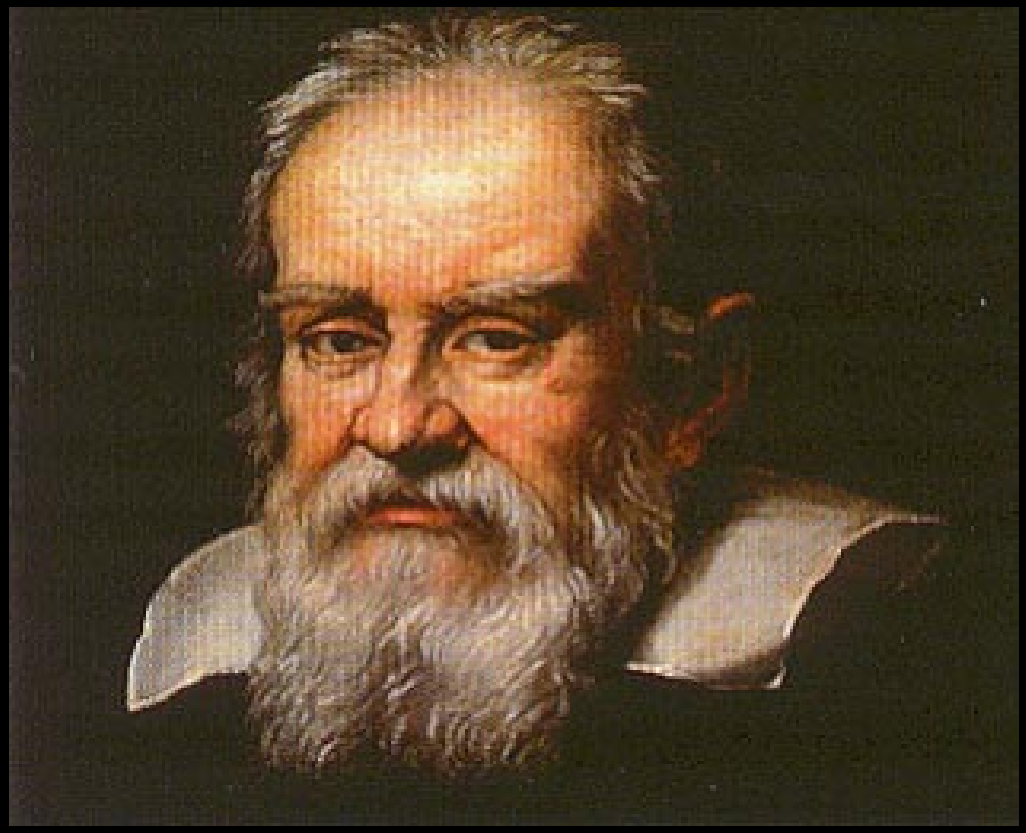
INAF - Osservatorio Astronomico di Bologna


Ma l’Universo è costituito solo
da materia luminosa?

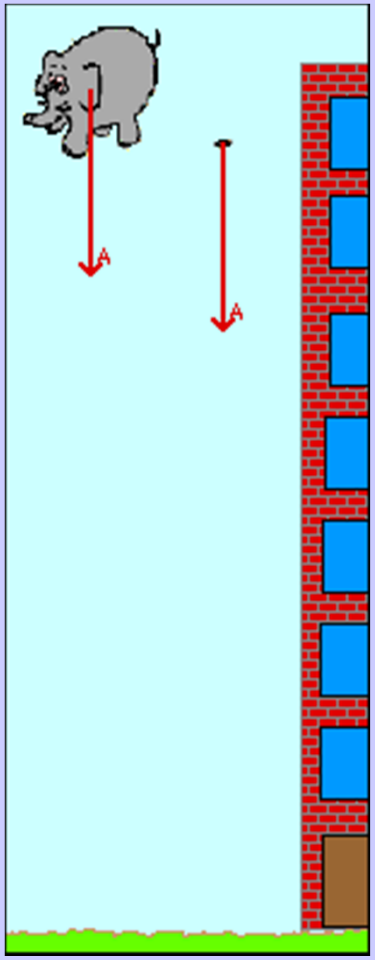
La forza di gravità



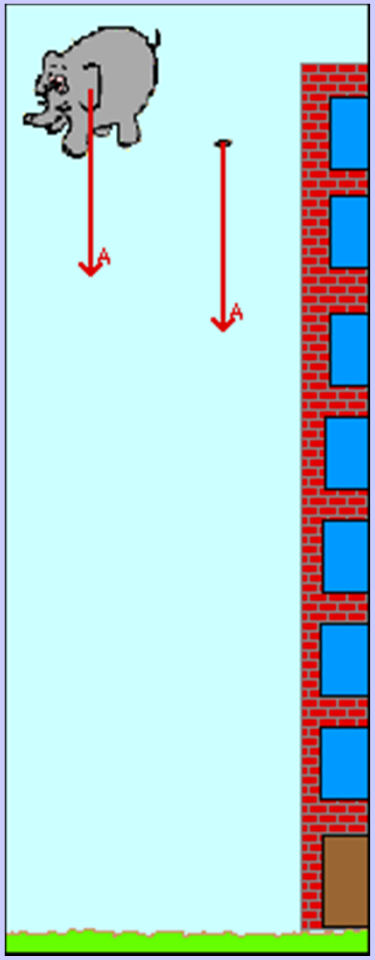
Galileo Galilei
(1564 – 1642)

Torre di Pisa

Nel Vuoto

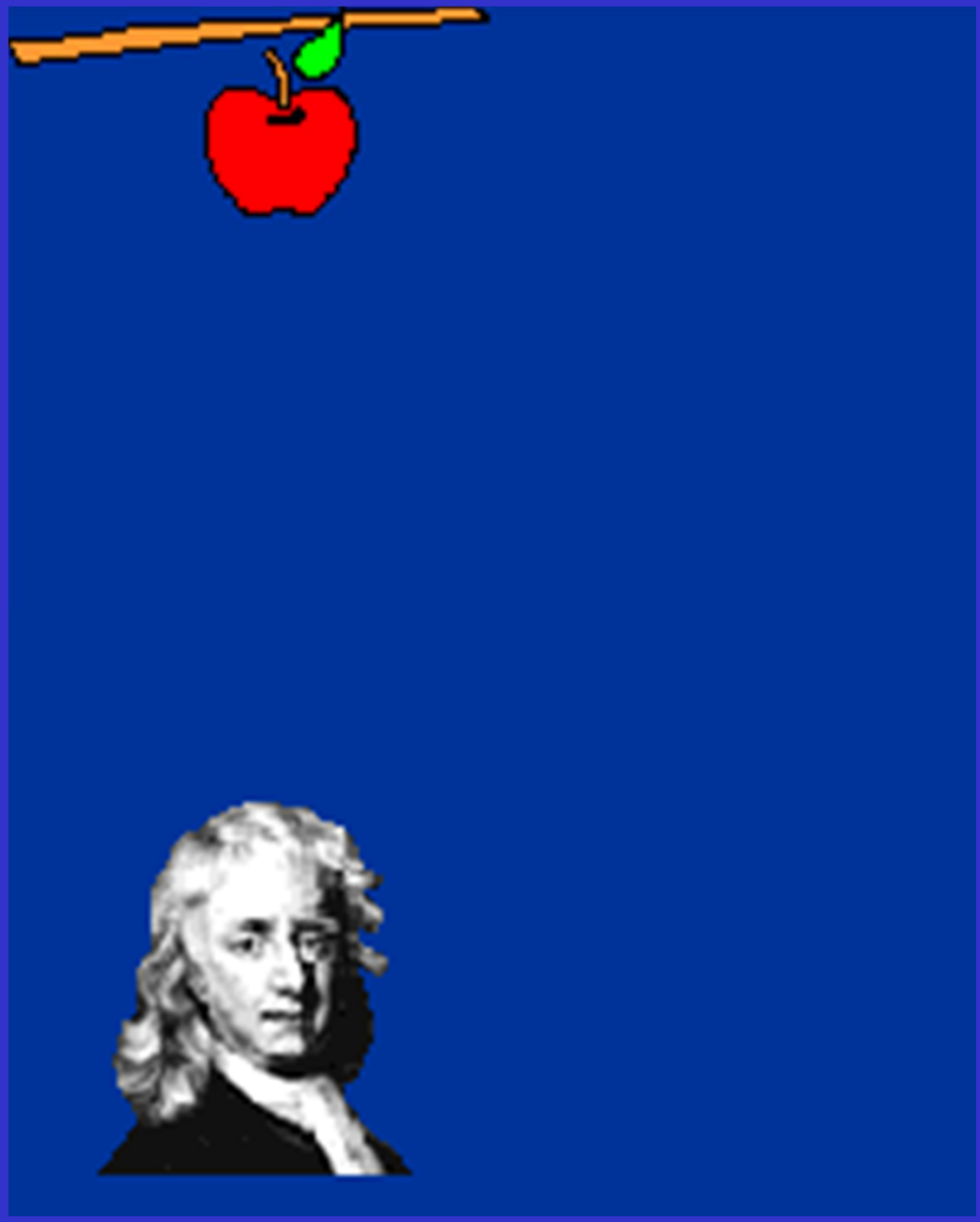


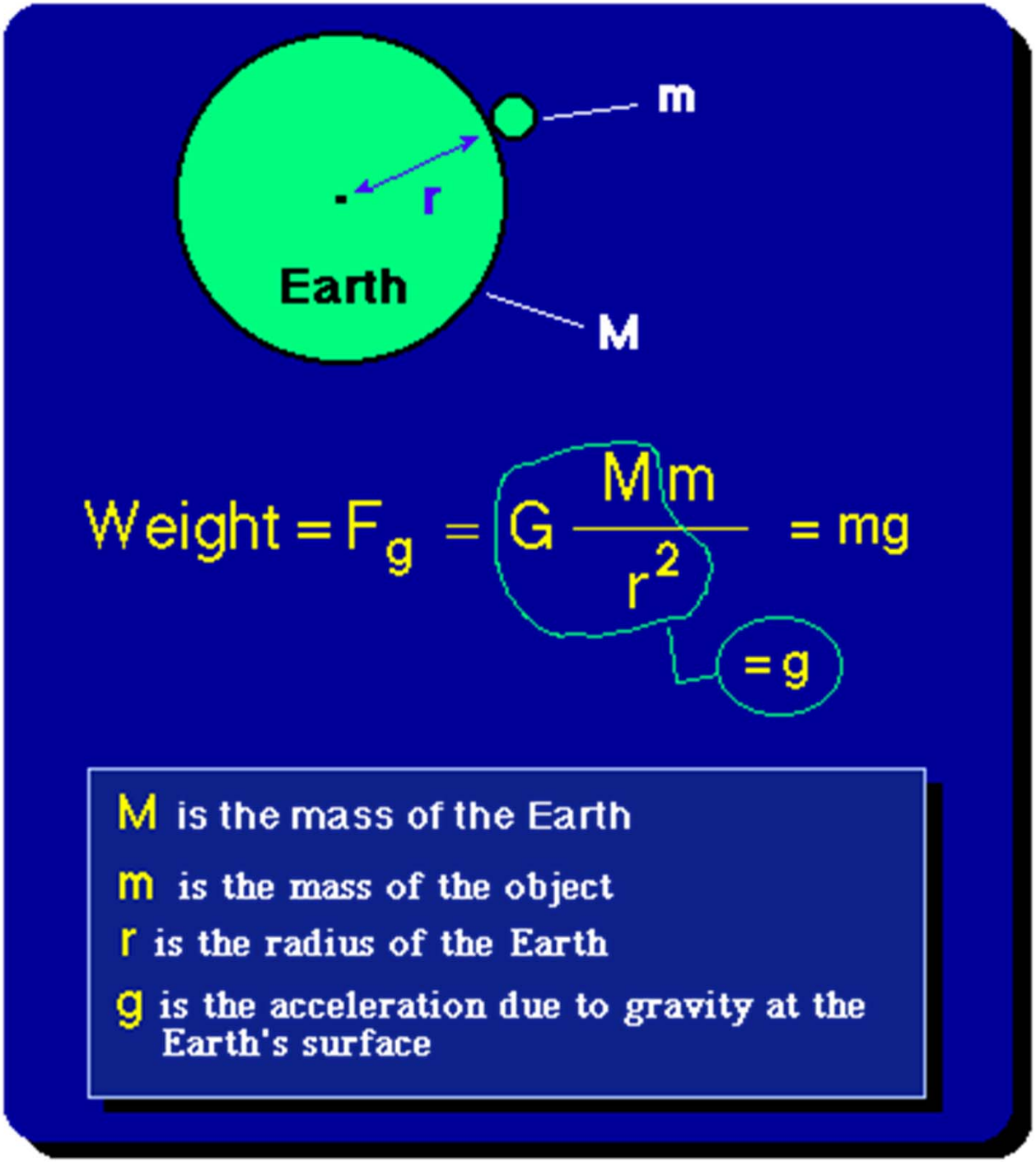
In presenza di aria



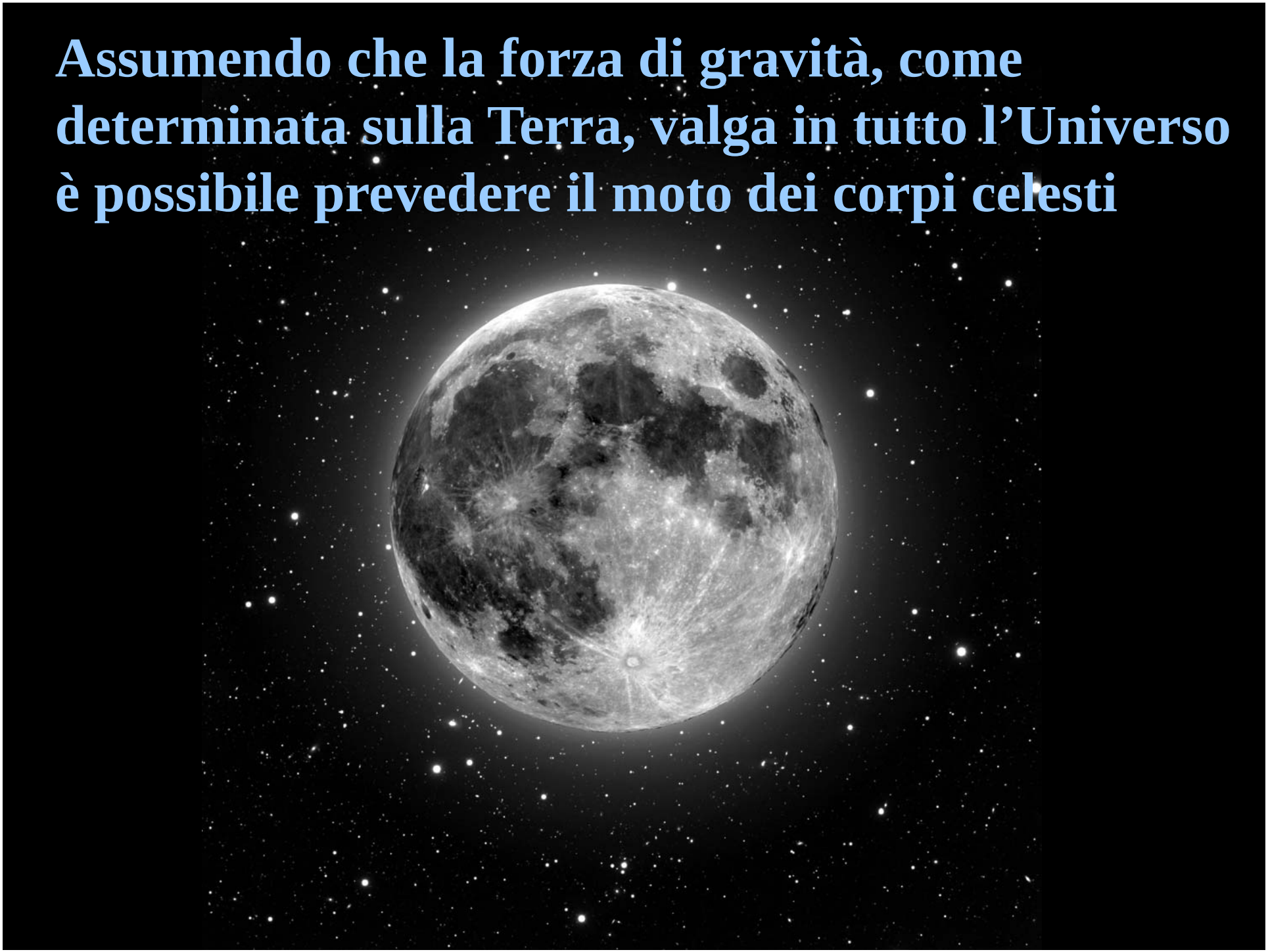
Tutti i corpi cadono sulla Terra con la stessa accelerazione

