

La struttura su grande scala dell'universo

Amedeo Balbi

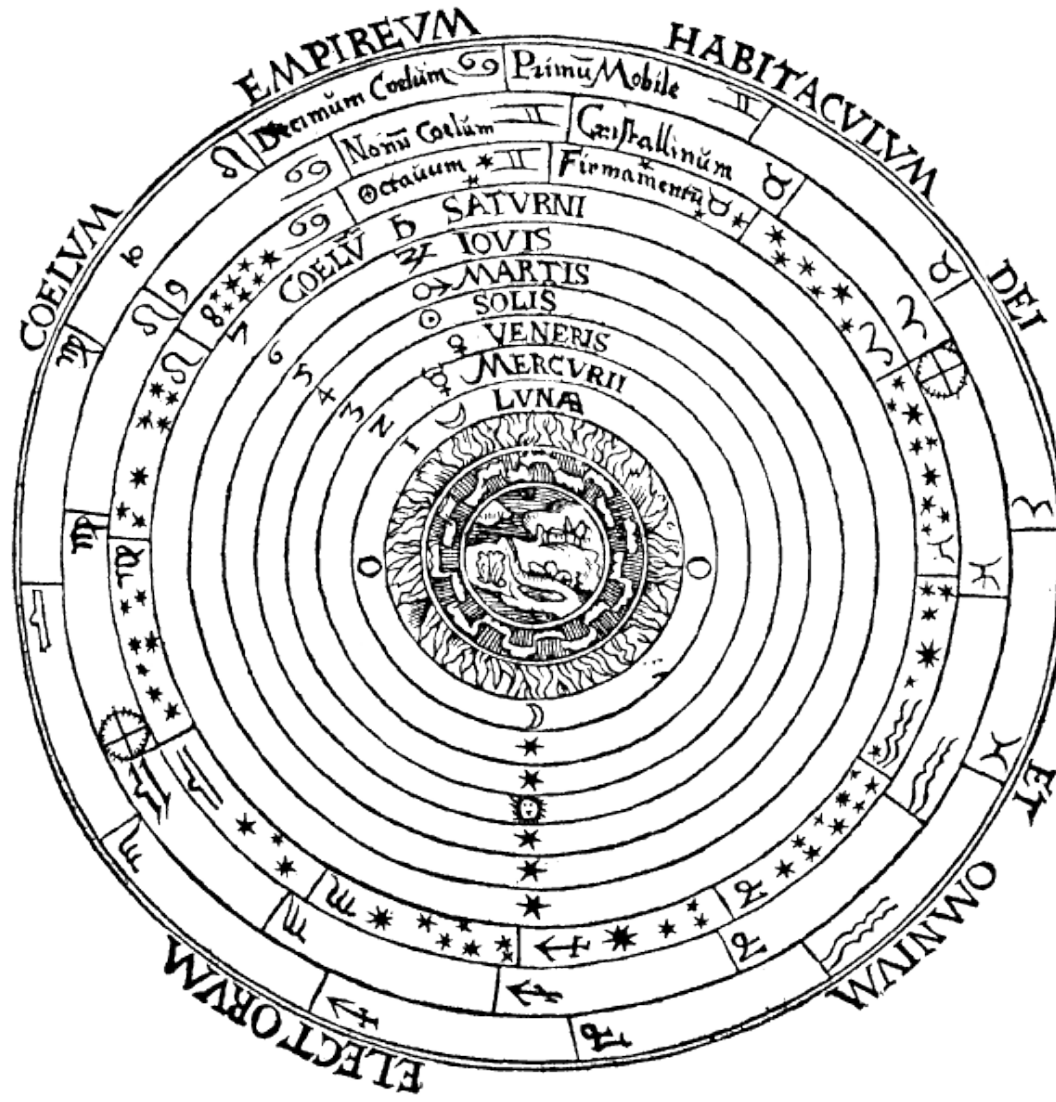
Principio cosmologico

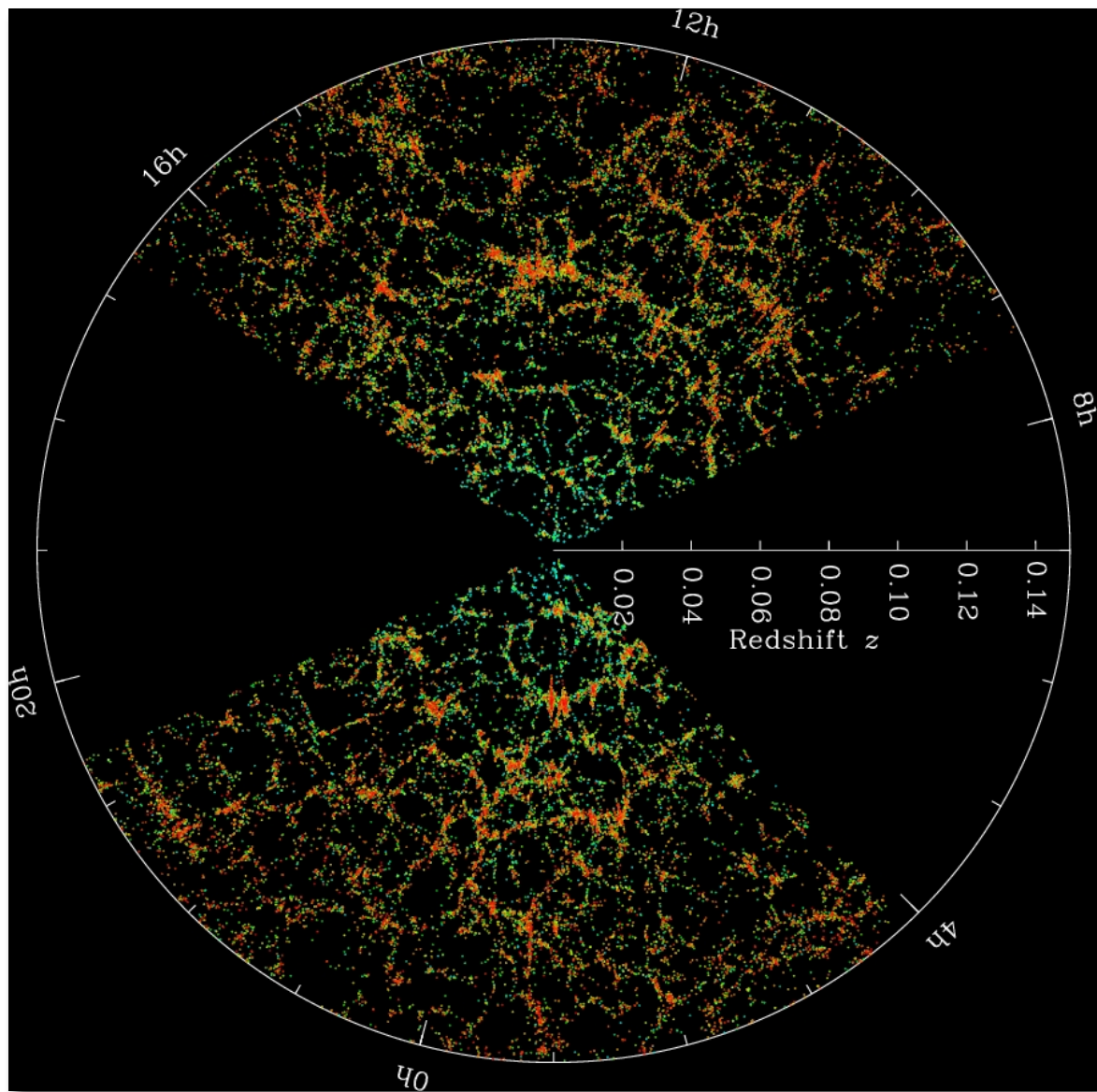
L'universo è (spazialmente) **omogeneo** e **isotropo**

Ovvero: le sue proprietà fisiche sono (in media) le stesse in qualunque punto e in qualunque direzione.



Schema huius præmissæ diuisionis Sphærarum .





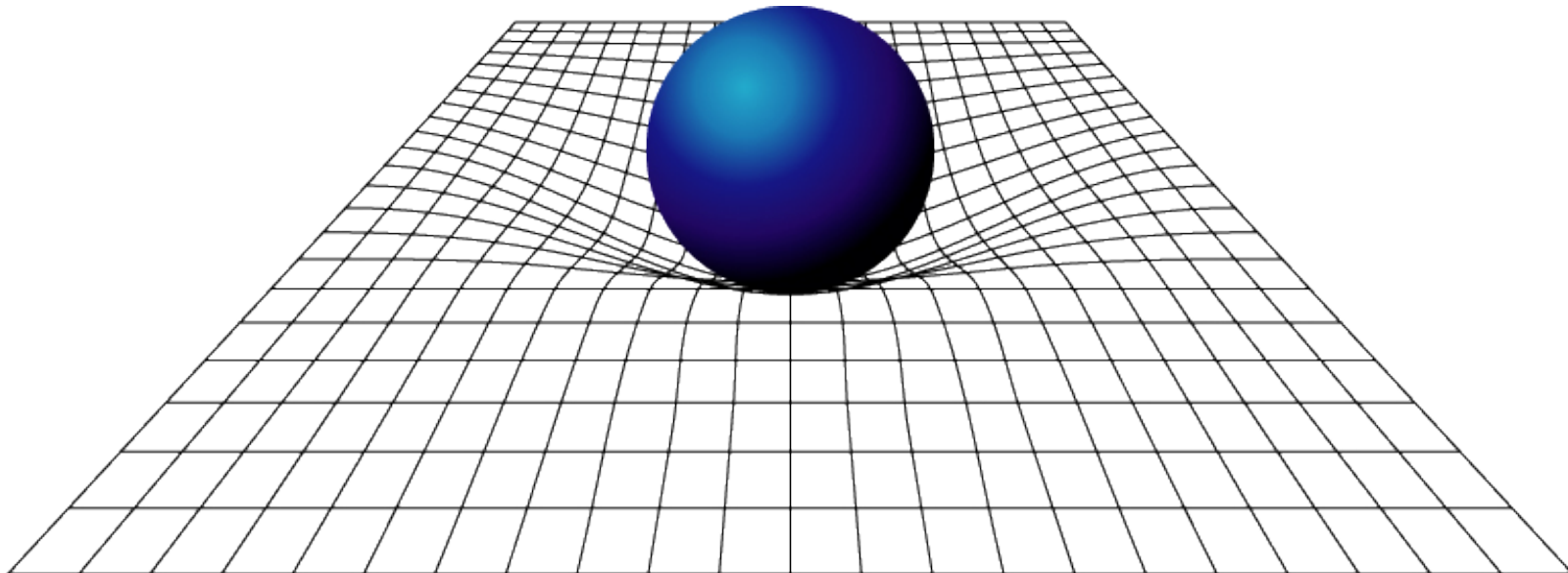
Albert Einstein (1917)

