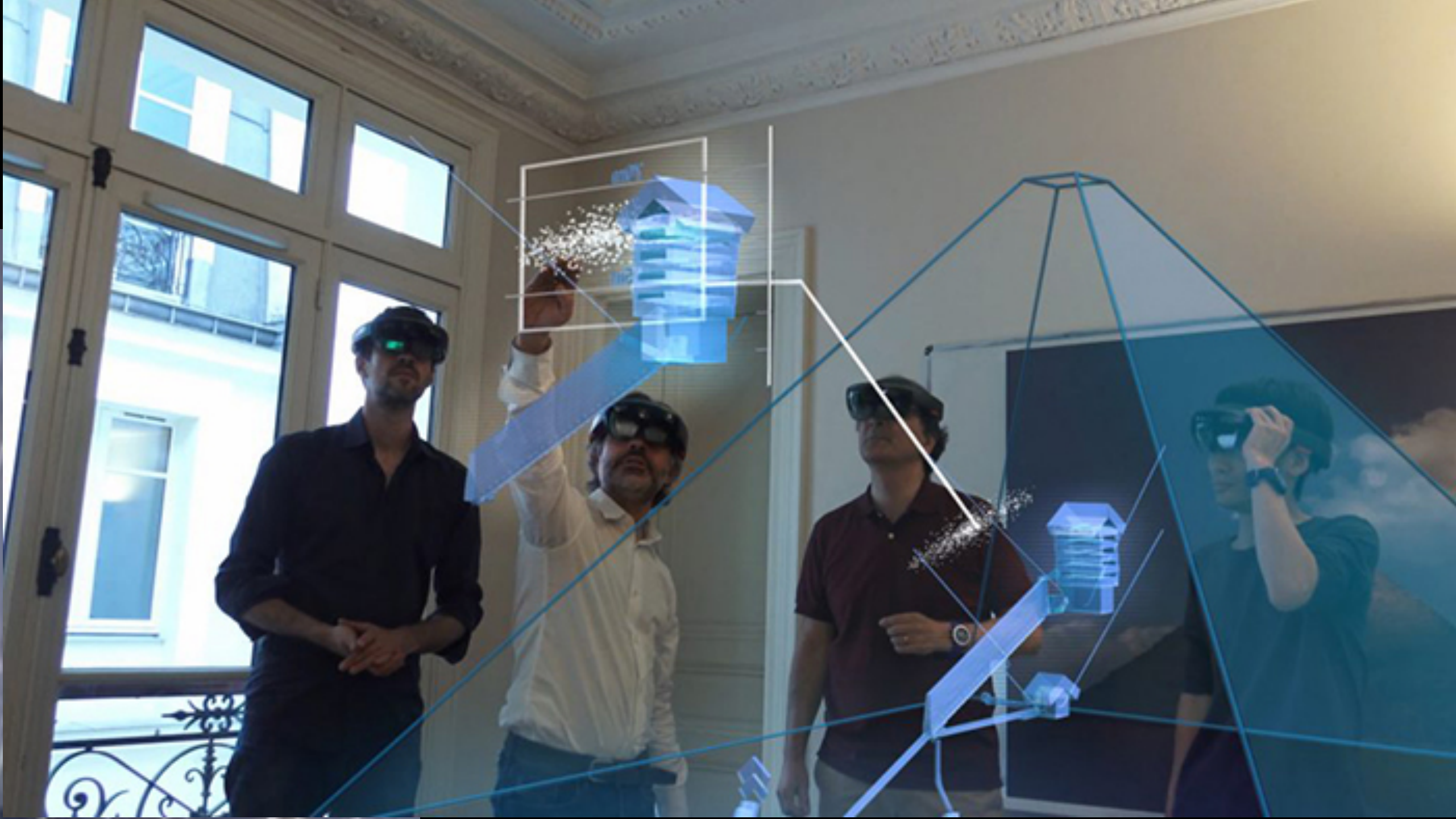
FDG Avid Tumor











11/28/2013 11:44:13 am
11:40 am 11:51 am

Running jobs: 214268
Transfer rate: 42.74 GiB/sec



WWW

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