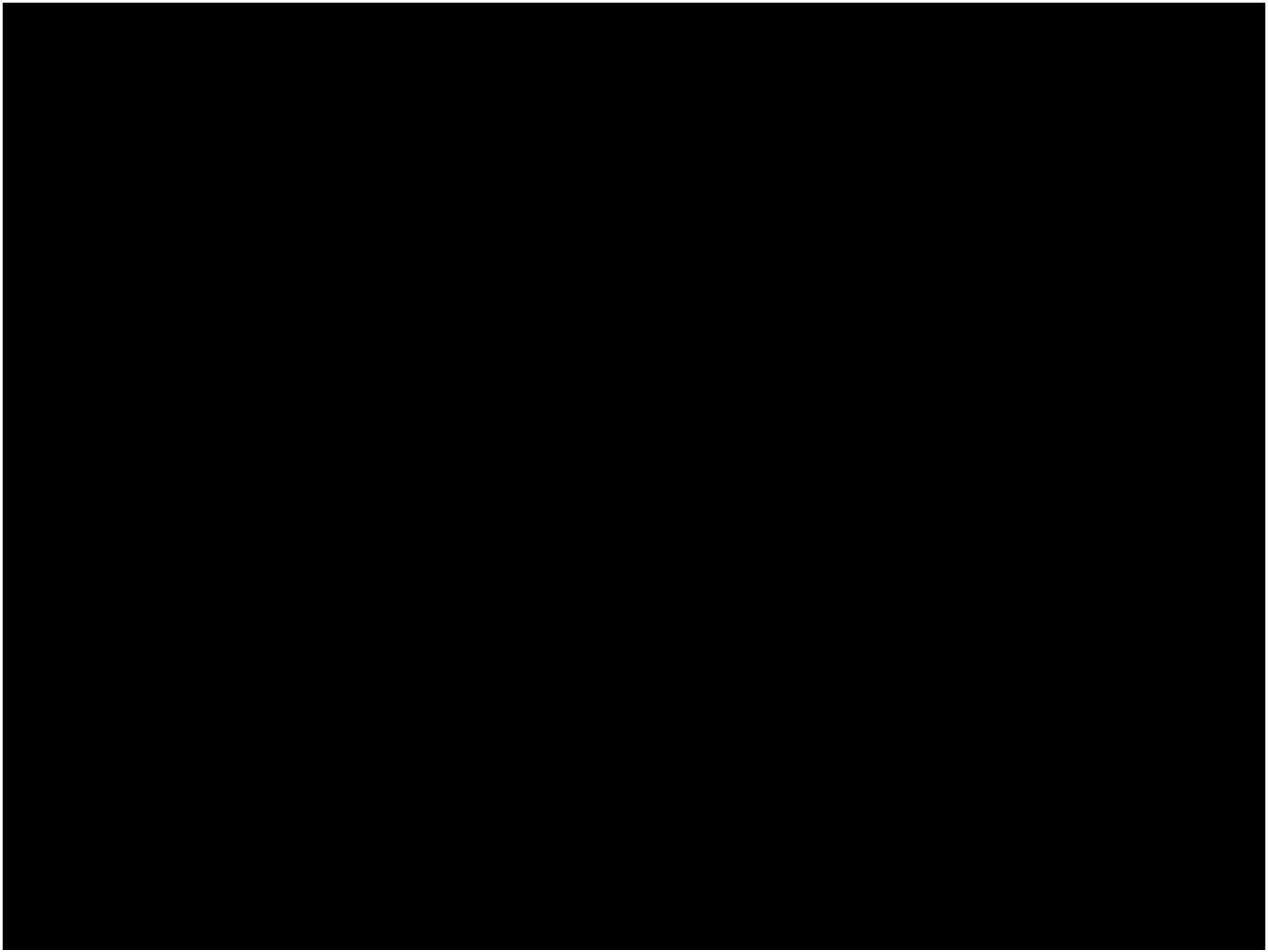
Isaac Newton
(1642 – 1727)



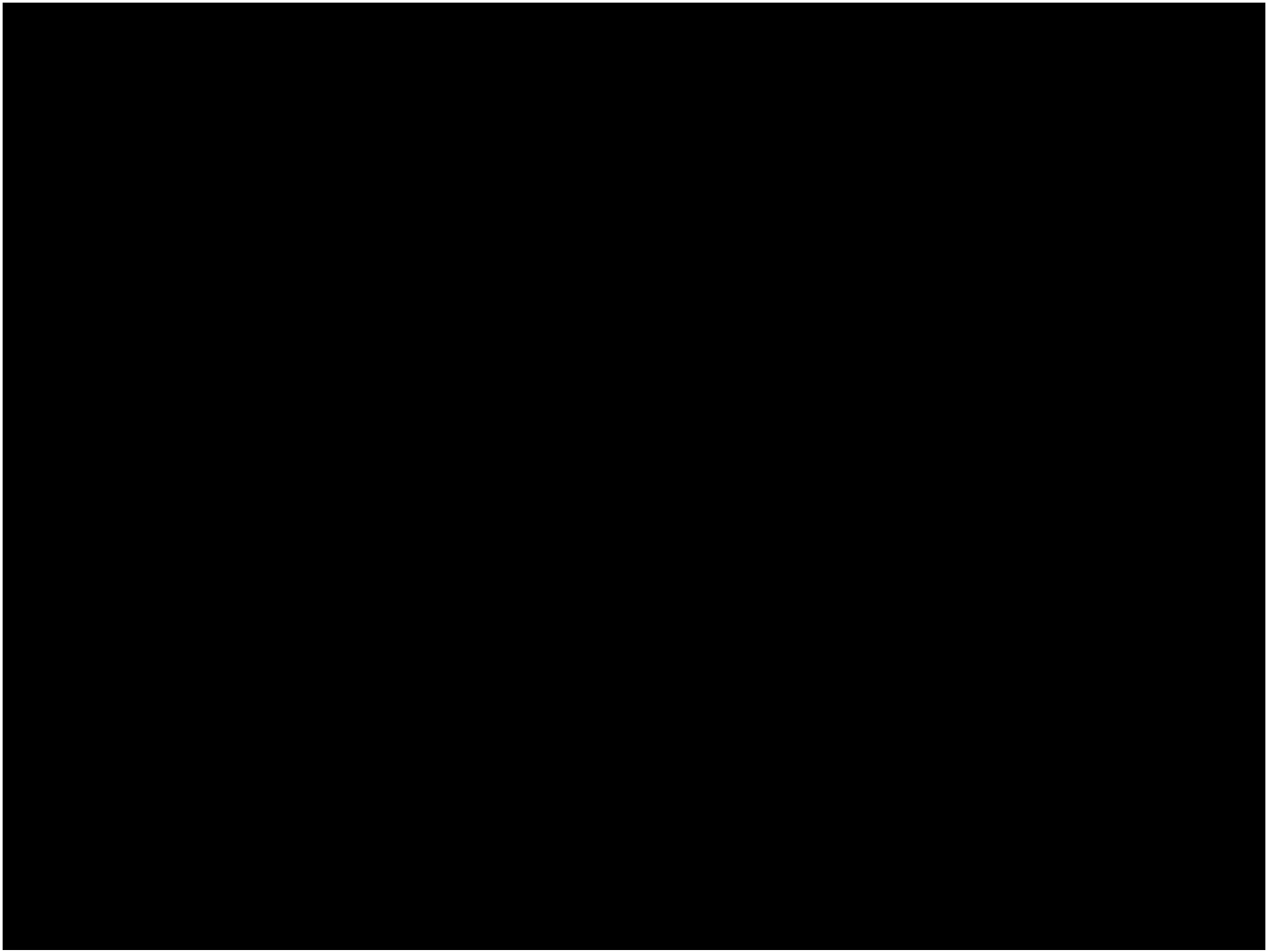

m
r
Earth
M
Weight = F_g = G $\frac{Mm}{r^2}$ = mg
= g
M is the mass of the Earth
m is the mass of the object
r is the radius of the Earth
g is the acceleration due to gravity at the Earth's surface

Assumendo che la forza di gravità, come determinata sulla Terra, valga in tutto l'Universo è possibile prevedere il moto dei corpi celesti





Luglio 1969 Apollo 11



La legge di gravitazione universale funziona in modo molto preciso nel nostro sistema solare

Ma cosa sappiamo di ciò che succede nell'Universo lontano?

I costituenti luminosi dell'Universo

Stelle $6.96\ 10^{10}$ cm $1.99\ 10^{33}$ gr

$= 1\ M_o$

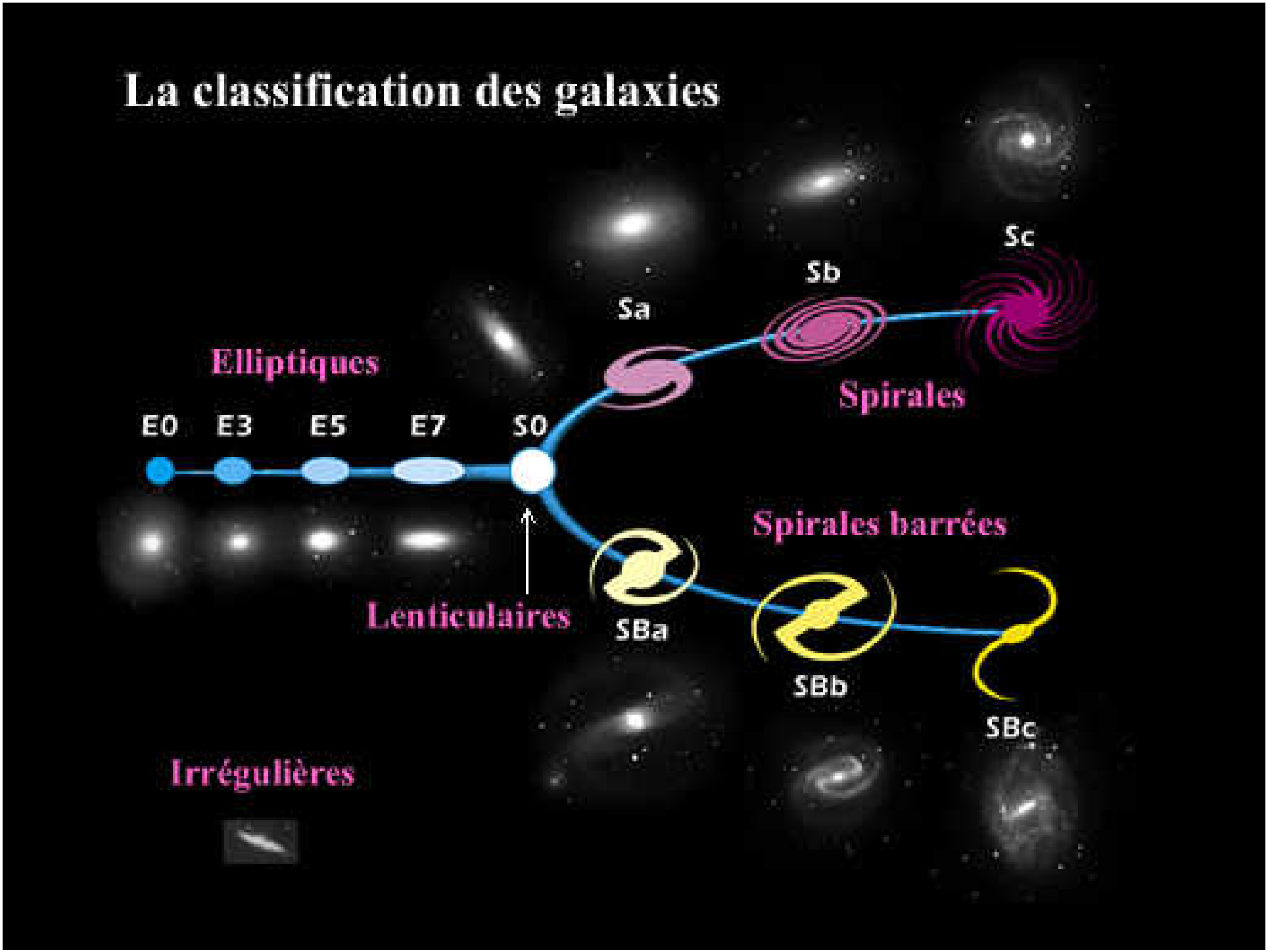
[1 pc = 3.26 a.l. = $3.09\ 10^{18}$ cm]

Galassie 25 kpc $10^{11}\ M_o$

Ammassi 2 Mpc $10^{14}\ M_o$

Superammassi 10 Mpc $10^{16}\ M_o$

Sono solo questi
i costituenti
dell'Universo?
E ciò che non vediamo?