Considerazioni cosmologiche sulla teoria della relatività generale

Universo omogeneo, isotropo e ~~statico~~

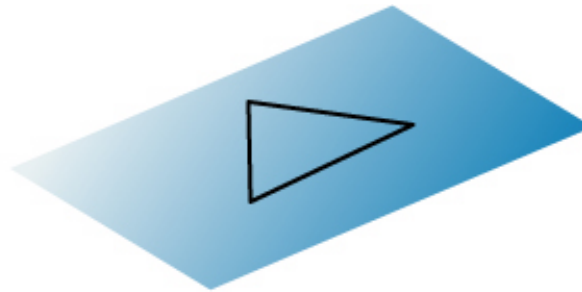
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

geometria = materia (o energia)

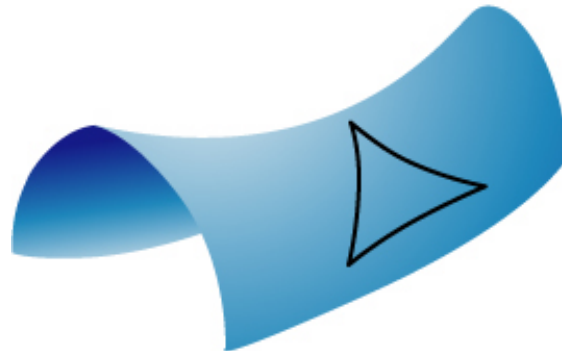


Metrica di Friedman-Robertson-Walker

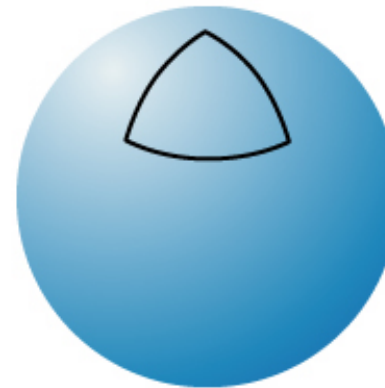
Sezioni spaziali **massimamente simmetriche**
(curvatura costante)



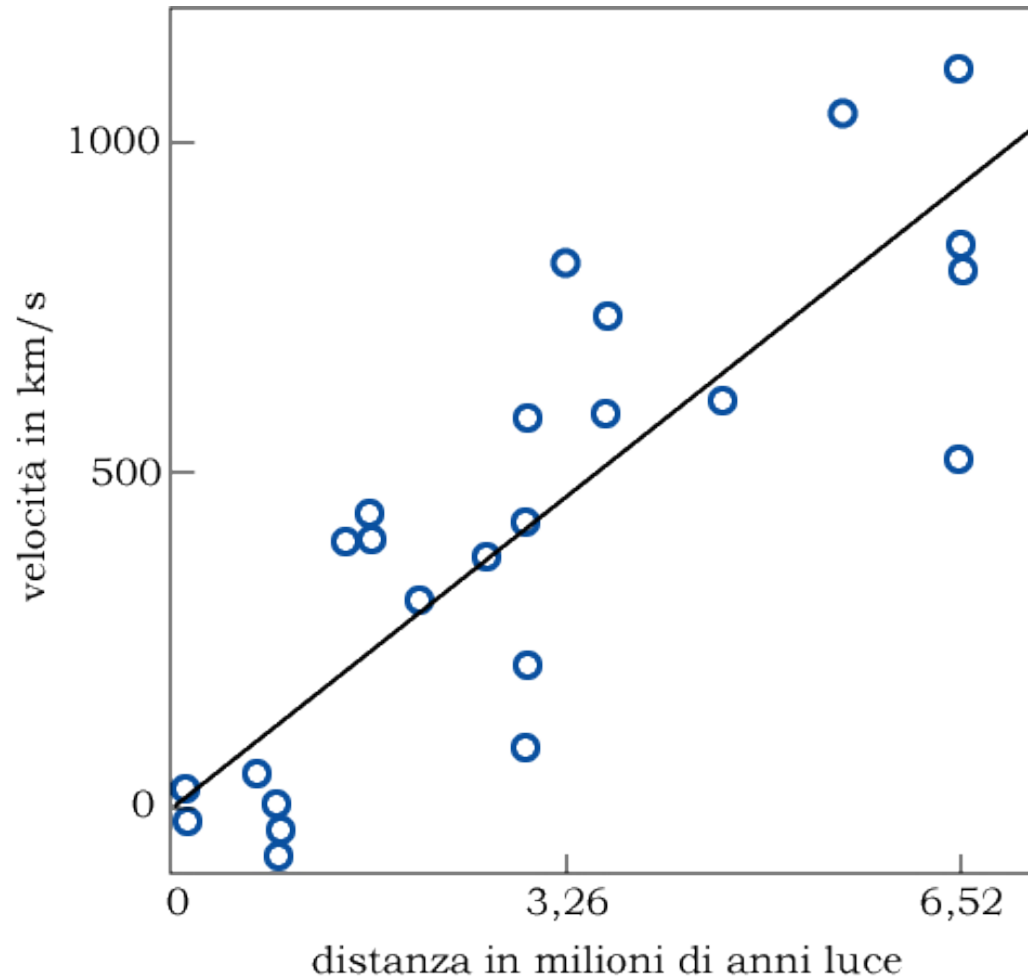
curvatura nulla
(Universo piatto)



curvatura negativa
(Universo aperto)



curvatura positiva
(Universo chiuso)



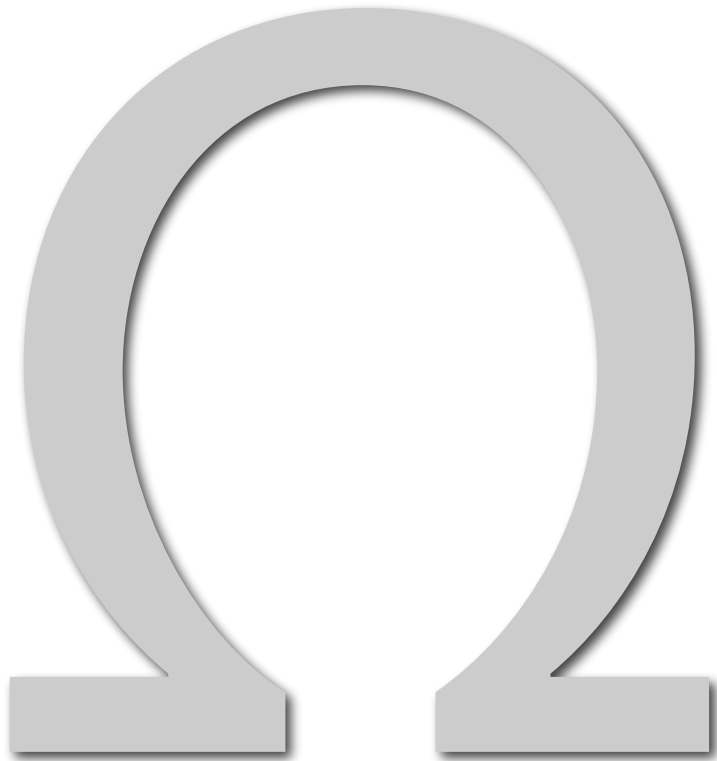
Hubble e Humason (1929)

“The results establish a roughly linear relation between velocities and distance among nebulae.”

Legge di Hubble:

$$v = H_0 d$$





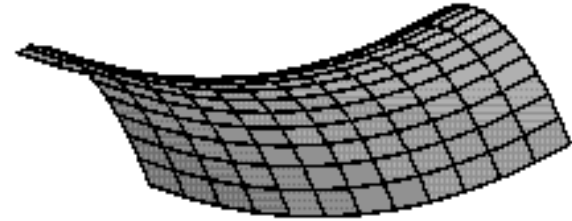
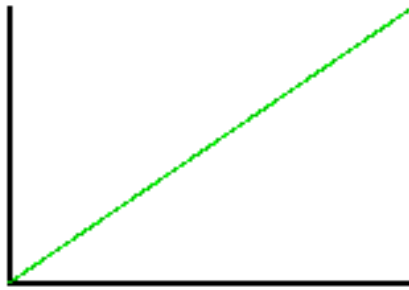
Densità critica ($\Omega=1$)

$$10^{-29} \text{g/cm}^3$$

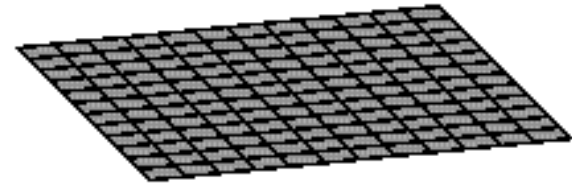
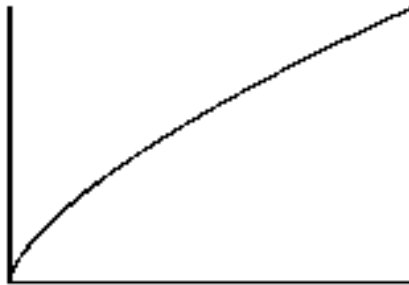
ovvero: 6 atomi di idrogeno per metro cubo

(densità dell'aria: 10^{25} atomi per metro cubo)

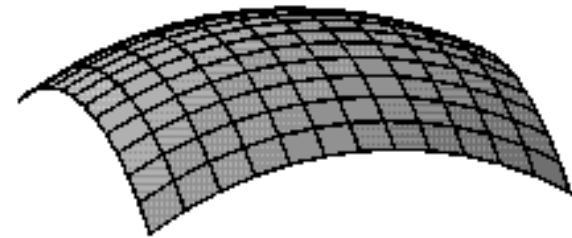
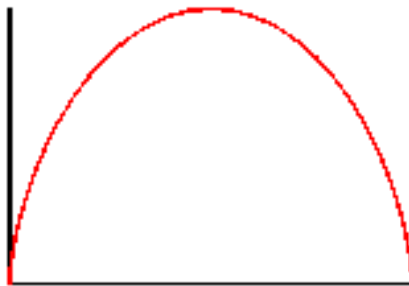
$\Omega < 1$



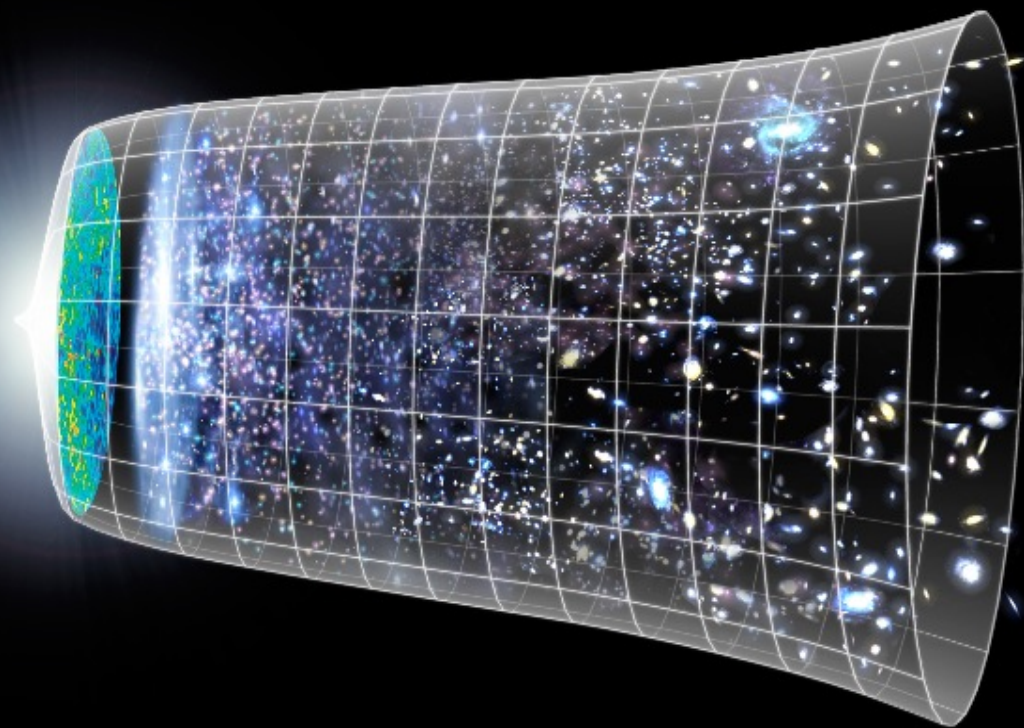
$\Omega = 1$



$\Omega > 1$



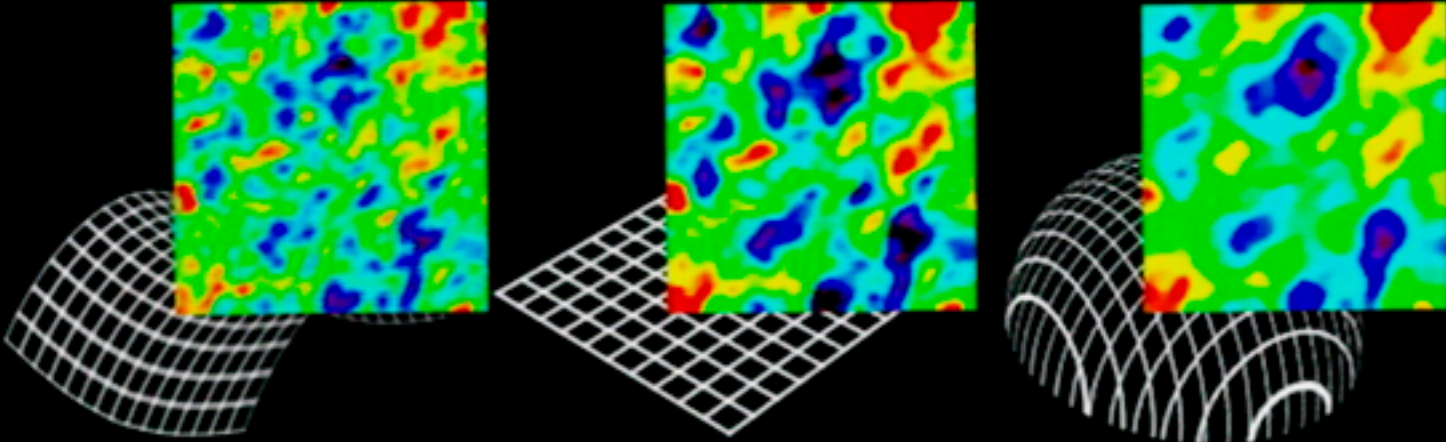
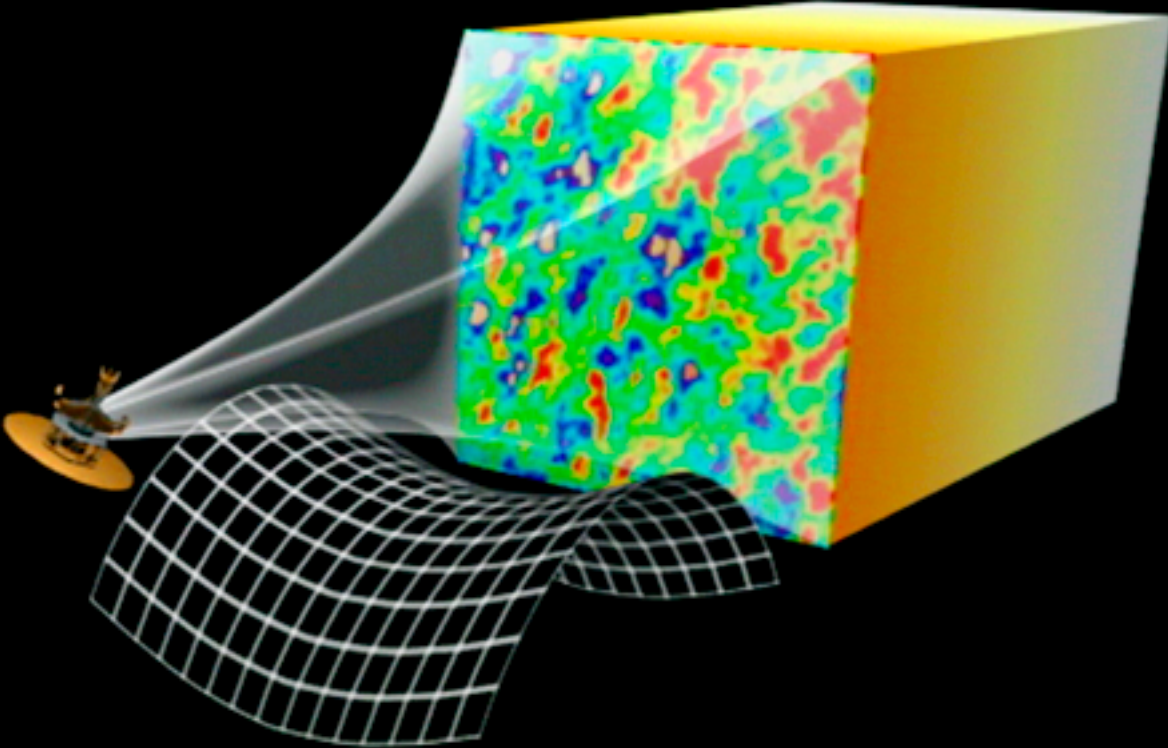
Big Bang