La classification des galaxies
Elliptiques
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirales
Lenticulaires
Spirales barrées
SBa
SBb
SBc
Irrégulières

Circa 100 miliardi di stelle

Spiral Galaxy NGC 300
(MPG/ESO 2.2-m + WFI)

ESO PR Photo 18a/02 (7 August 2002)

Galaxies NGC 2207 and IC 2163

Hubble Heritage

NASA and The Hubble Heritage Team (STScI) • Hubble Space Telescope WFPC2 • STScI-PRC99-41

Curva di rotazione

Assumendo la massa M concentrata entro un raggio r si eguaglia la forza centripeta con quella gravitazionale

$$\frac{mv^2}{r} = \frac{GmM}{r^2}$$

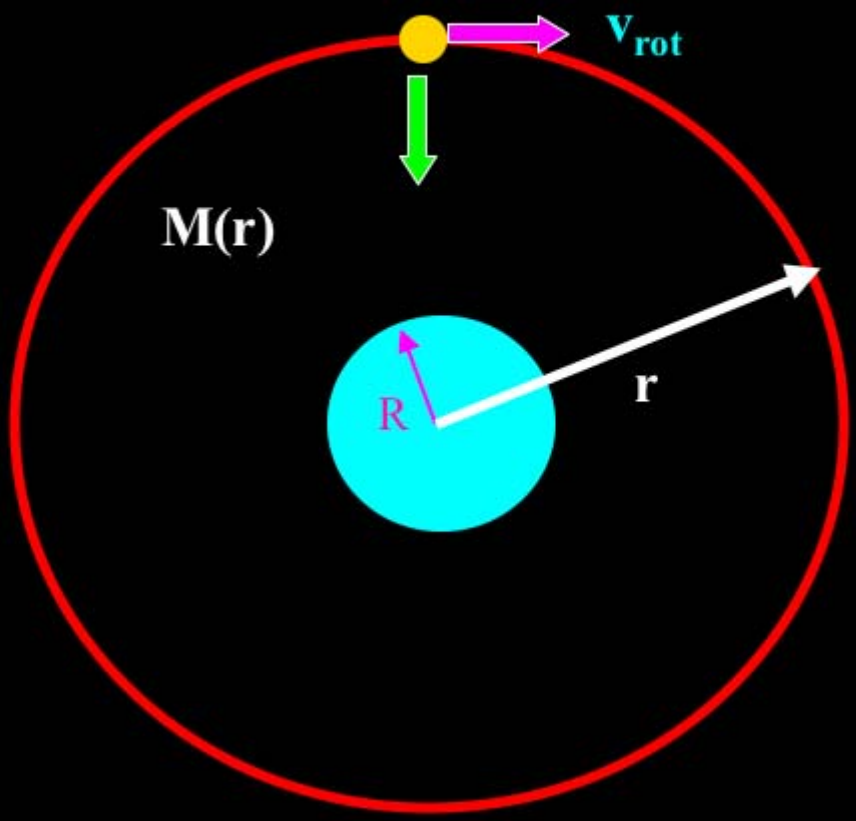
$$v = \sqrt{\frac{GM}{r}}$$

Andamento kepleriano

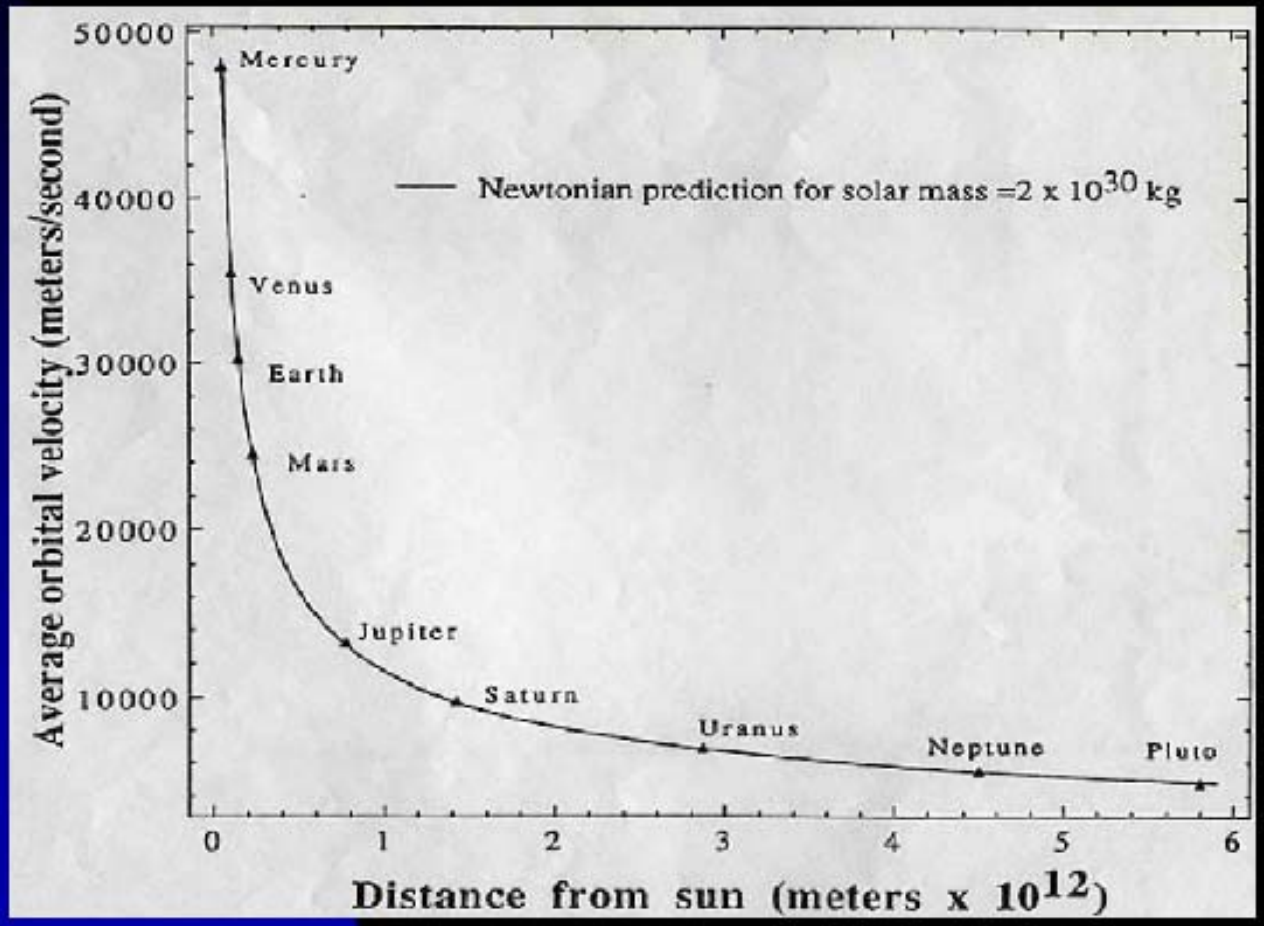
Use Motion to Infer Mass

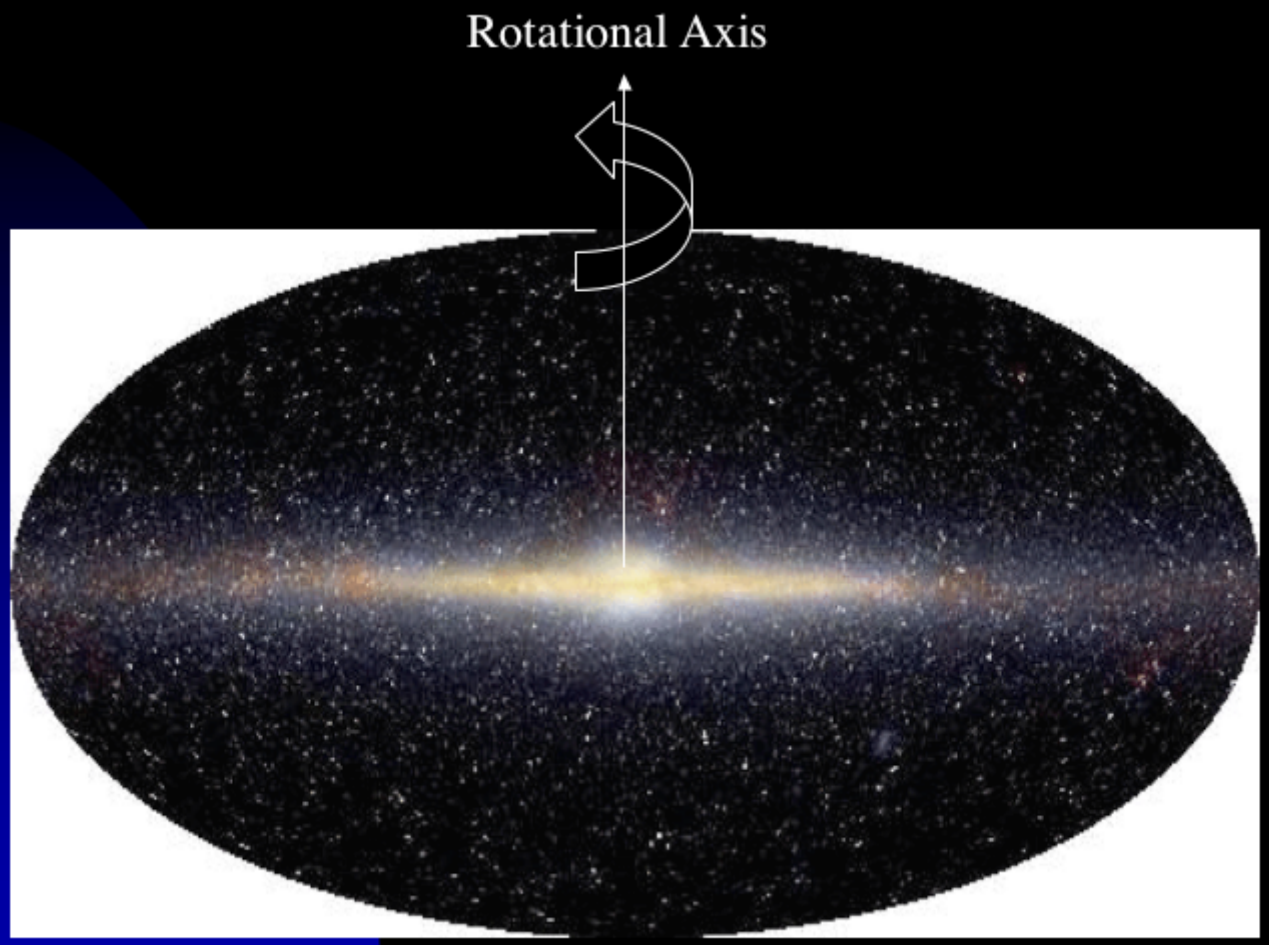
$v_{rot}^2 = GM(r)/r$

M(r>R)= const
ρ(r>R) = 0
⇒
$v \sim r^{-1/2}$

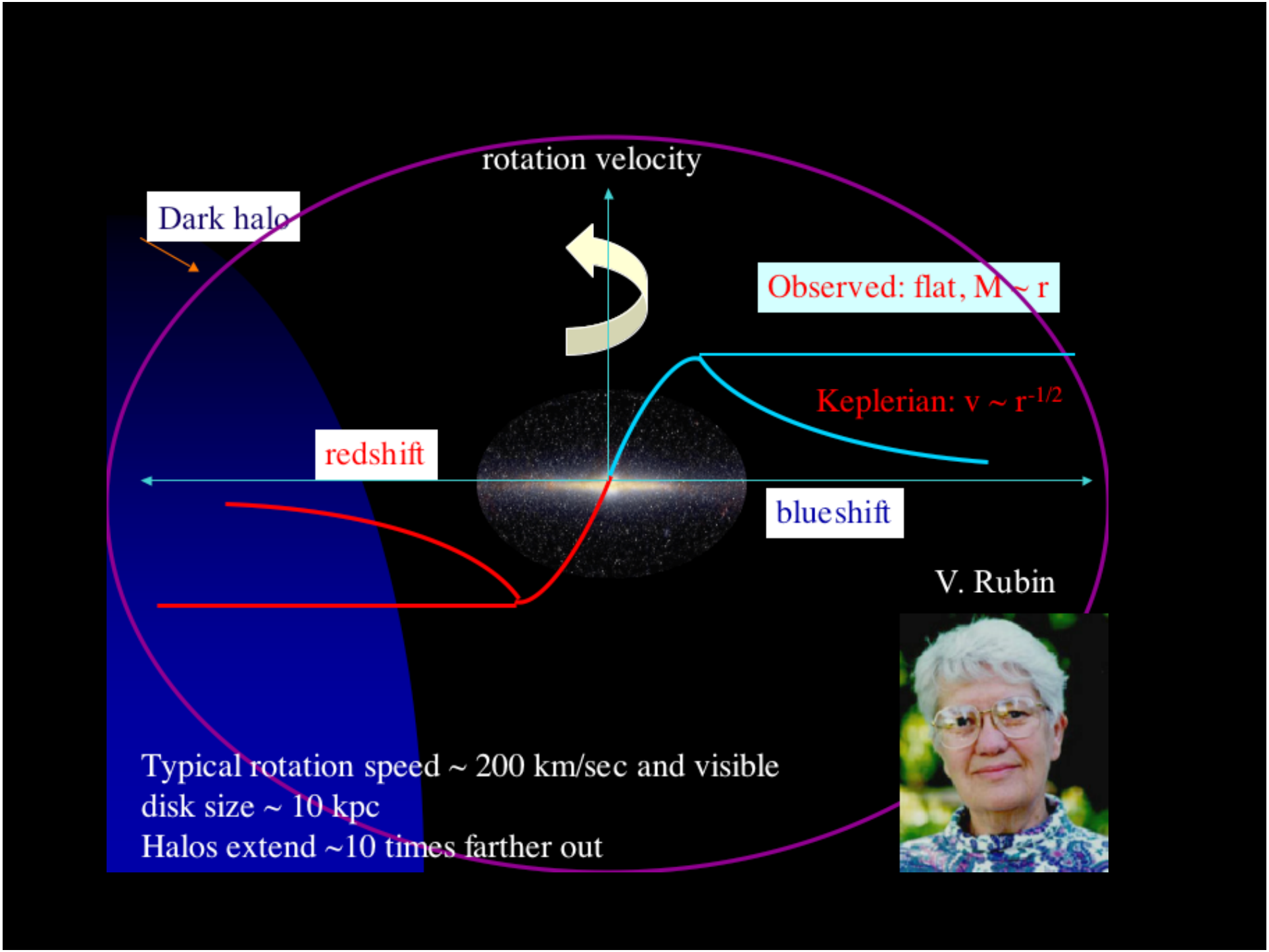


Solar System





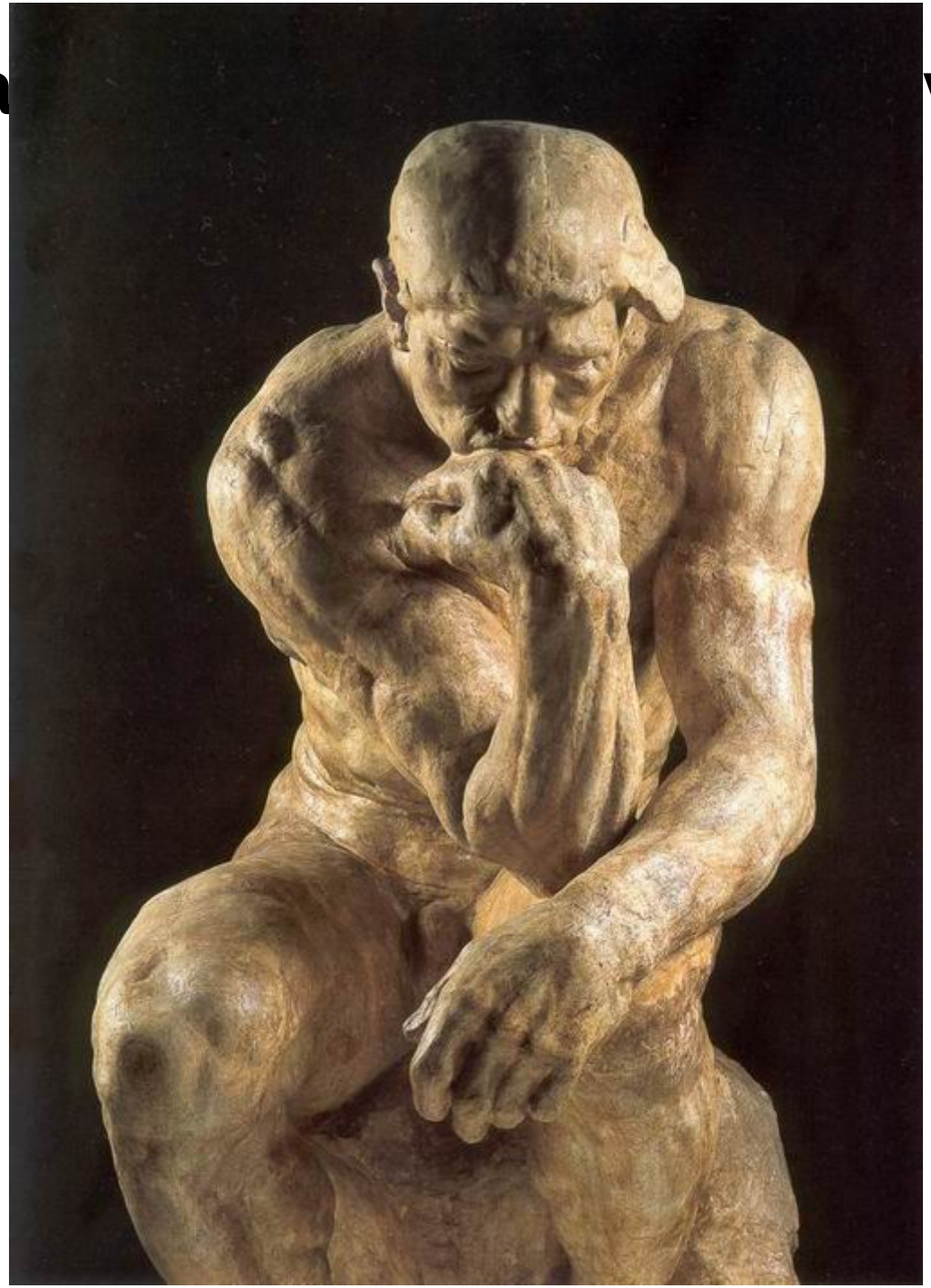
Milky Way (FIRAS)


rotation velocity
Dark halo
Observed: flat, M ~ r
Keplerian: v ~ r^-1/2
redshift
blueshift
V. Rubin
Typical rotation speed ~ 200 km/sec and visible
disk size ~ 10 kpc
Halos extend ~10 times farther out

cir la massa

e !!

Zwicky 1930

Le ga  **vuto….**

La materia oscura

THE DARK SIDE of the UNIVERSE

M.S. Turner / Final-U. Chicago

--NOT JUST A PHANTOM MENACE ANYMORE!
95% OF THE UNIVERSE!

PARTICLE DARK MATTER DETECTED!

$\Omega_\nu \gtrsim \Omega_{stars}$ ... CDM NEXT?

DARK ENERGY DETECTED! $\Omega_X \sim 0.6$!

"ENERGY ACCOUNTING" ACCELERATING UNIVERSE

MYSTERIOUS DARK ENERGY

VACUUM ENERGY? FRUSTRATED DEFECTS? ROLLING SCALAR FIELD?

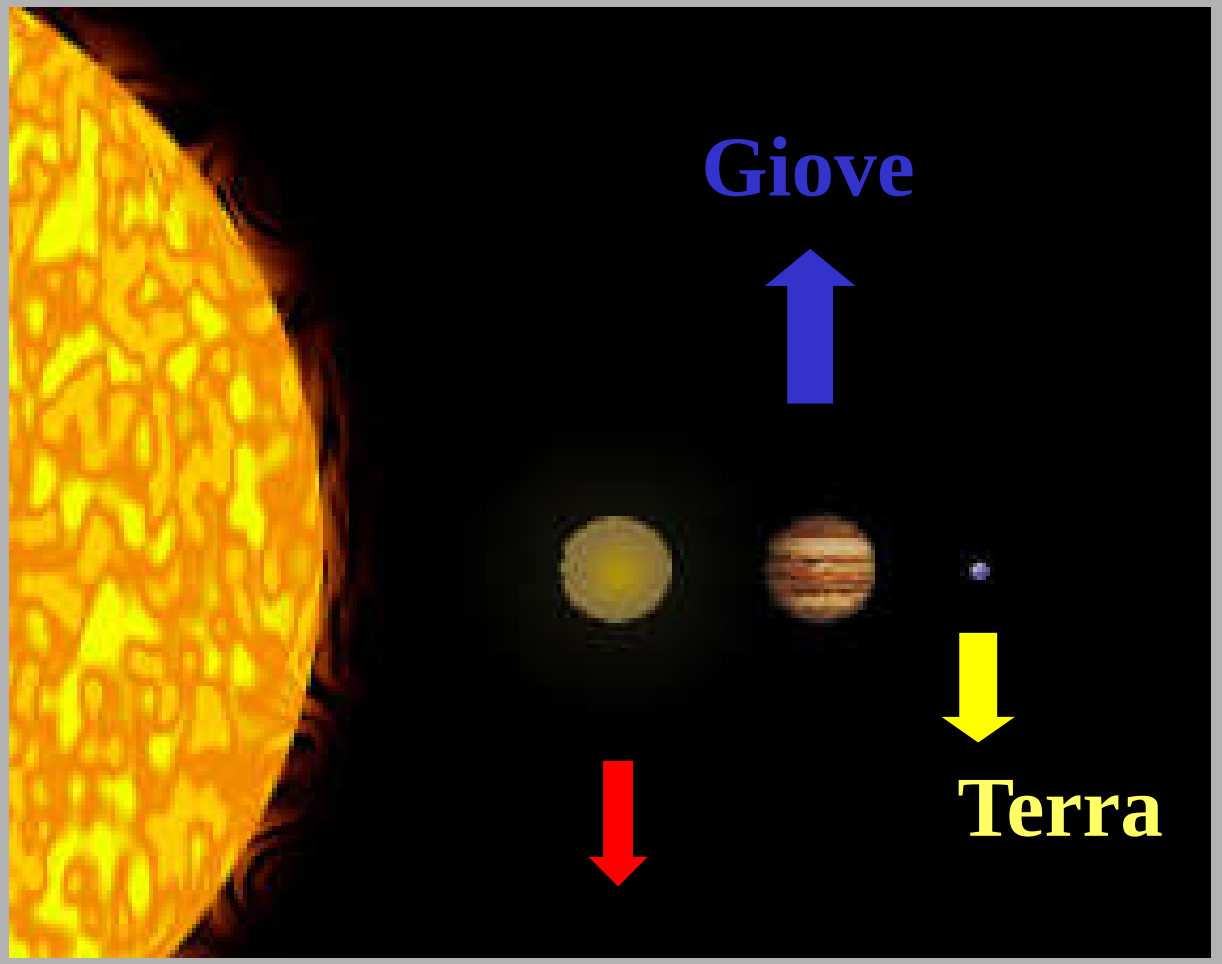
WHATEVER IT IS, IT IS FUND PHYSICS!

FIRST SOLID EVIDENCE FOR INFLATION

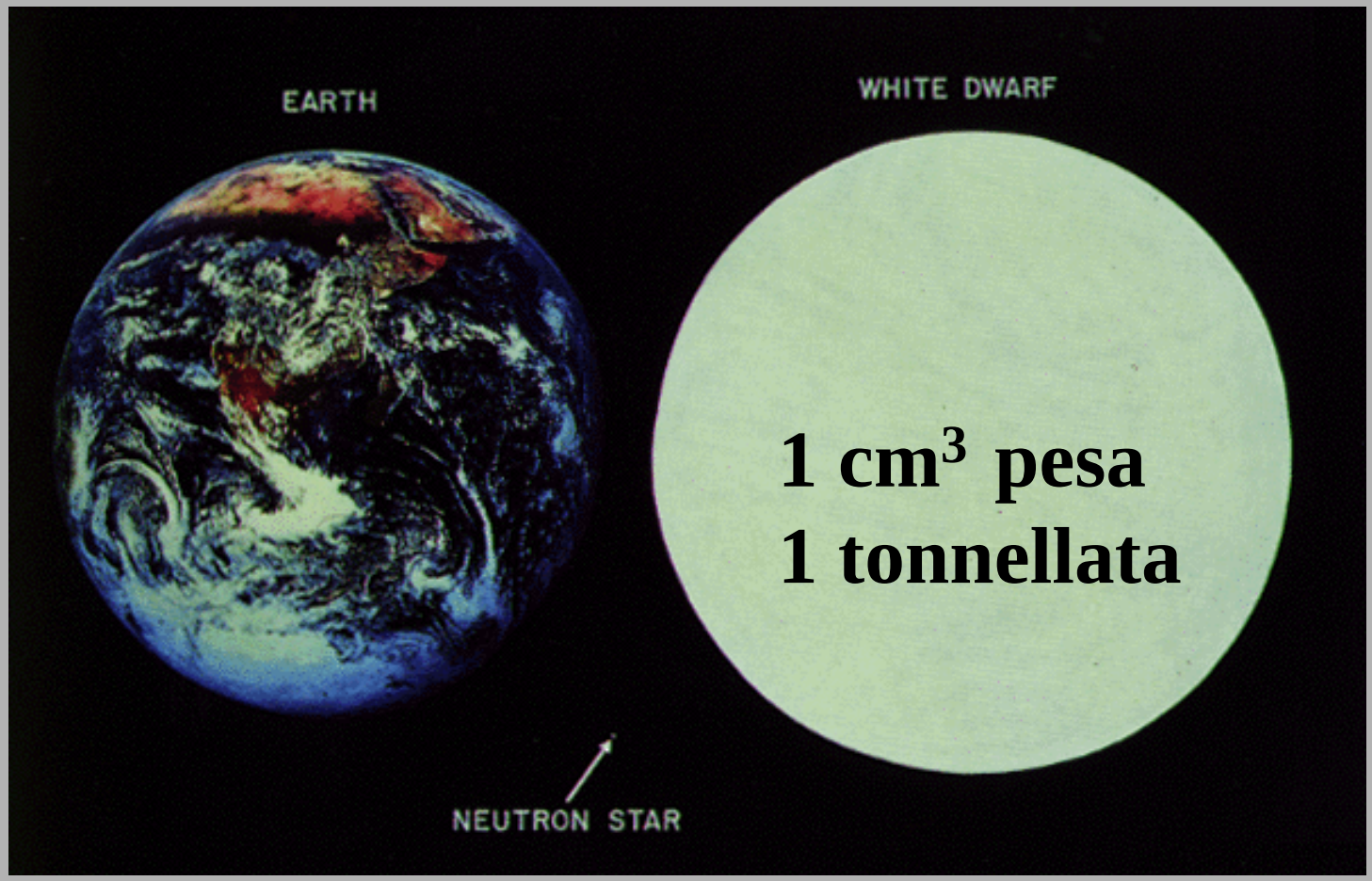
FLAT UNIVERSE, QUANTUM-PRODUCED $\delta\rho/\rho$

Candidati per la materia oscura

- **Pianeti giganti, nane brune (stelle mancate)**
- **Nane bianche, stelle di neutroni, buchi neri**
- **Materia non barionica**

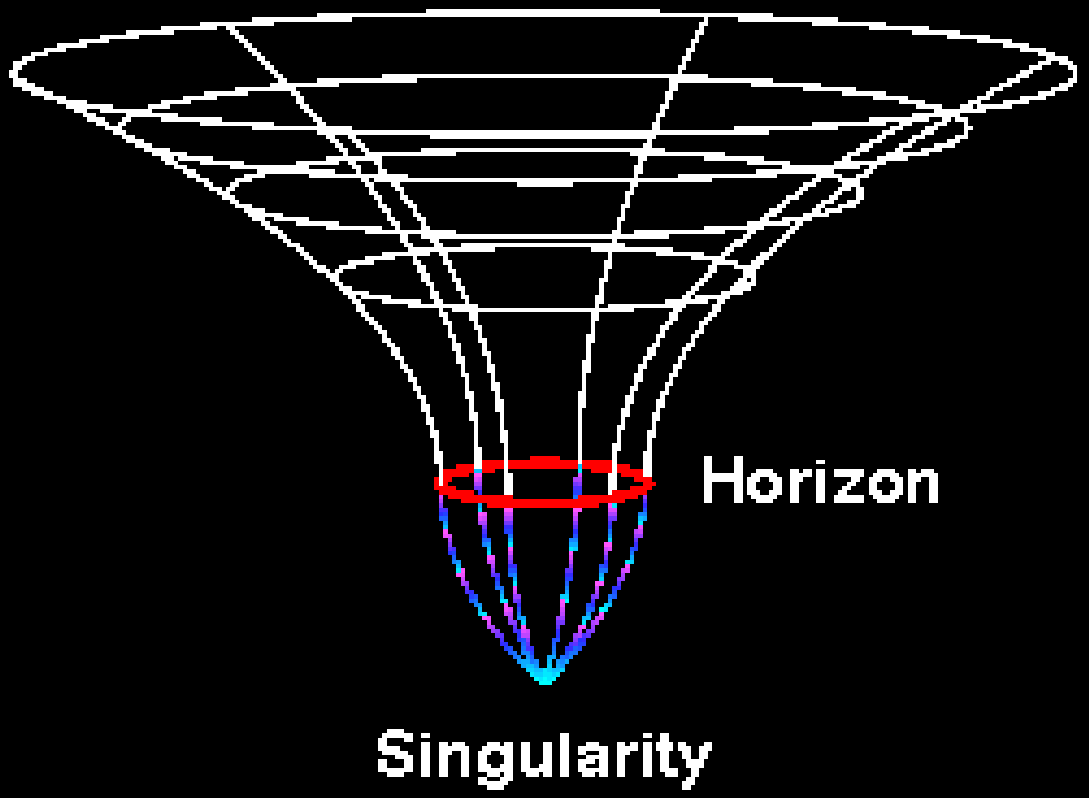


Nana bruna
(massa < 0,1 masse solari)