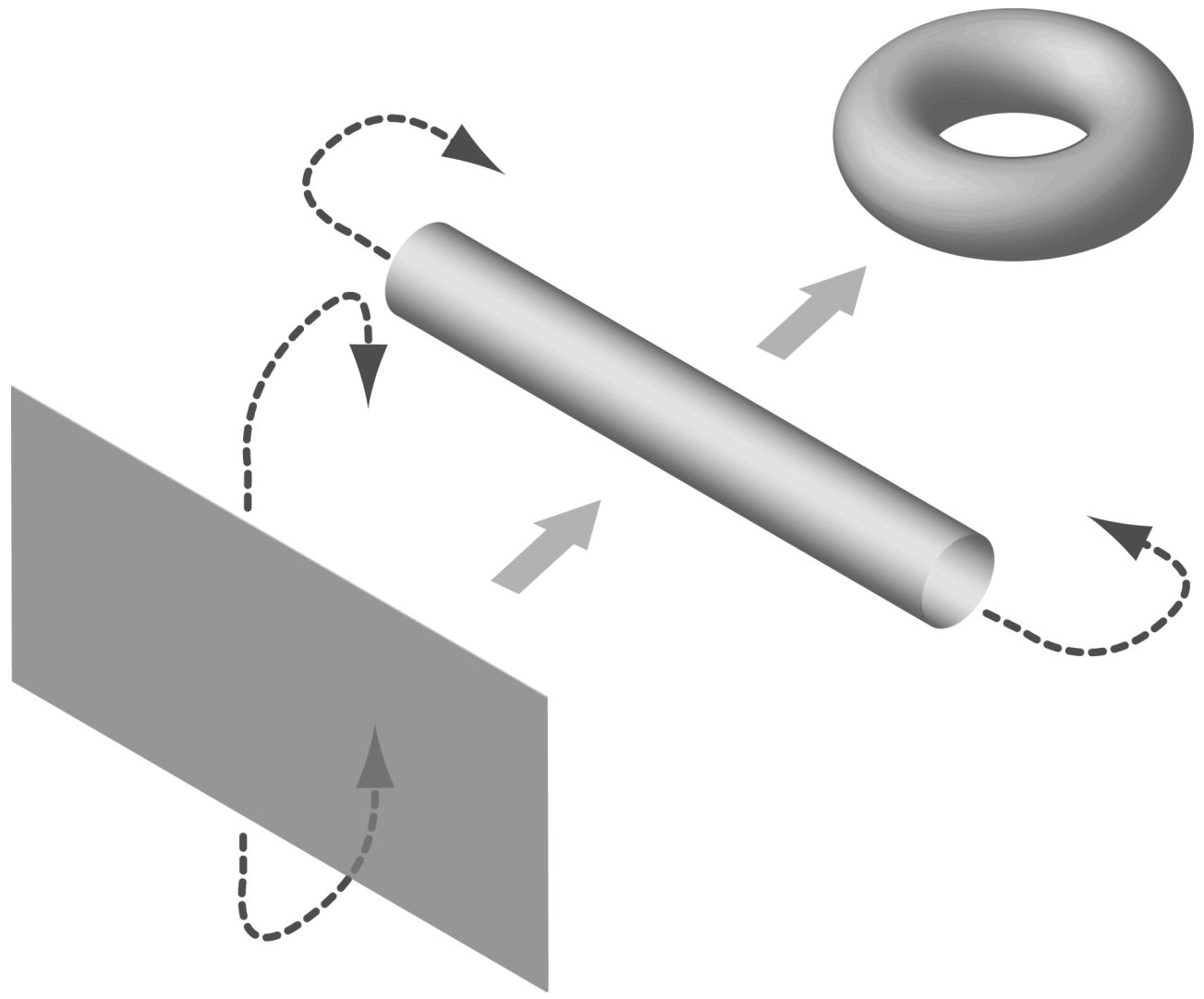


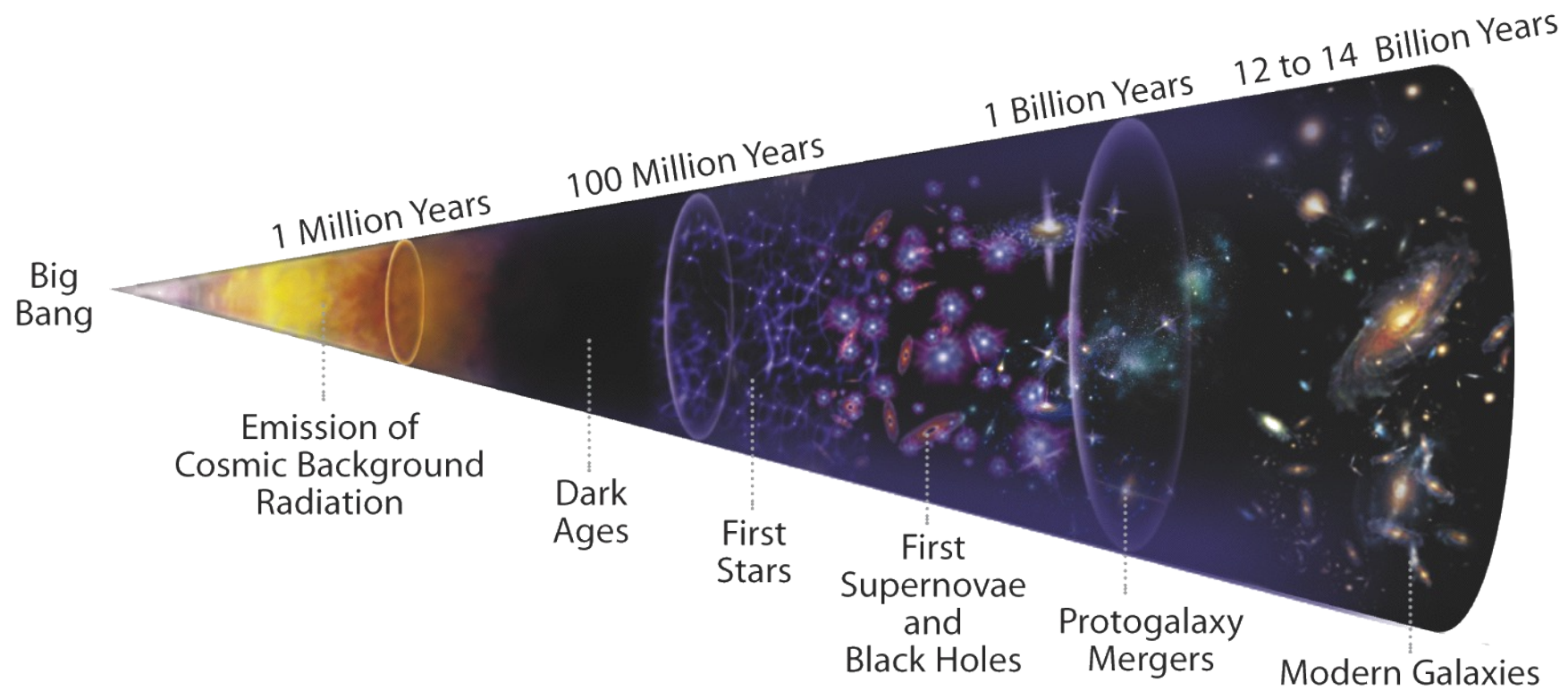
oggi



13.7 miliardi di anni







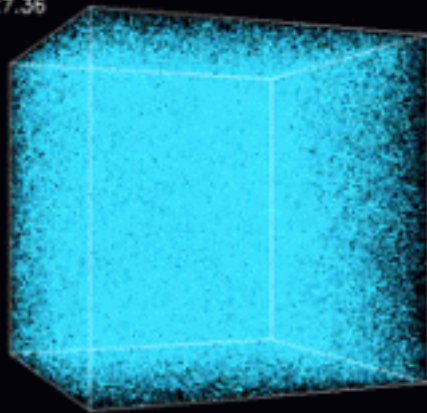
semplice



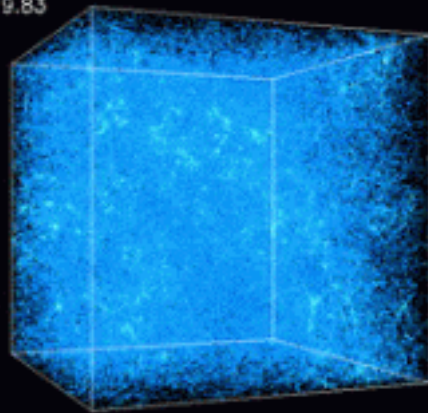
tempo

complesso

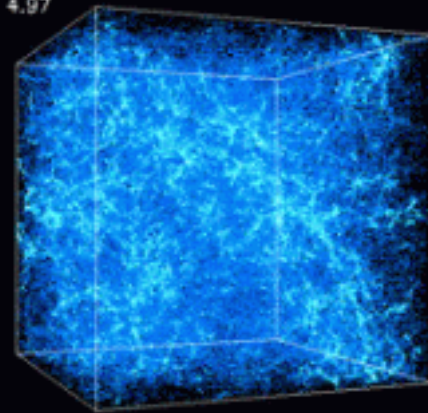
Z=27.36



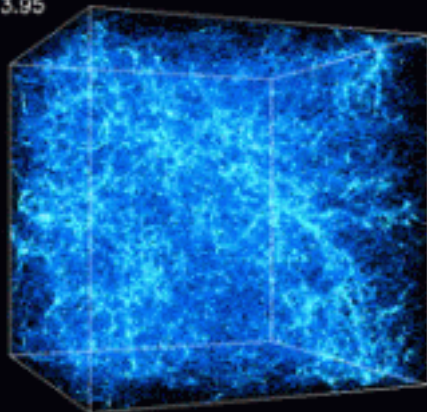
Z= 9.83



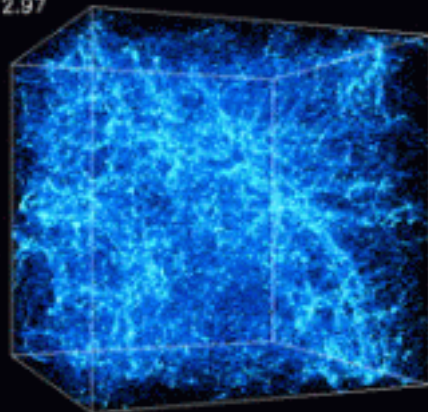
Z= 4.97



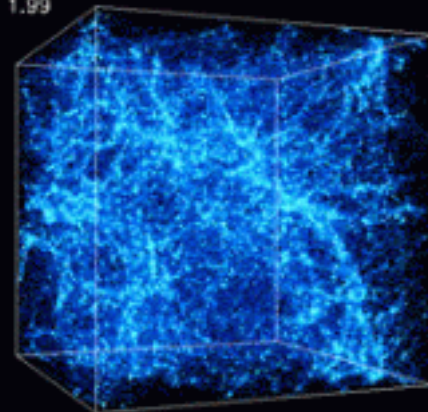
Z= 3.95



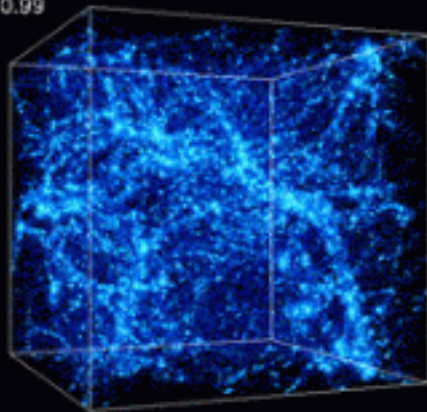
Z= 2.97



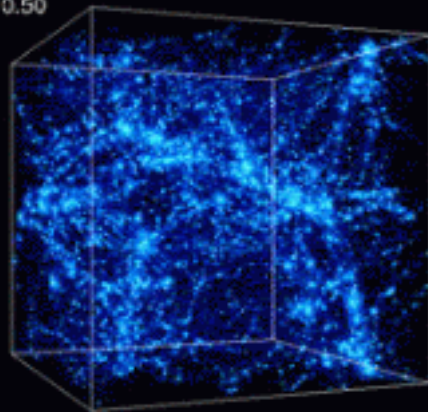
Z= 1.99



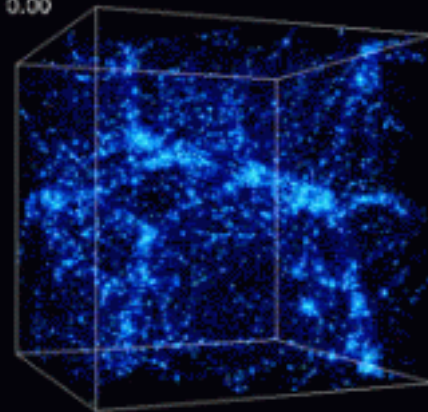