circa massa solare

Buchi neri



se il Sole fosse un buco nero

avrebbe un raggio di 3 km

Materia oscura non barionica

È un tipo di materia “strana” che non si comporta come la materia ordinaria

I neutrini come “ladri” di energia

$$n \longrightarrow p + e + \bar{\nu}_e$$

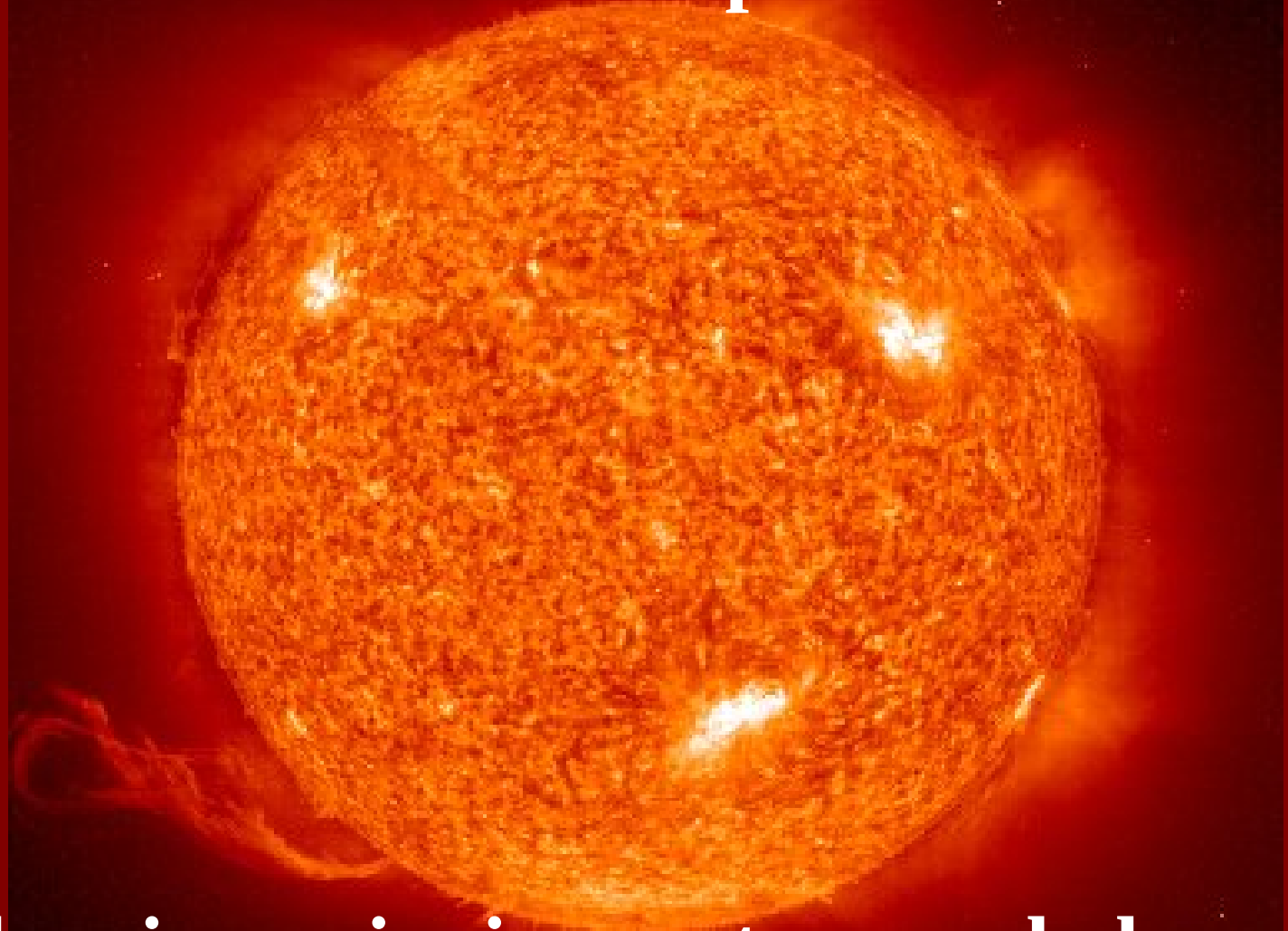
Si conserva la carica

0	**+**	**-**	0

Non si conserva lo spin

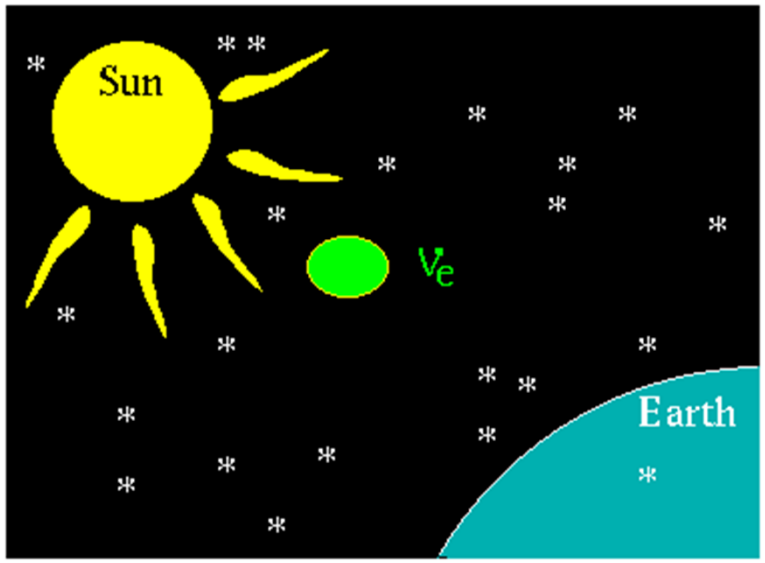
½	½	½	½

Dalle reazioni termonucleari si può calcolare quanti neutrini devono provenire dal Sole



Dalle misurazioni se ne trova solo la metà!
(problema dei “neutrini scomparsi”)

Ipotesi di Pontecorvo:
ci sono tre specie di neutrini e ogni neutrino può oscillare nei diversi stati

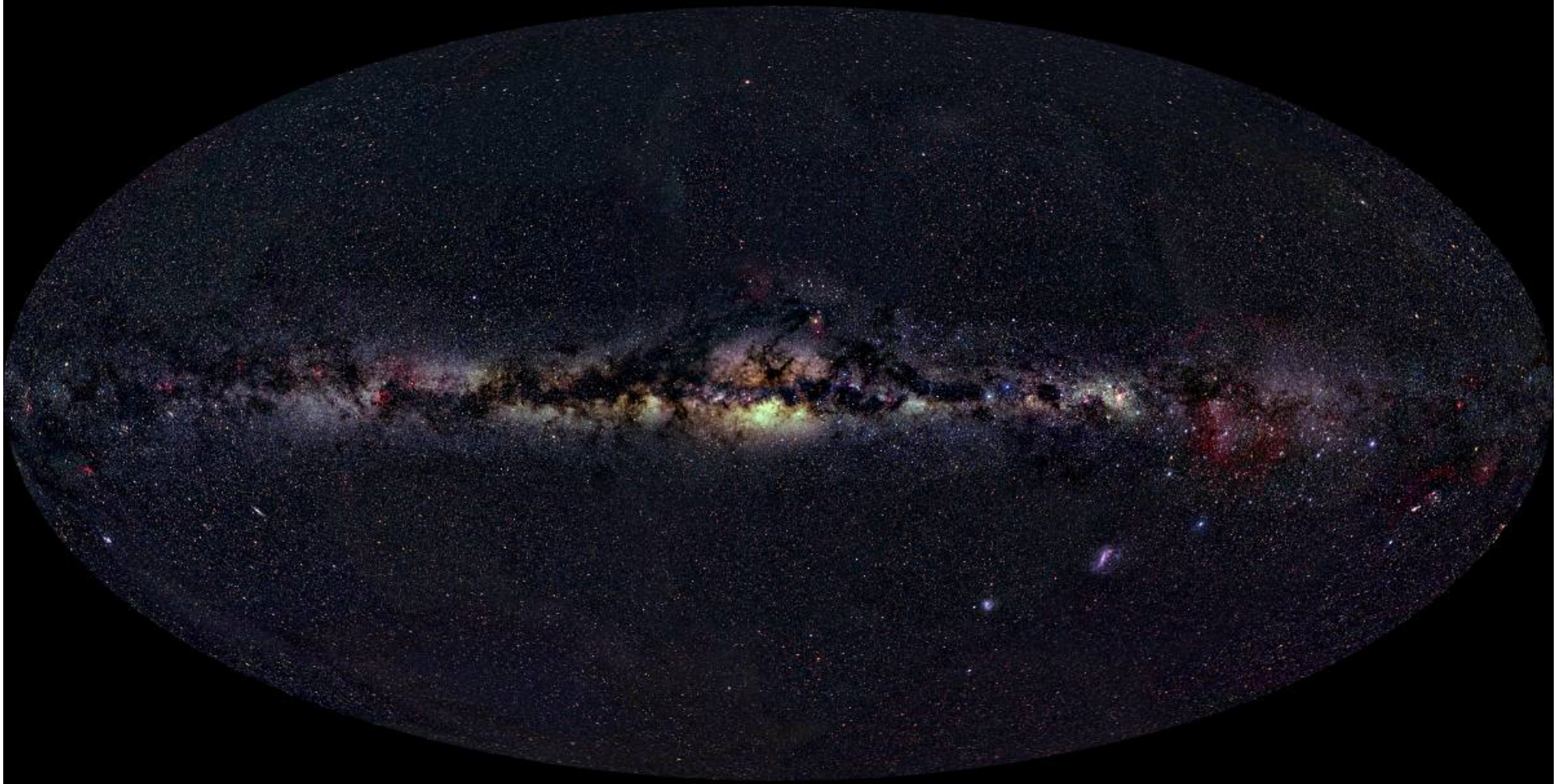


Questo avviene solo se la massa è non nulla

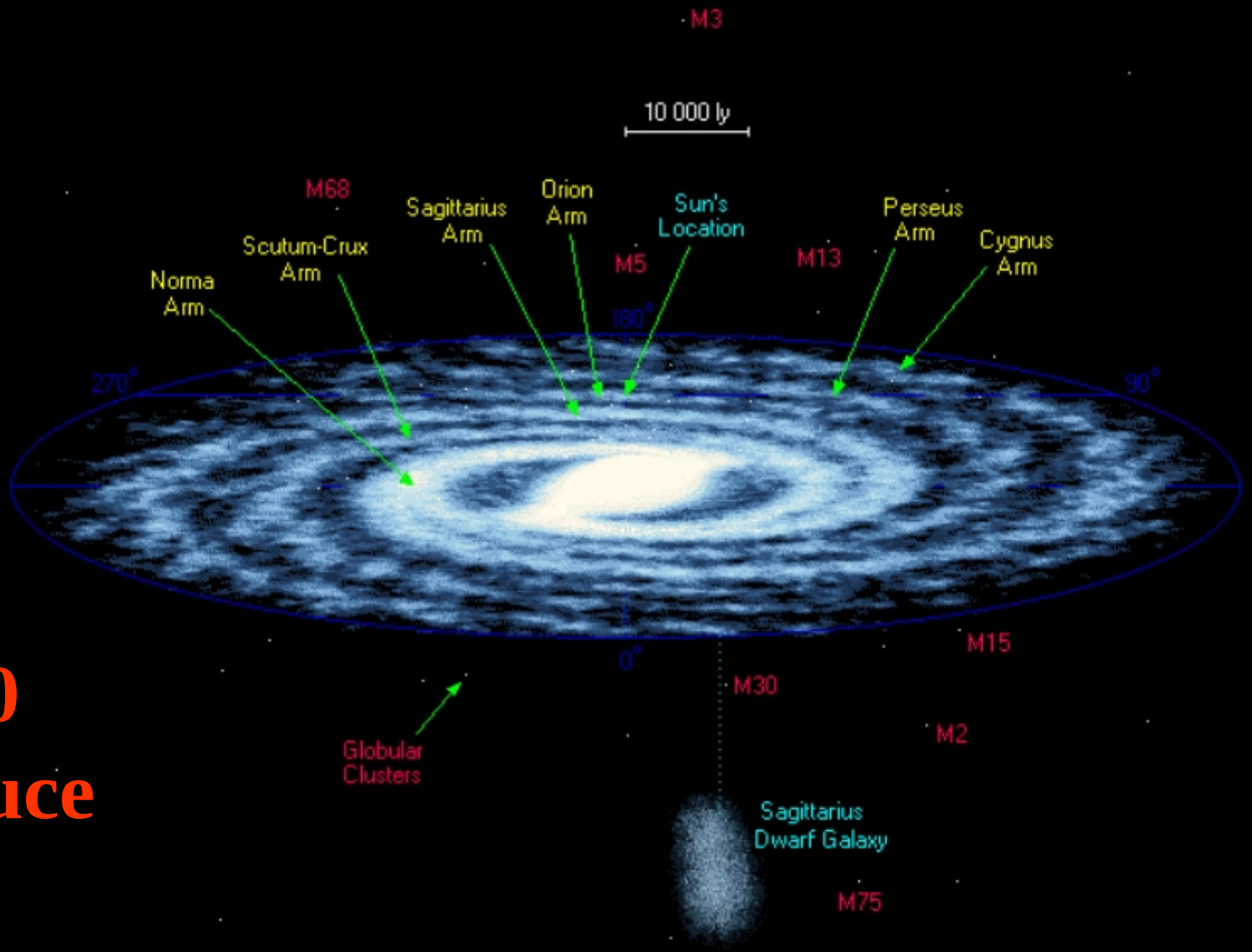
ESPERIMENTO OPERA

I primi risultati indicano che il contributo della massa del neutrino e` trascurabile (circa 1.5% in totale)

The Deep Sky

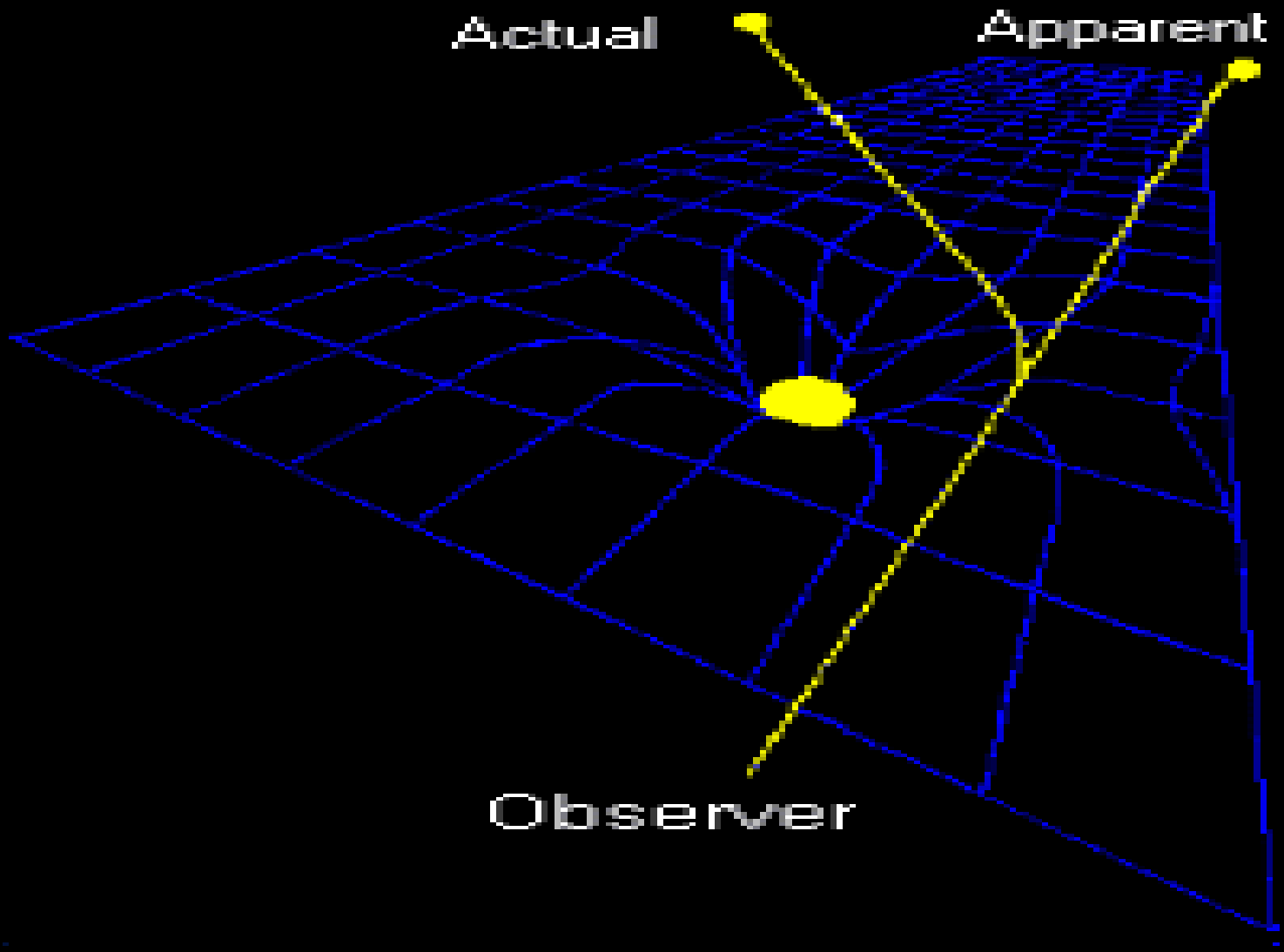


100.000 anni luce

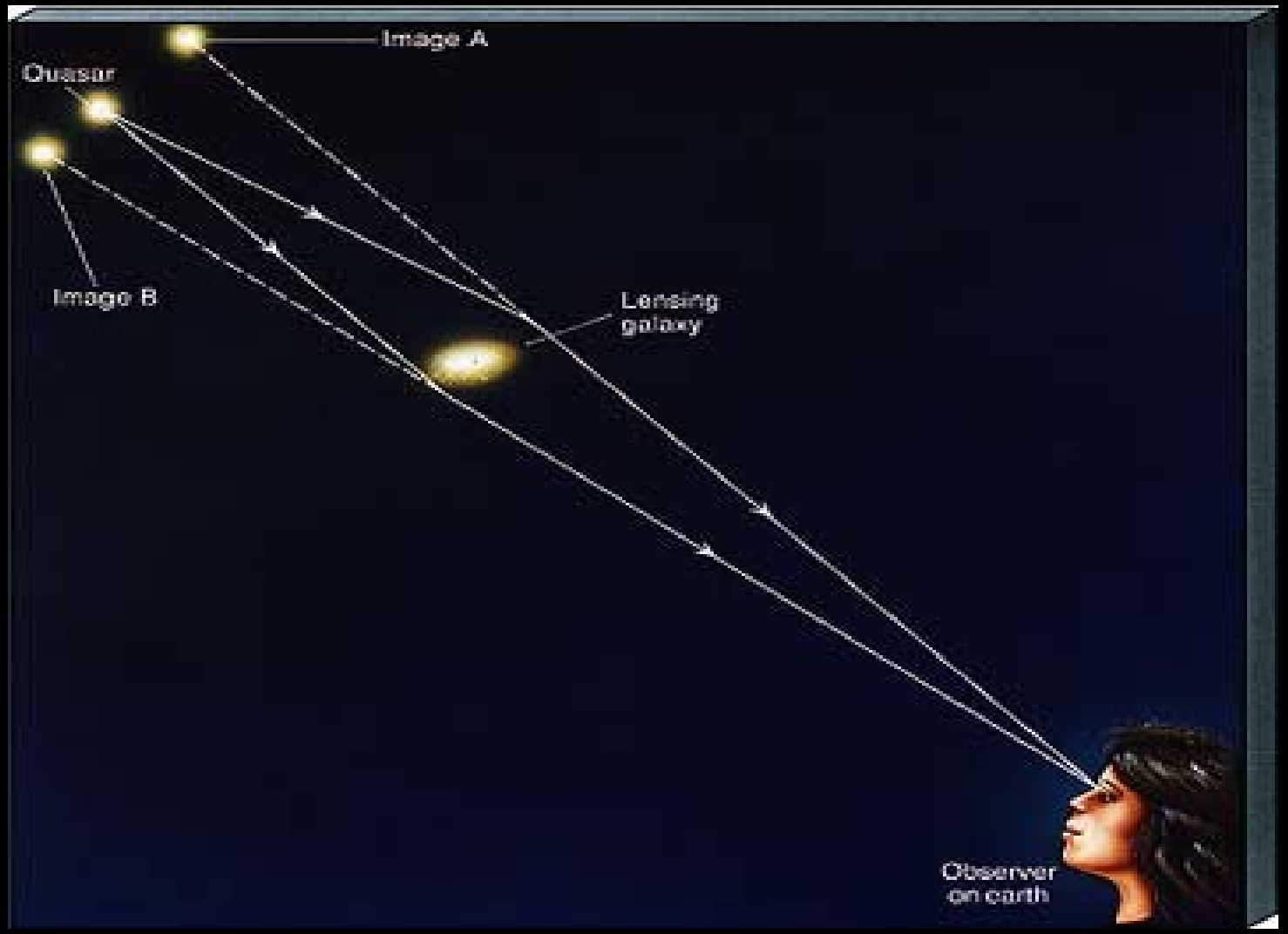


2000 anni luce

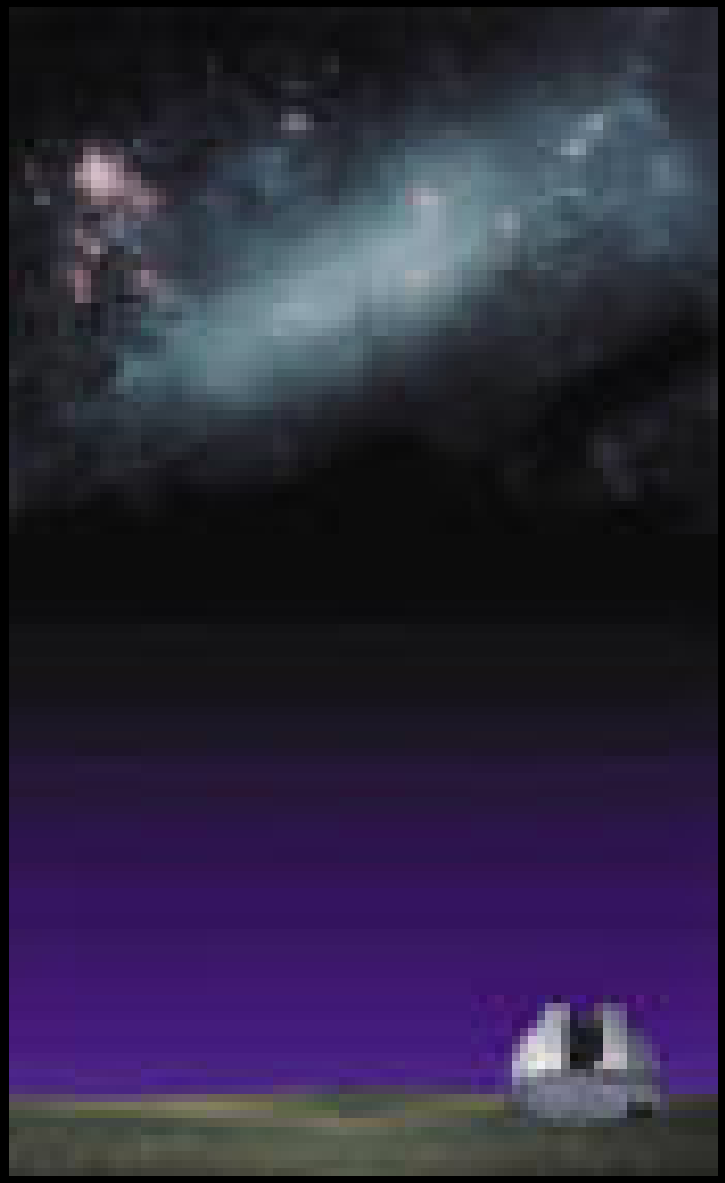
Curvatura dei raggi di luce

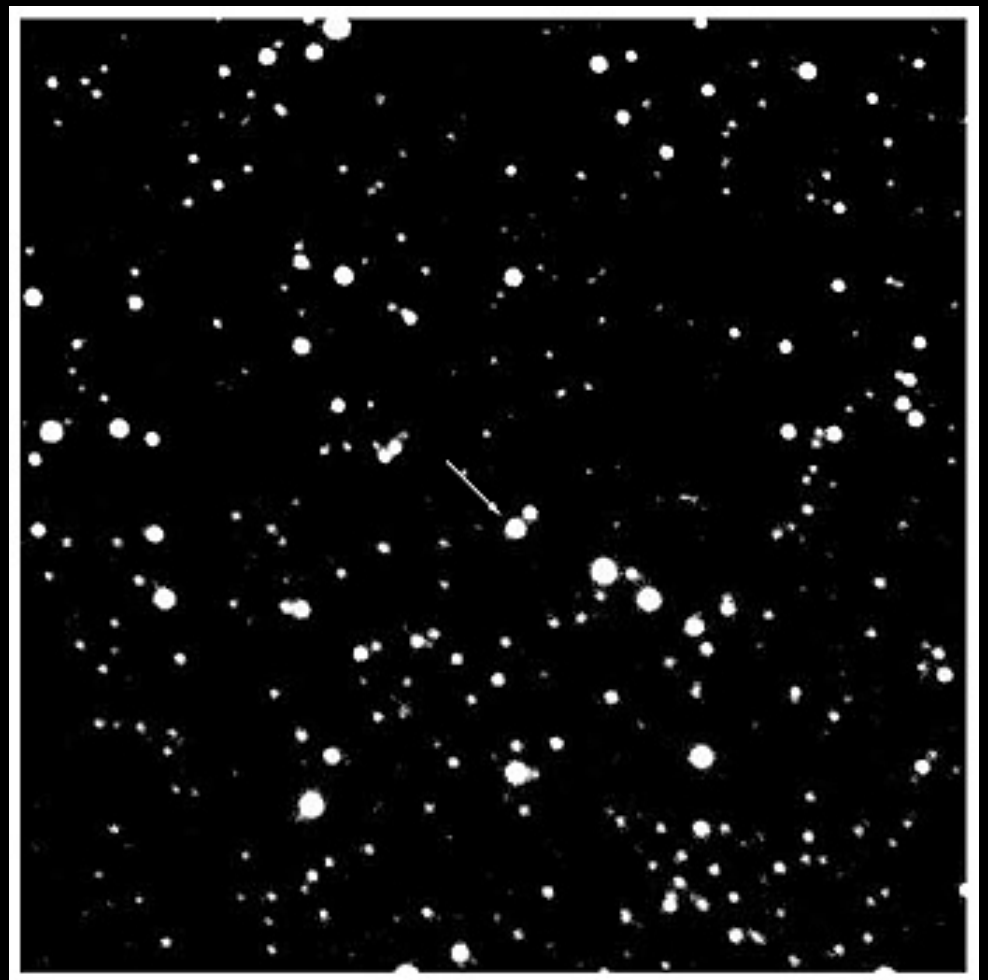


Einstein cross



Grande Nube di Magellano
(165 mila anni luce)





EROS-BLG-2000-5
(VLT ANTU + FORS1)

ESO PR Photo 16b/01 (25 April 2001)

Quanta materia oscura c'è nella nostra Galassia?

Dagli studi delle collaborazioni MACHOs (MAssive Compact Halo Objects) e EROS (Experience de Recherche d'Objects Sombres) risulta che circa il 20 - 30% della massa oscura della nostra Galassia è composta da oggetti "normali"