Z= 0.99



Z= 0.50

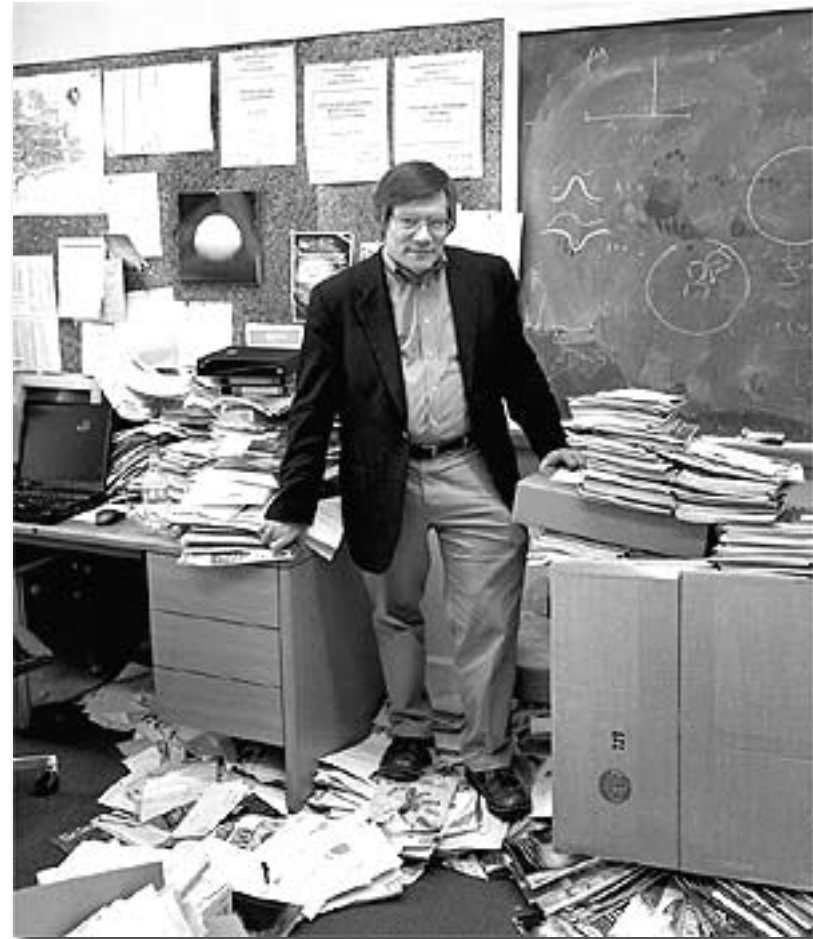


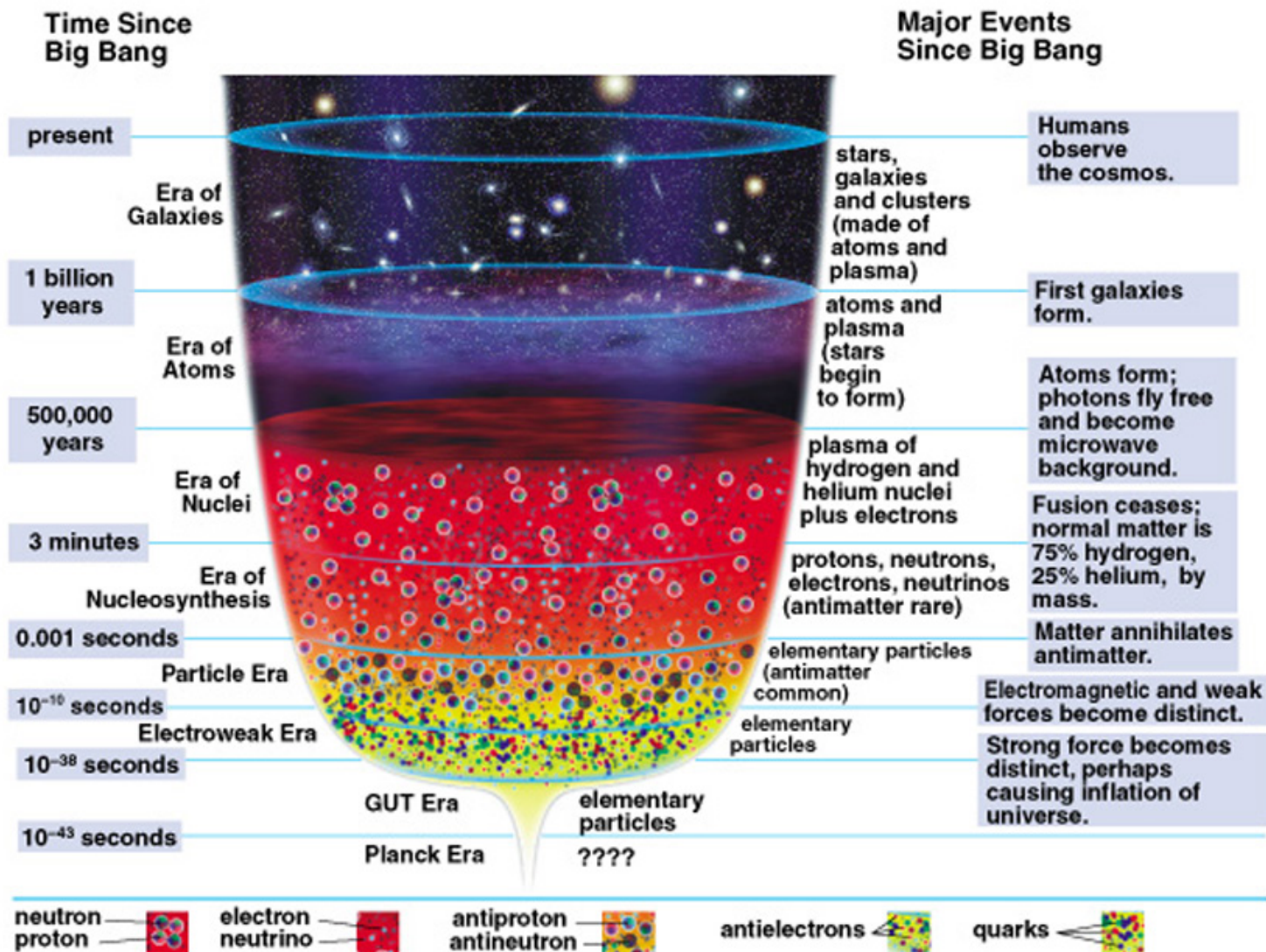
Z= 0.00

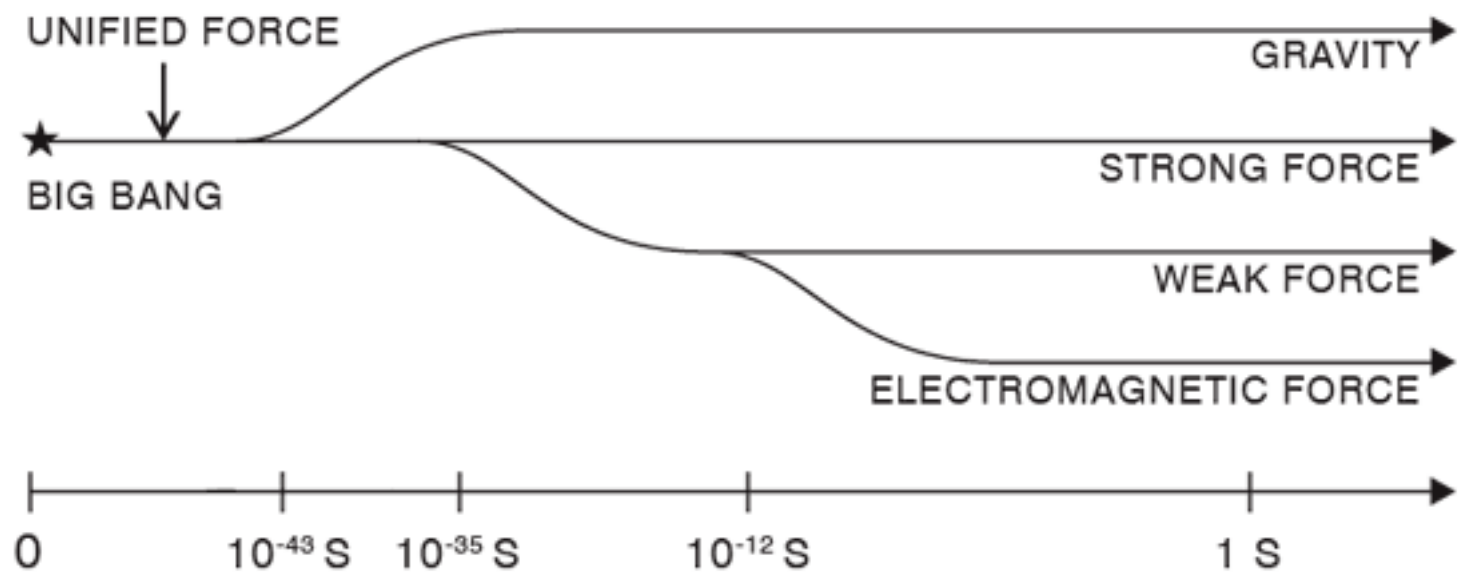


1. Quale meccanismo ha annullato la curvatura dello spazio?
2. Quale meccanismo ha reso l'universo simmetrico?
3. Quale meccanismo ha generato le perturbazioni primordiali?

Inflazione cosmica
[Alan Guth](#) (1981)

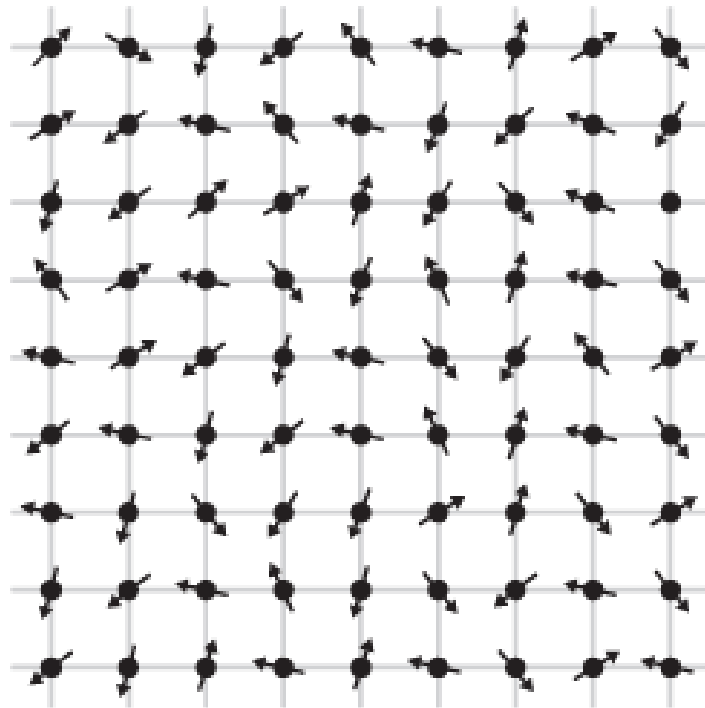






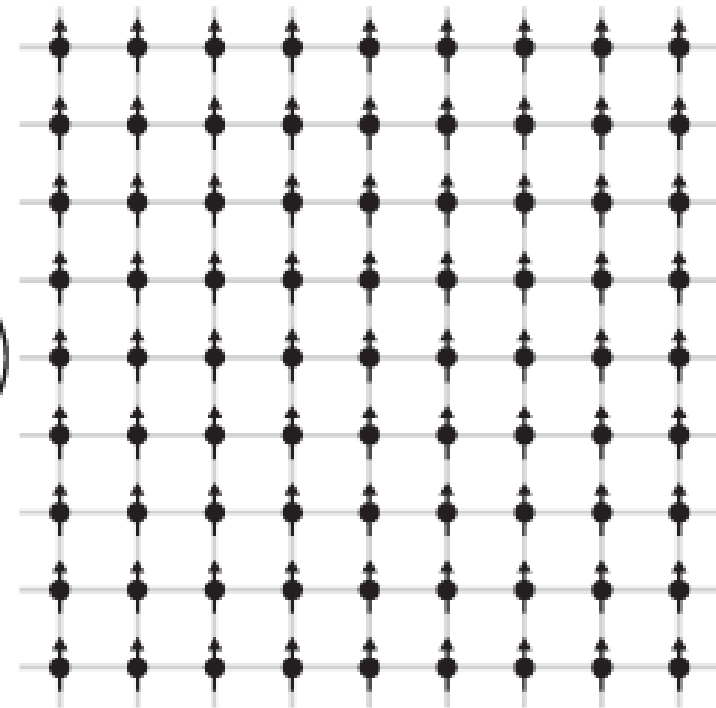
Stato fondamentale (minima energia)

$T > T_c$



(a)

$T < T_c$

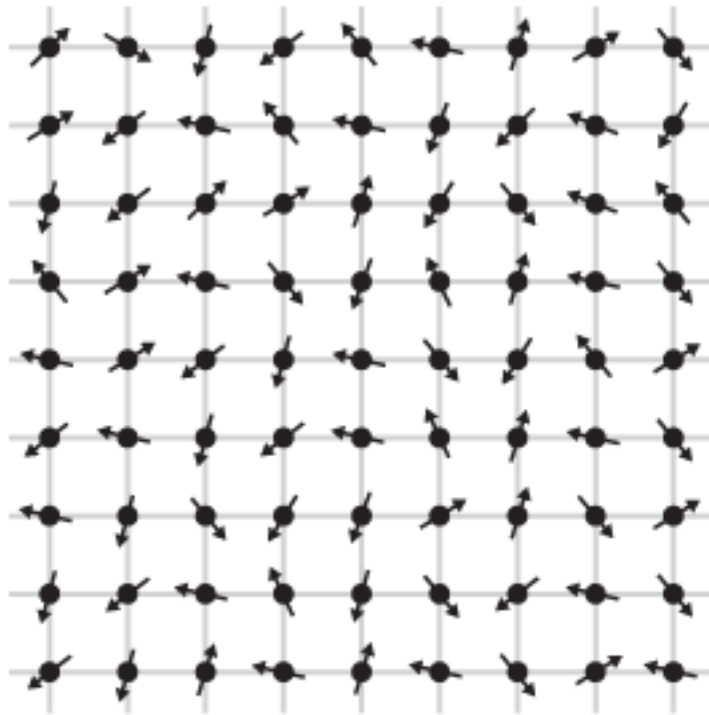


(b)

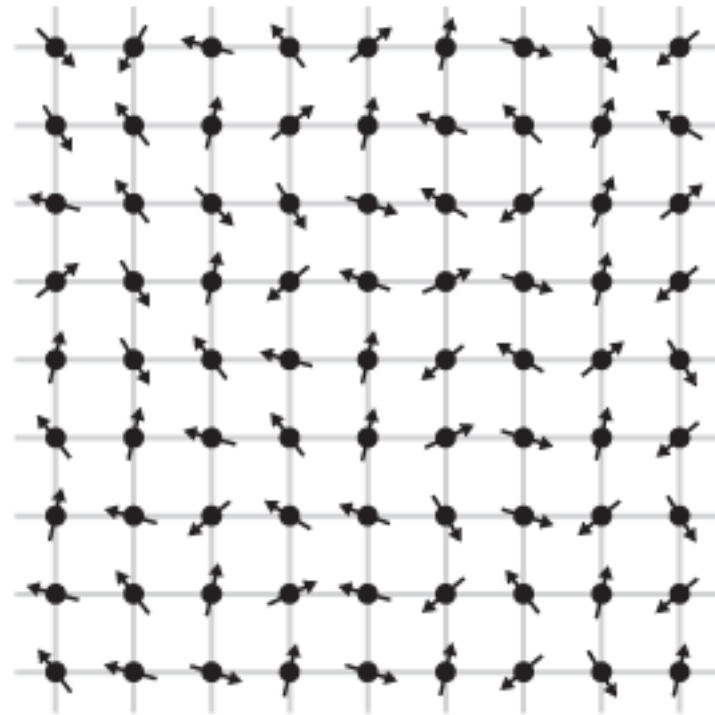
Magnet



Stato fondamentale **simmetrico**

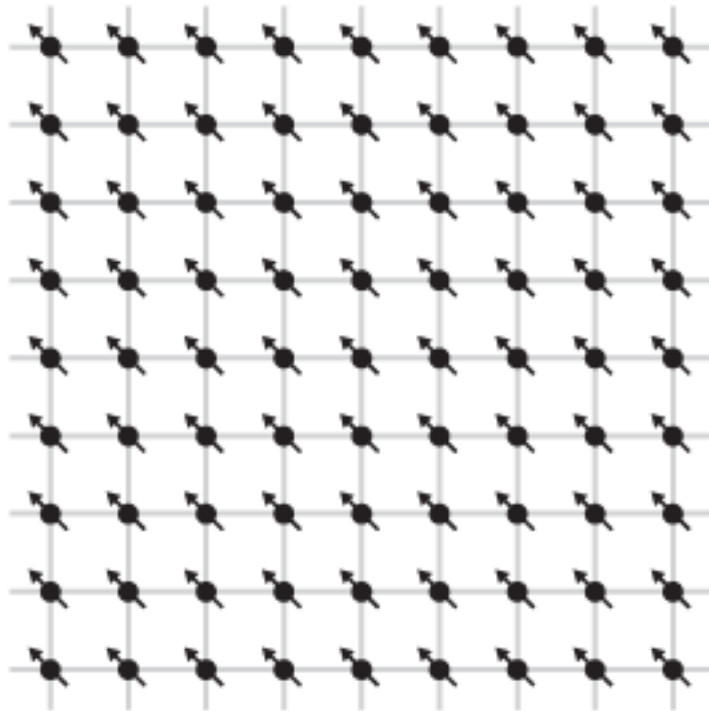


(a-i)

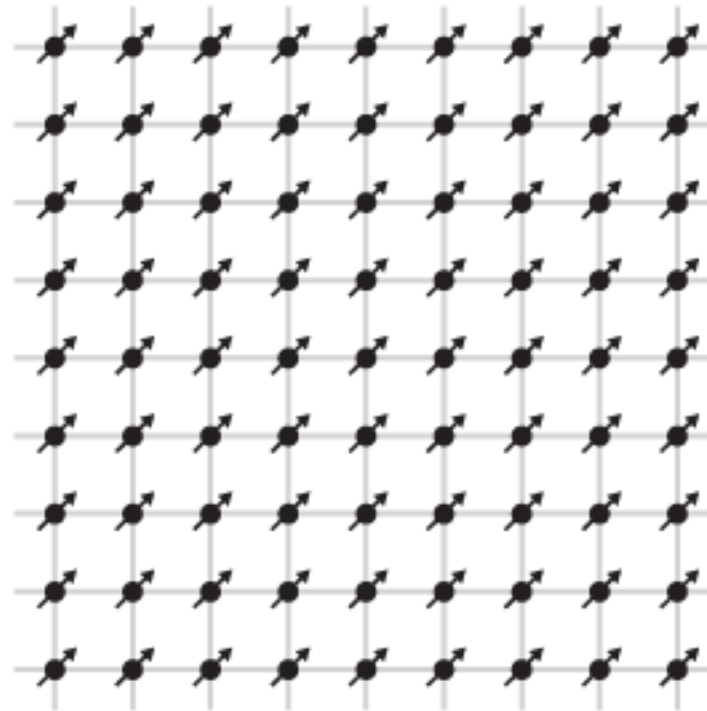


(a-ii)

Stato fondamentale **non simmetrico**

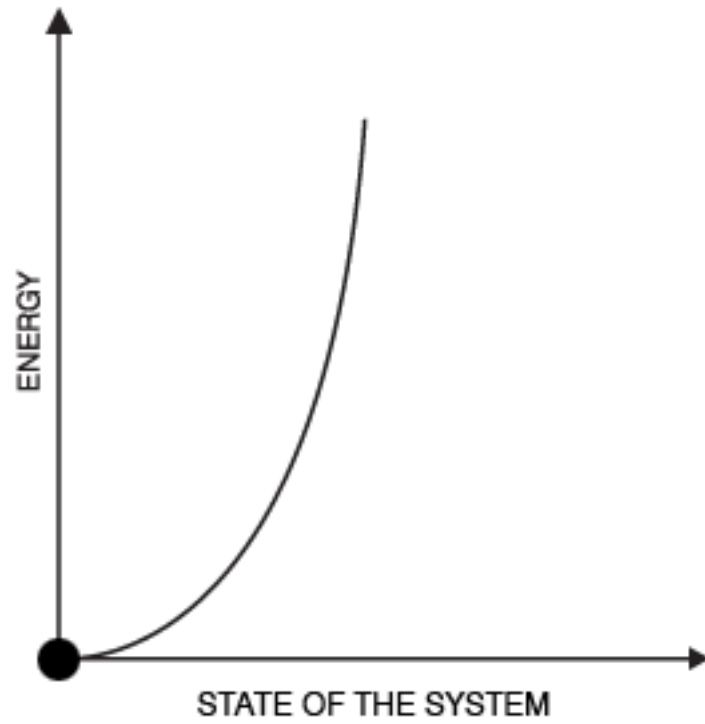


(b-i)

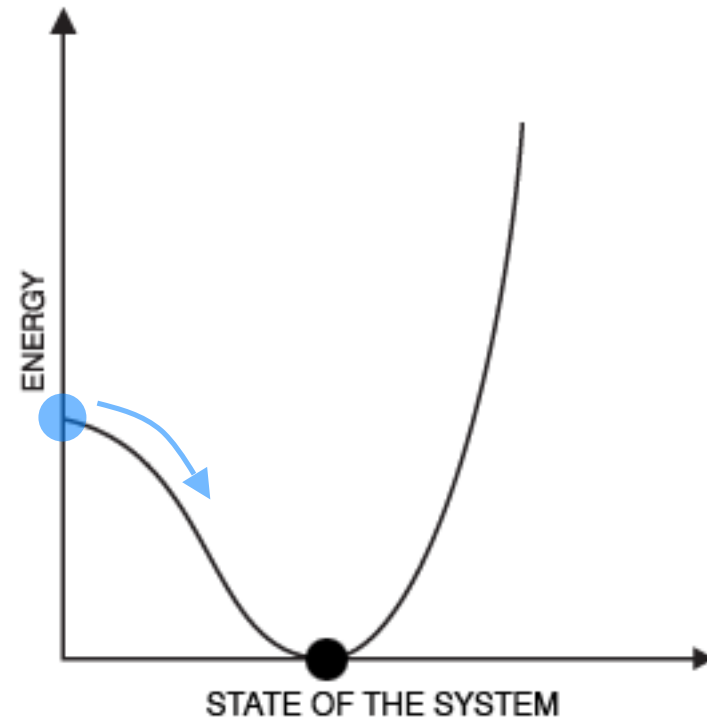


(b-i)

Rottura spontanea di simmetria



(a)



(b)