Ammassi di galassie

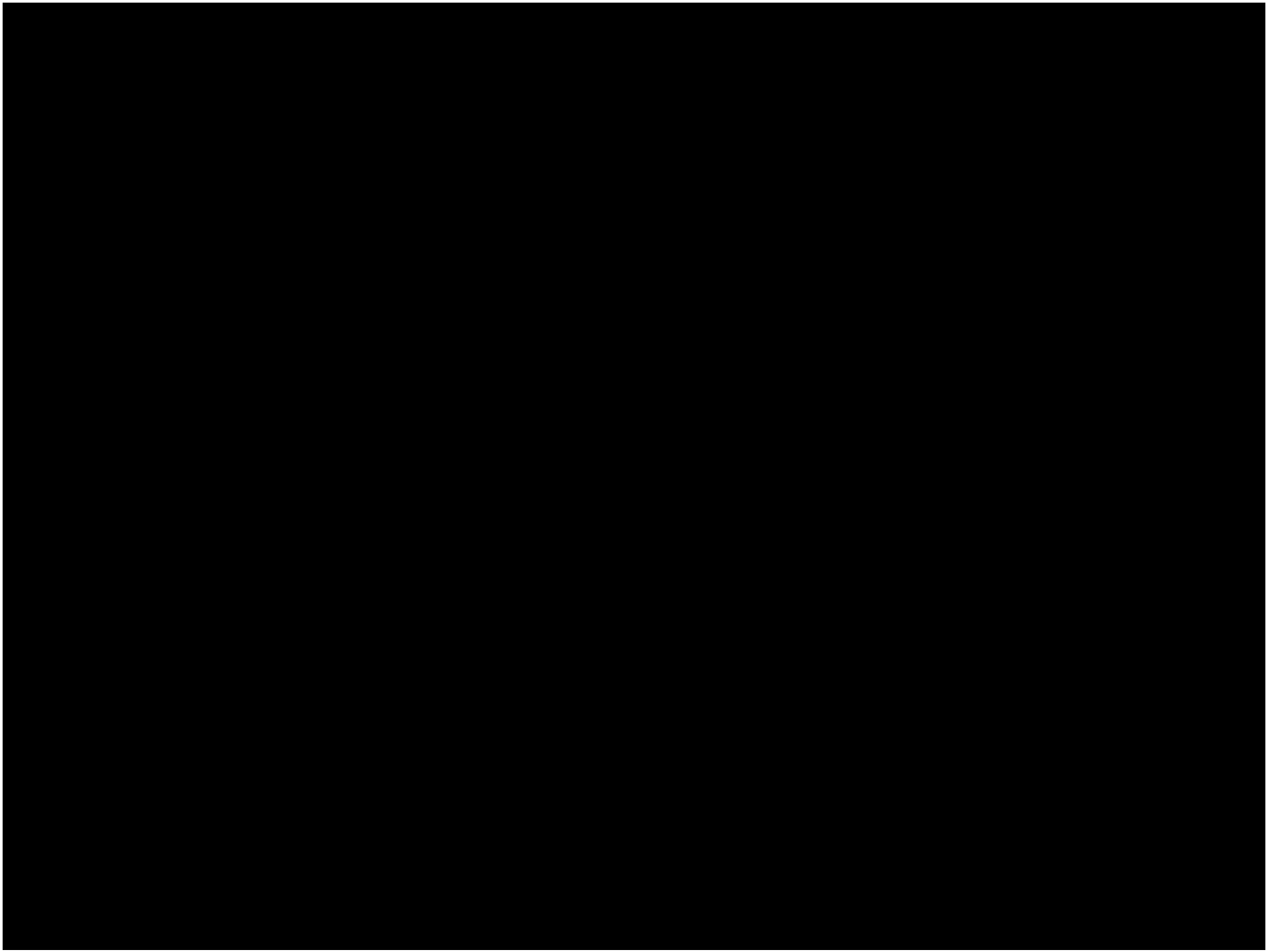
circa 100 – 1000 galassie

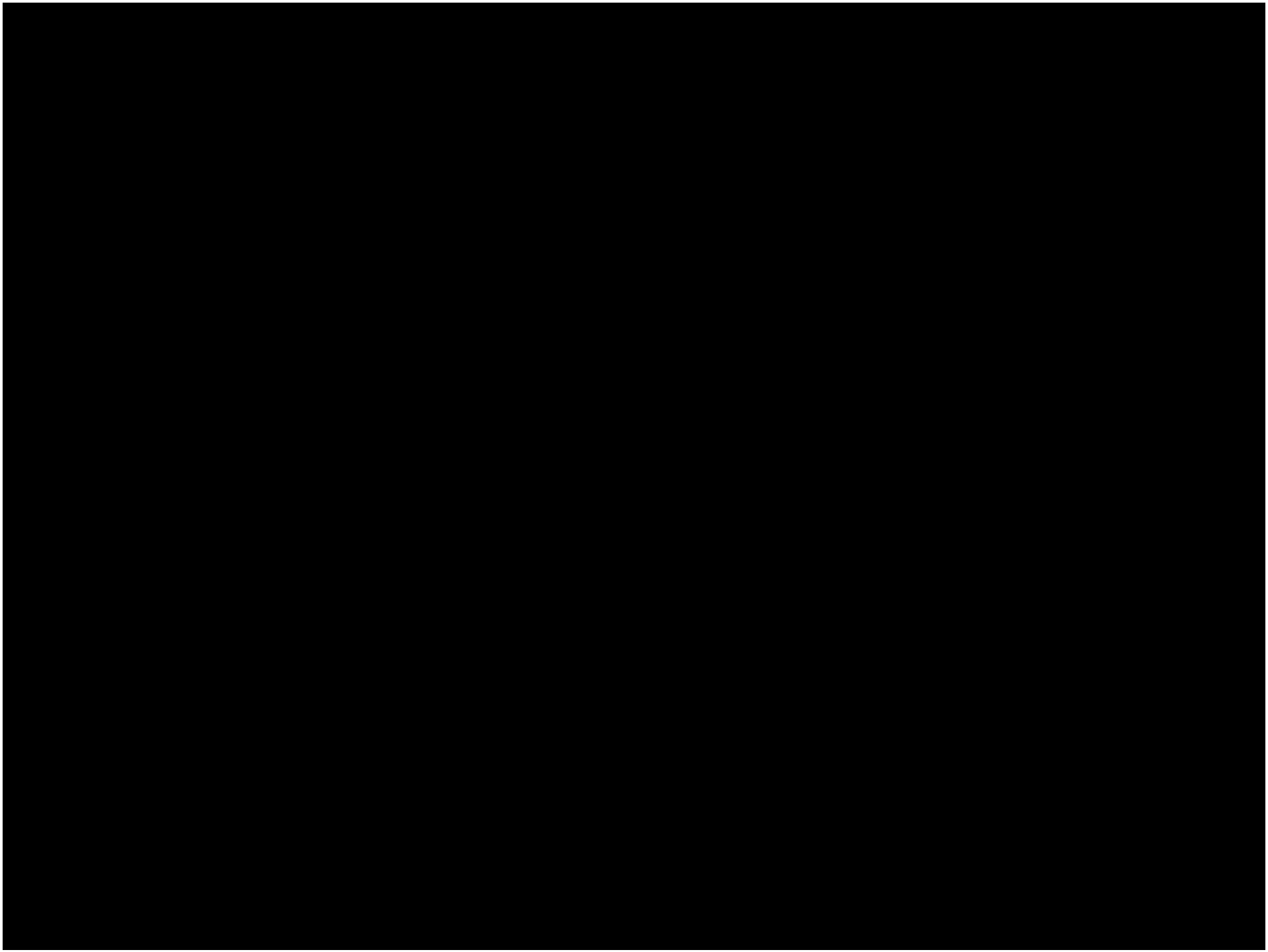
Ammassi di galassie

circa 100 – 1000 galassie

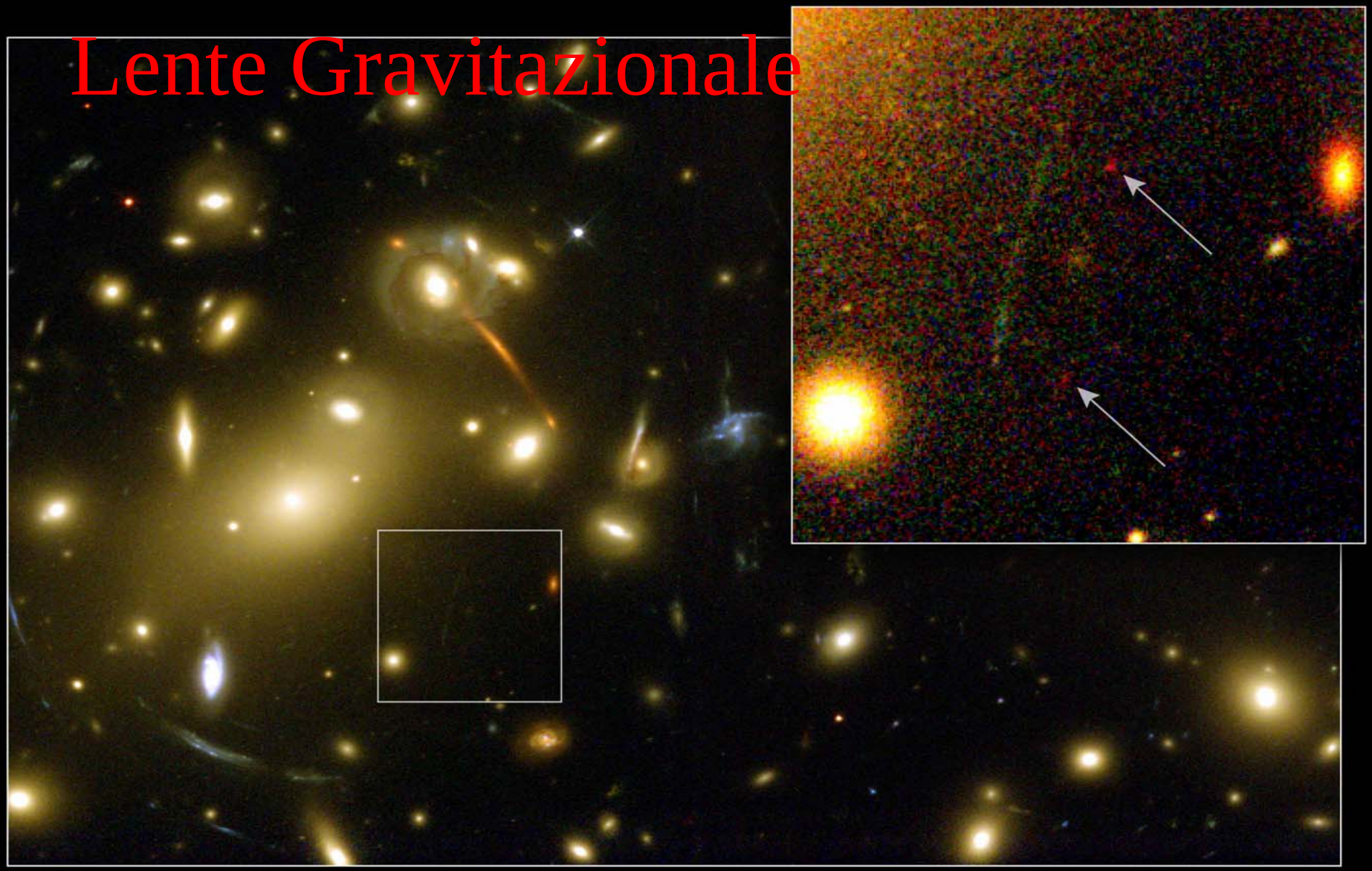
Gas caldo negli ammassi

Anche in questo caso il 90% della massa non è luminosa





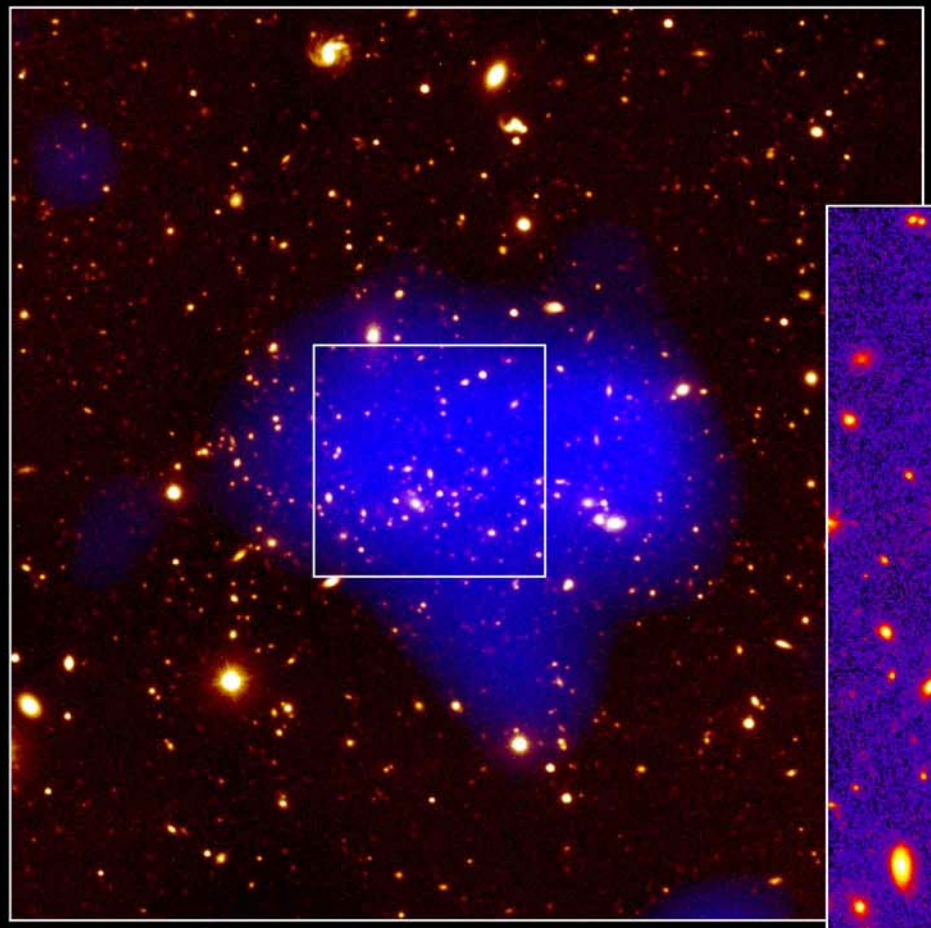
Lente Gravitazionale



Distant Object Gravitationally Lensed by Galaxy Cluster Abell 2218
Hubble Space Telescope • WFPC2

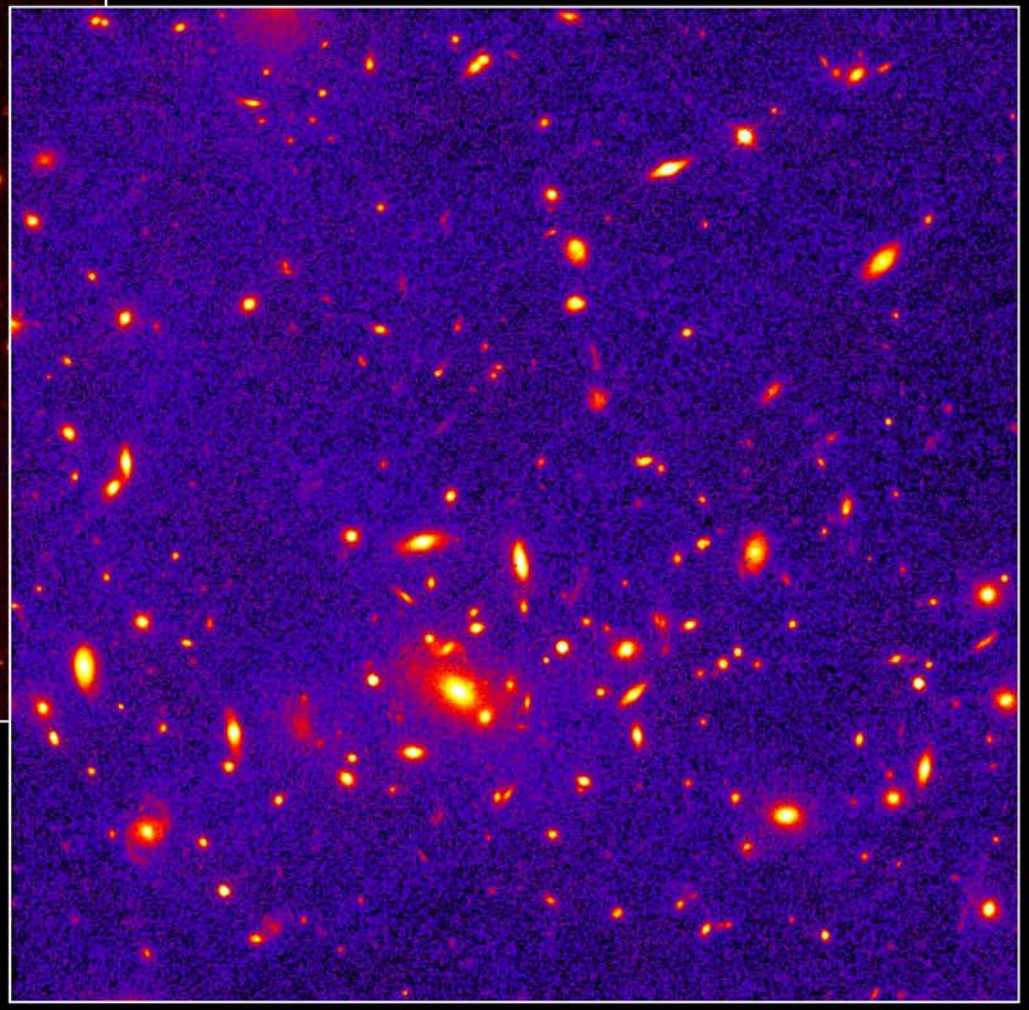
NASA, ESA, R. Ellis (Caltech) and J.-P. Kneib (Observatoire Midi-Pyrenees) • STScI-PRC01-32