Universo prima
dell'inflazione

$$\Omega \rightarrow 1$$

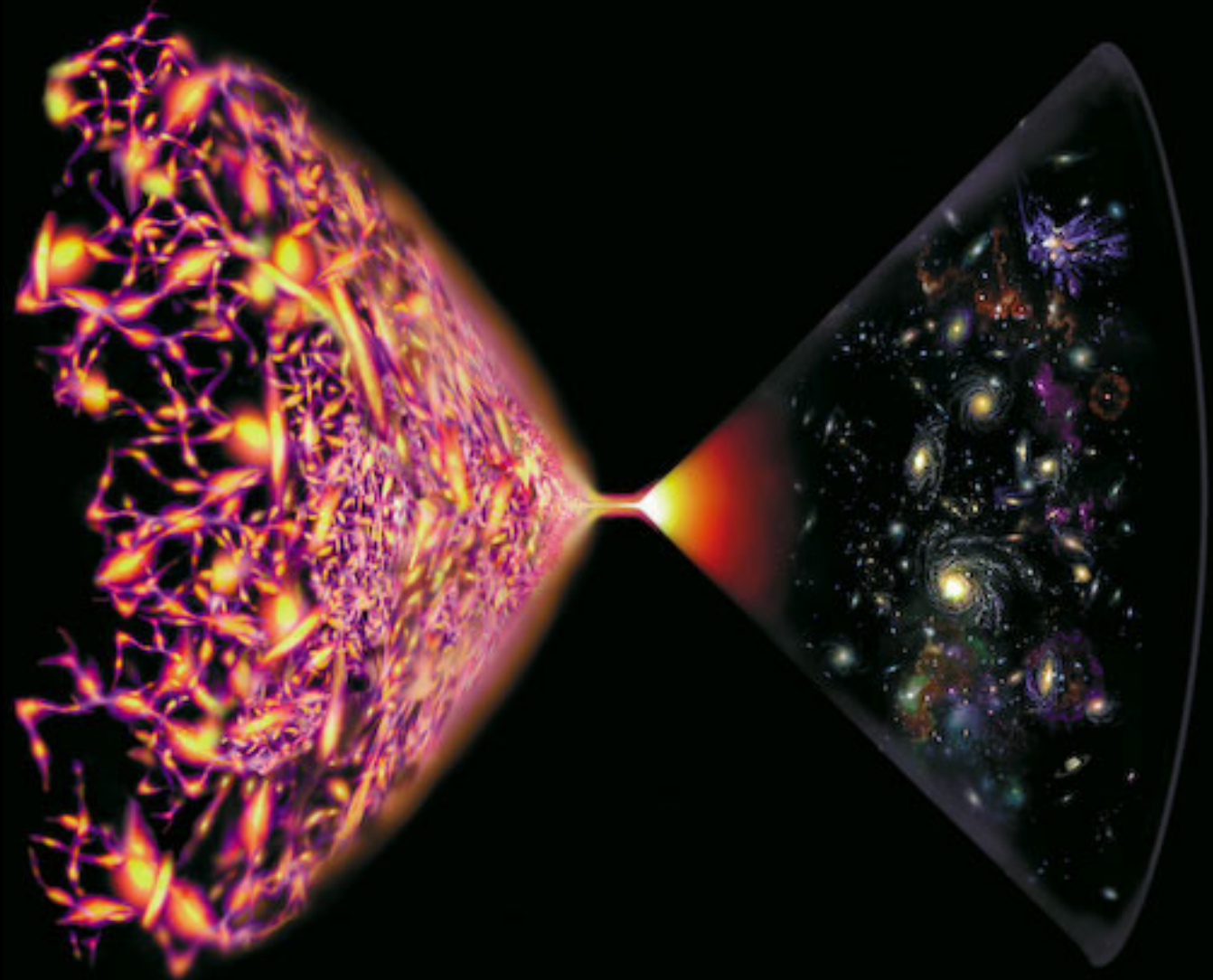



Universo dopo
l'inflazione



Principio di indeterminazione

$$\Delta E \Delta t \sim h$$

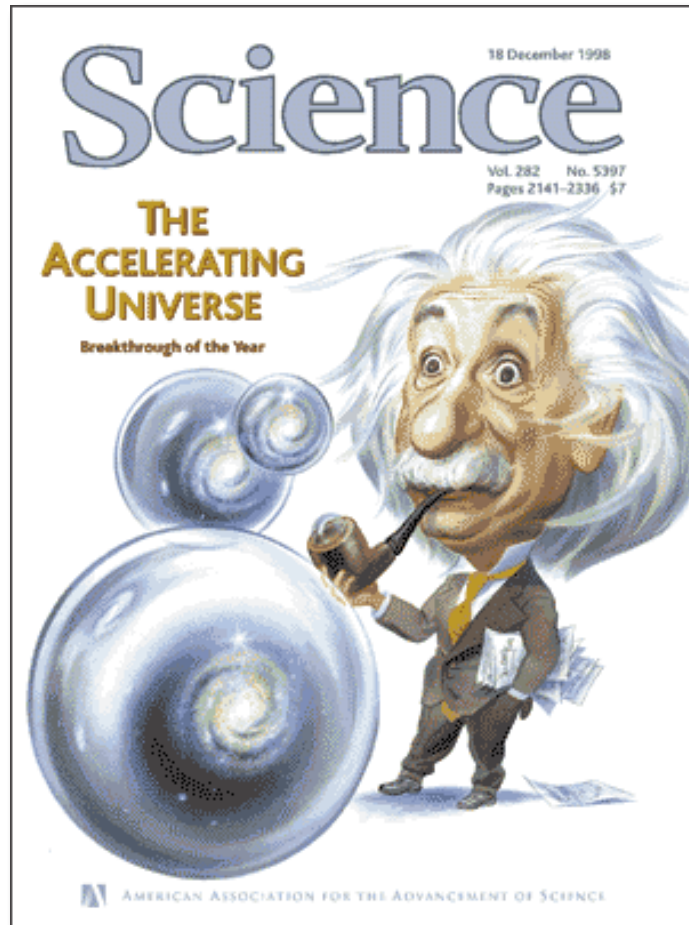


An iceberg floating in a blue ocean under a blue sky. The tip of the iceberg is above the water, while the much larger base is submerged. A large white question mark is centered on the submerged part of the iceberg. Text labels are placed to the right of the iceberg, corresponding to the different components of the universe.

Materia ordinaria 4%
(meno dell'1% è visibile)

Materia oscura 22%

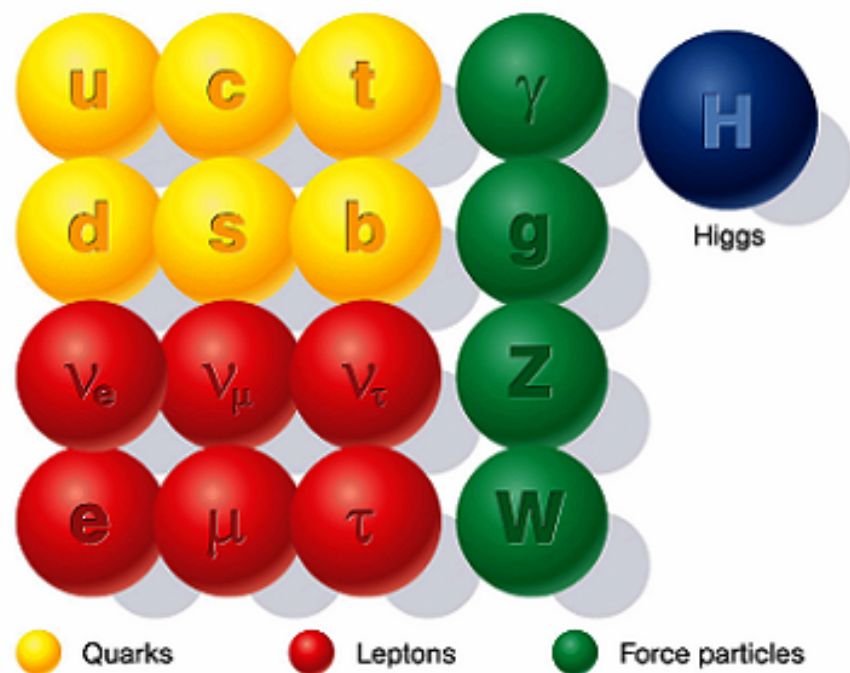
Energia oscura 74 %



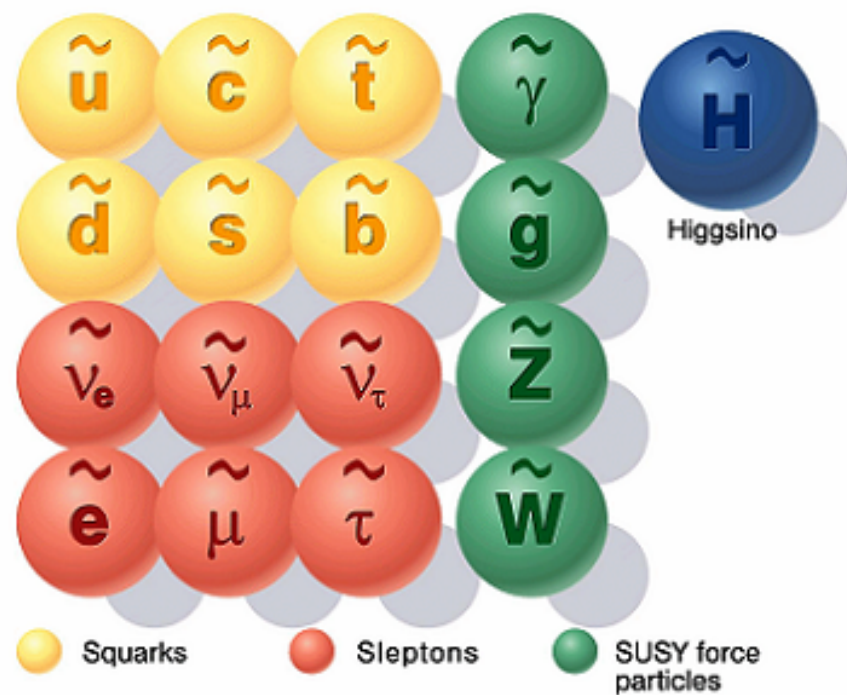
“Una volta, mentre discutevamo di problemi cosmologici, Einstein mi disse che l'introduzione della costante cosmologica era stato **il più grande abbaglio della sua vita.**”

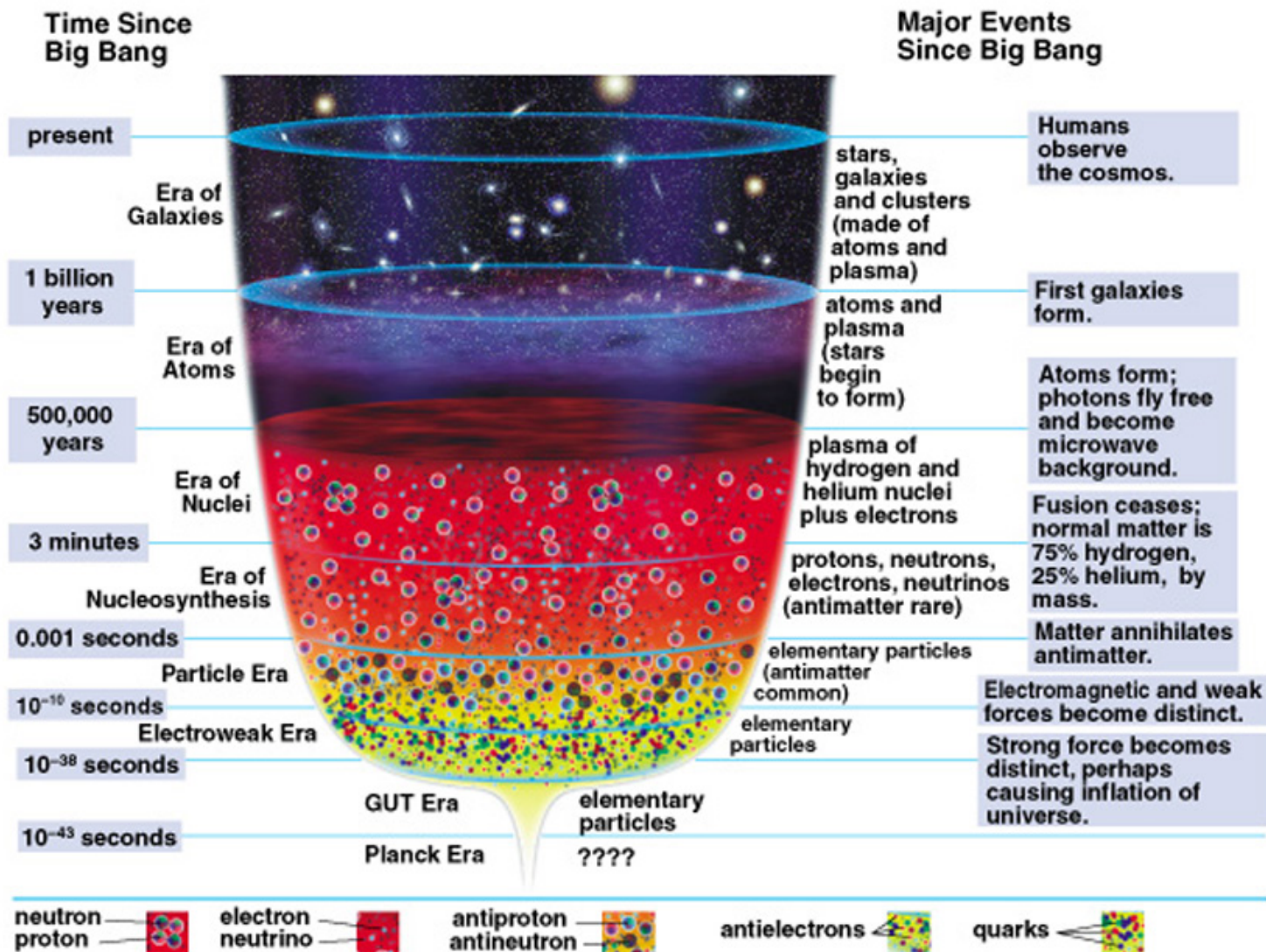
— George Gamow (1970)

Standard particles



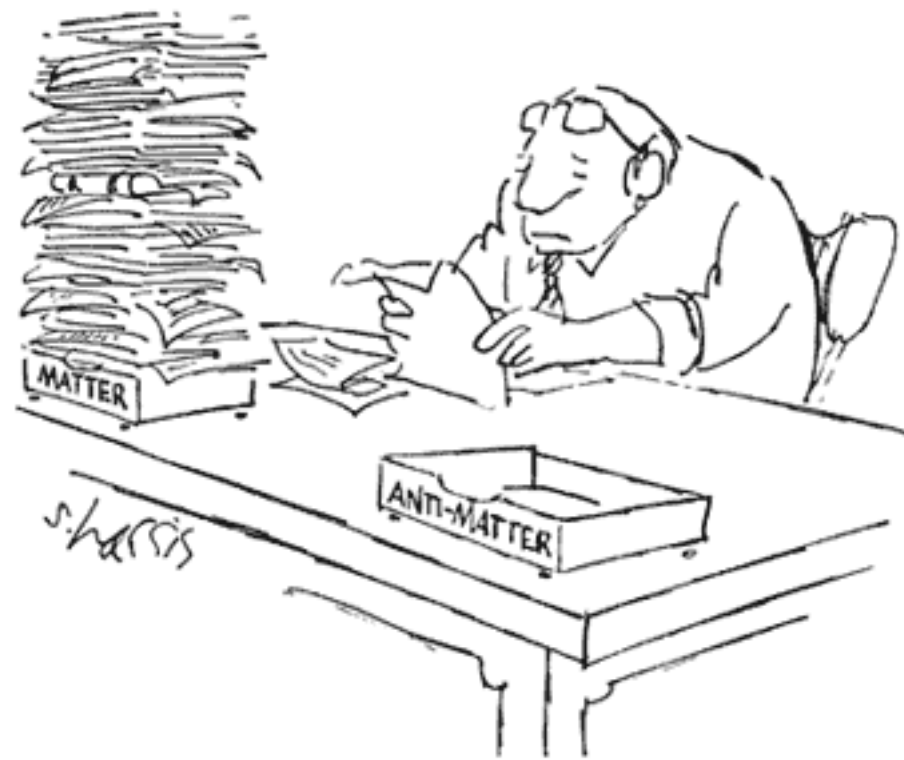
SUSY particles

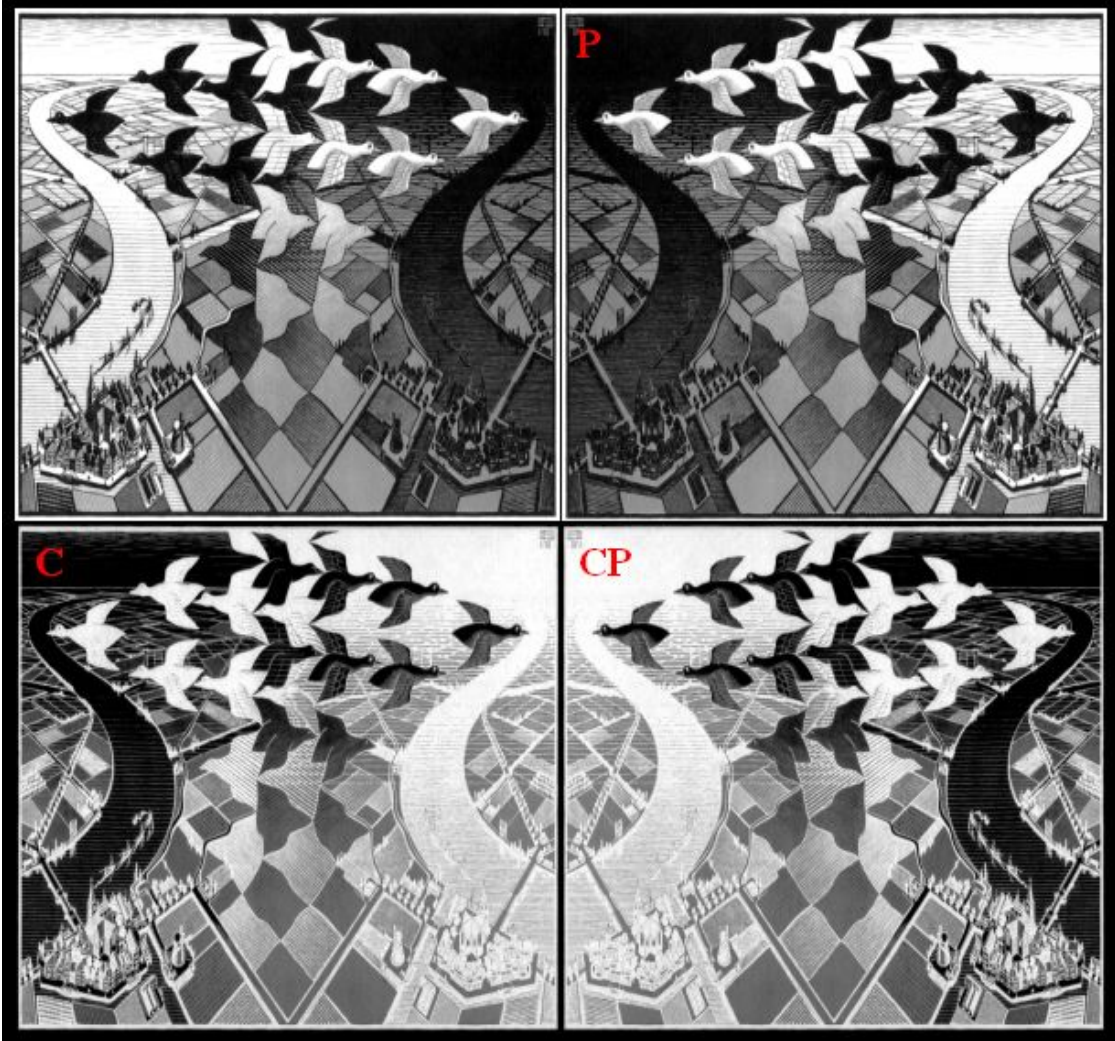


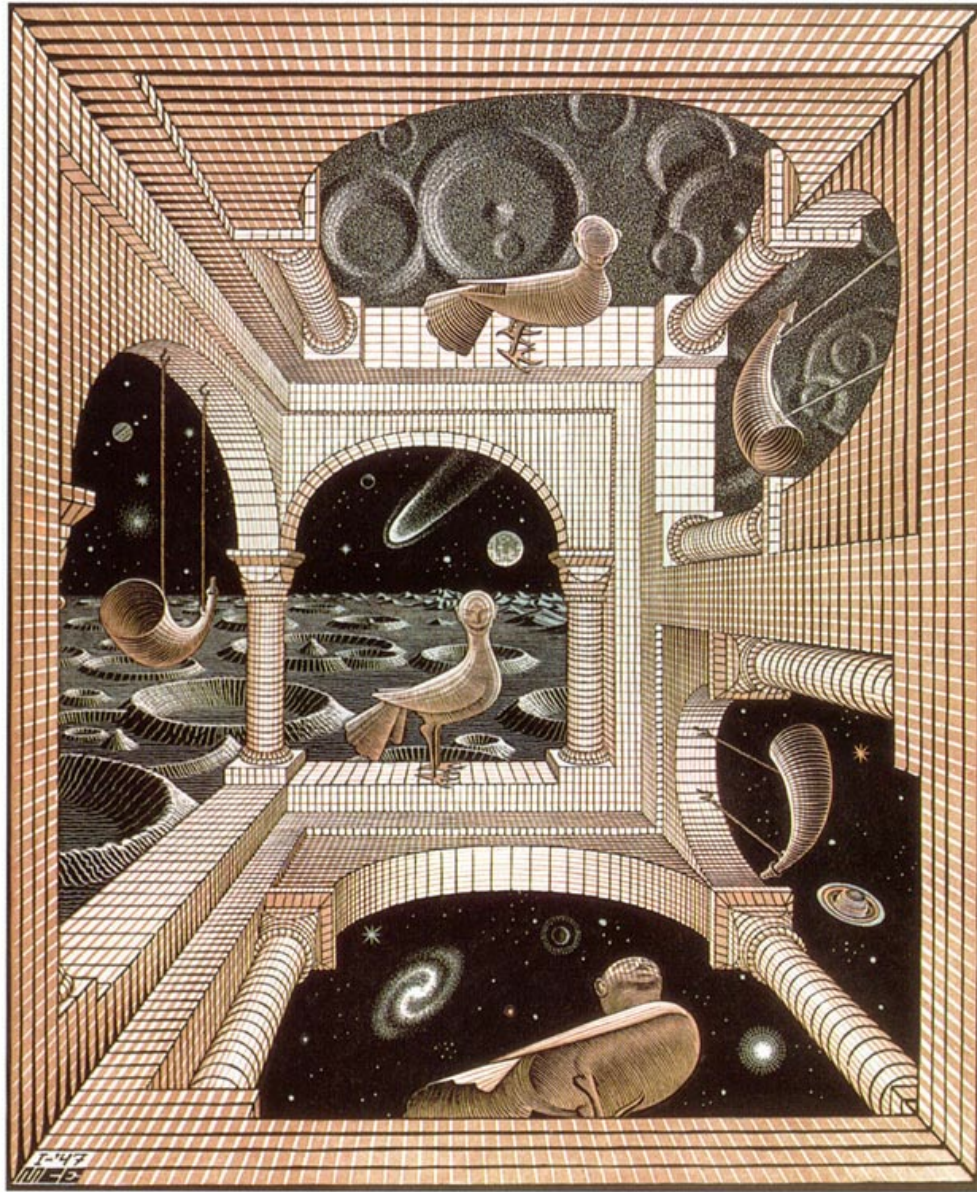


neutron — [neutron icon] electron — [electron icon] antiproton — [antiproton icon] antielectrons — [antielectrons icon] quarks — [quarks icon]

proton — [proton icon] neutrino — [neutrino icon] antineutron — [antineutron icon]







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