La massa del gas caldo e’ 20% del totale



Ground + X-ray

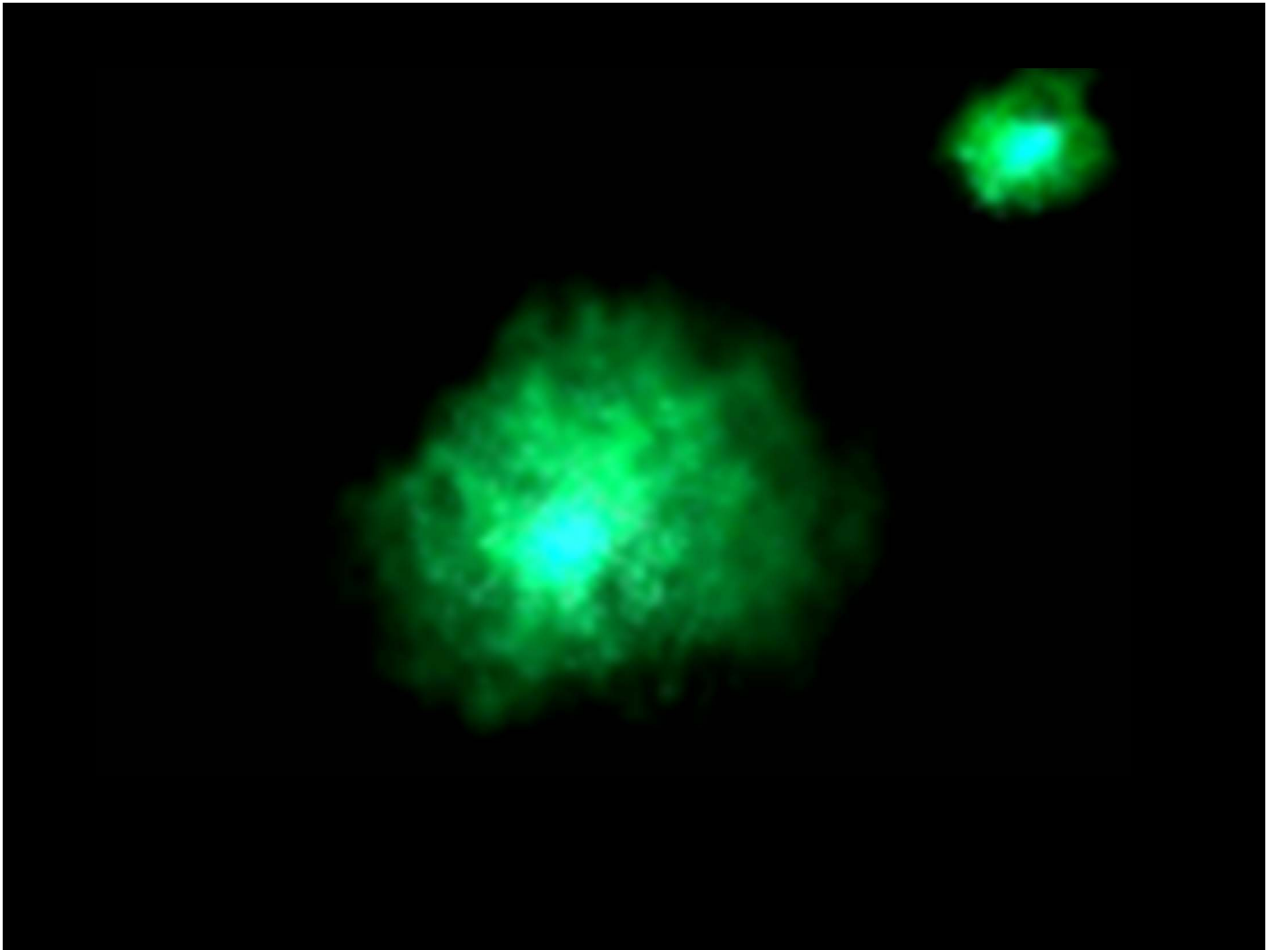
HST

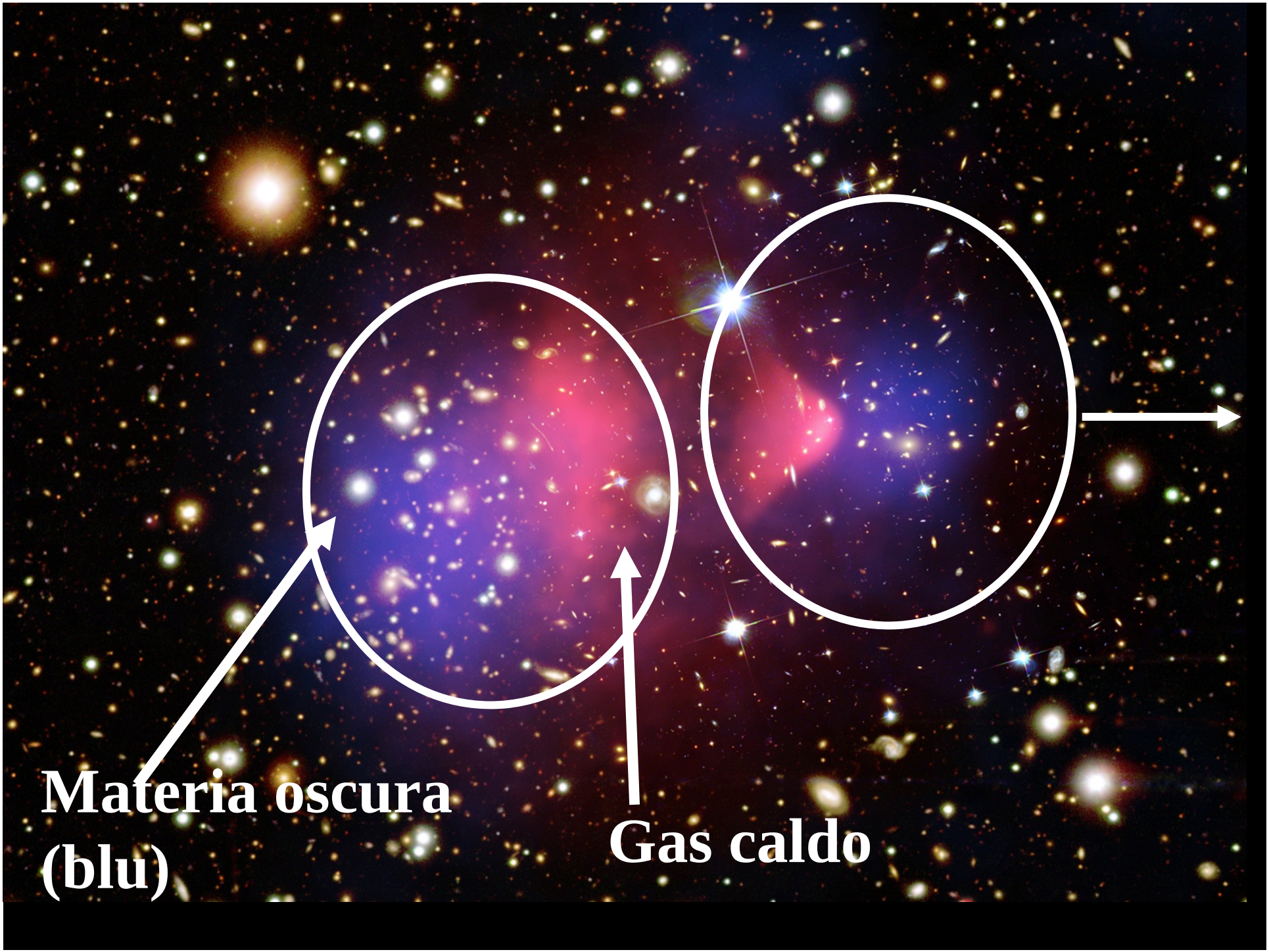


T=10-100
Milioni di gradi

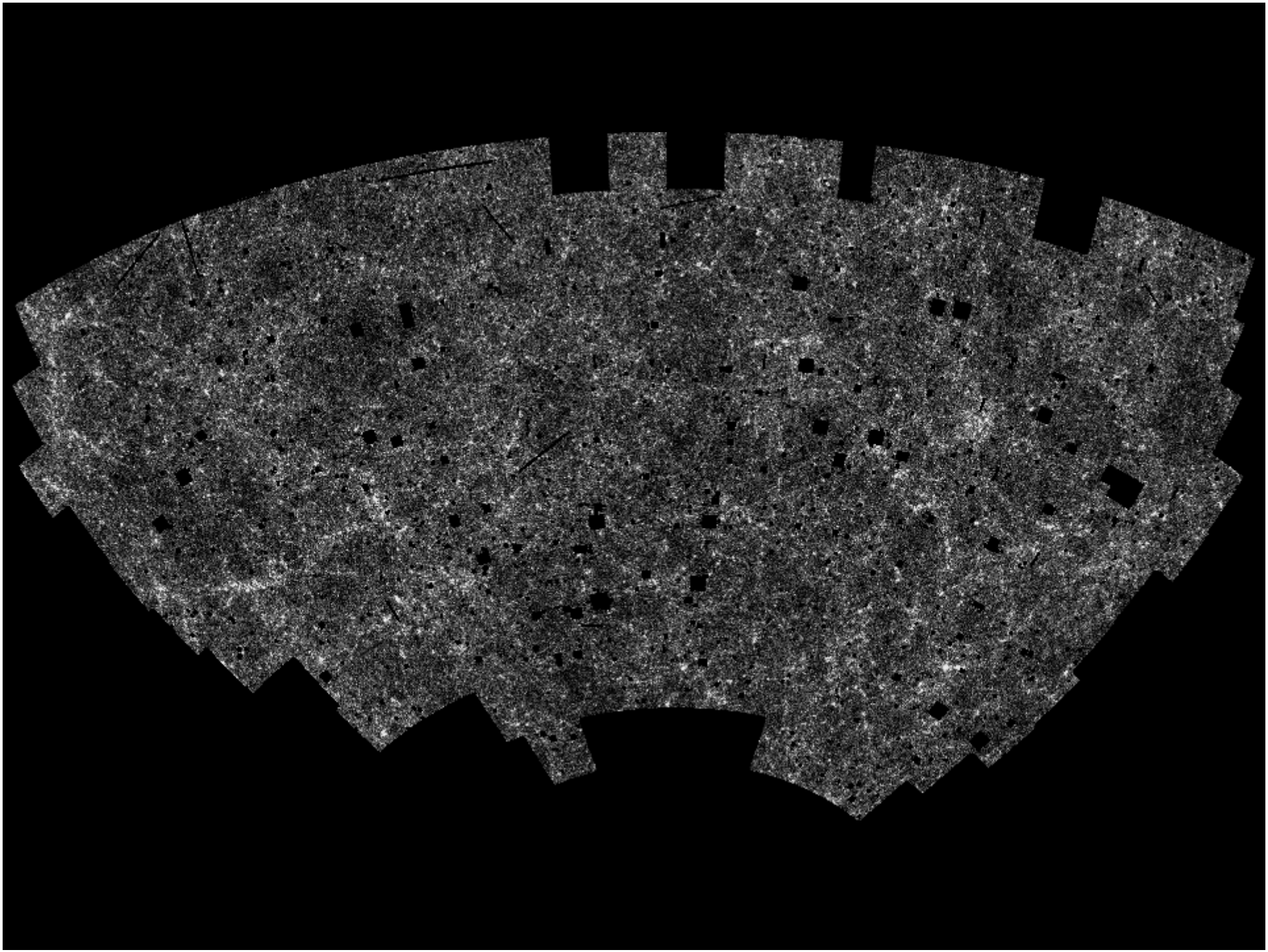
Distant Galaxy Cluster MS1054-0321 **Z=0.8**

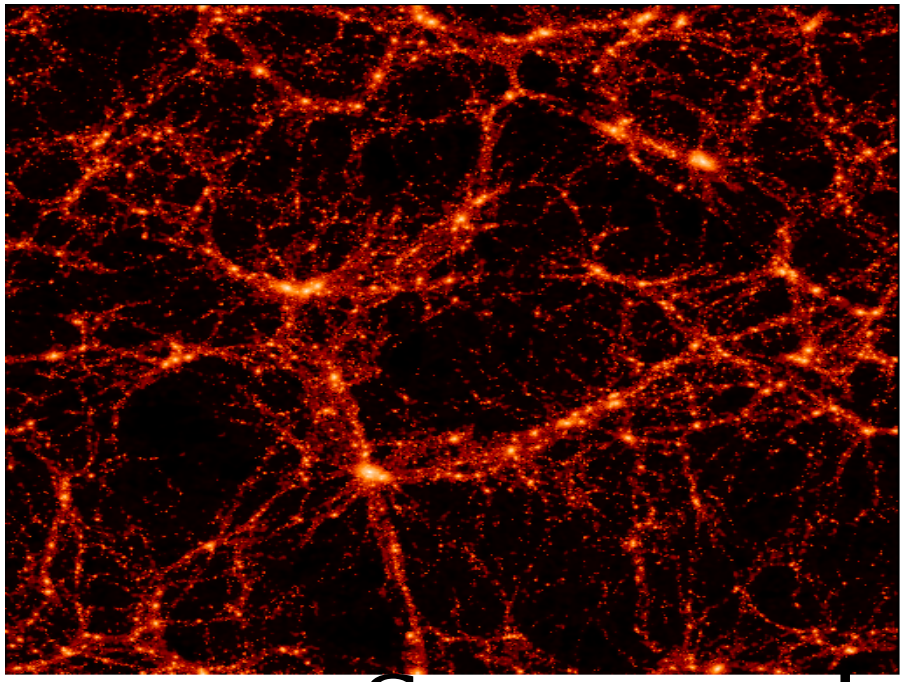
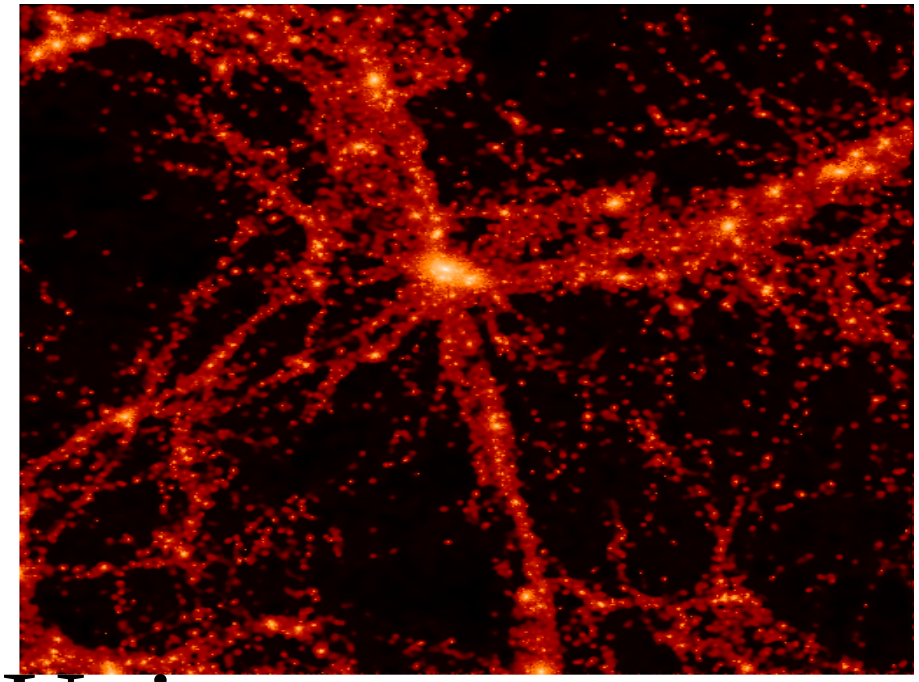
Hubble Space Telescope • Wide Field Planetary Camera 2



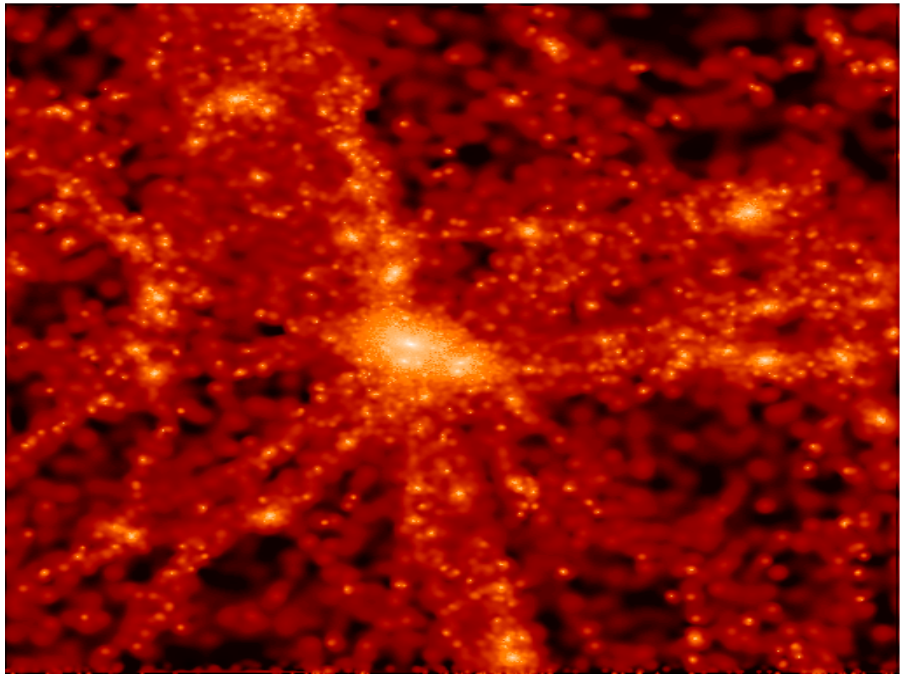
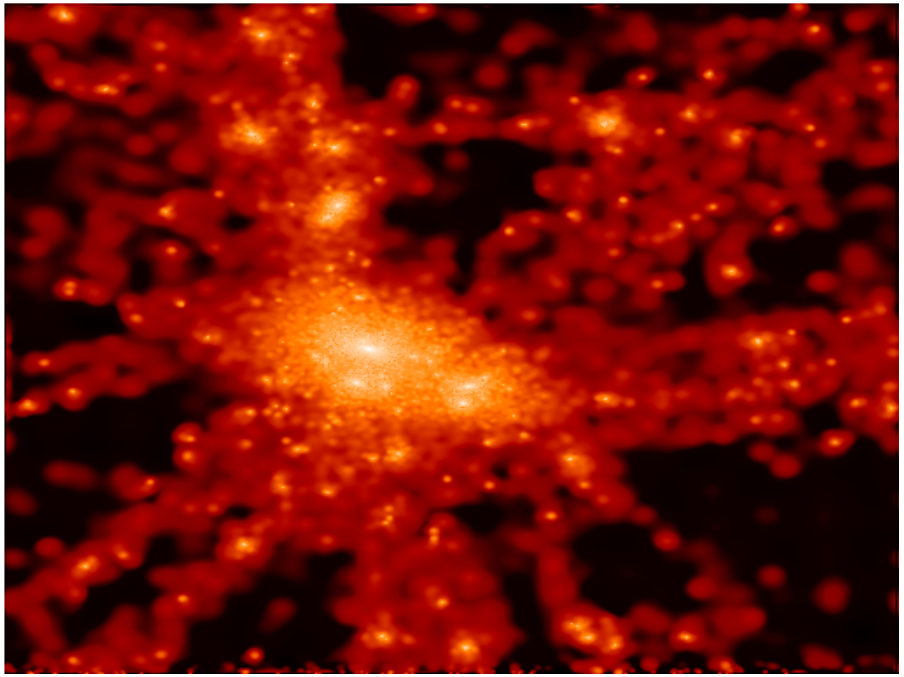

Materia oscura
(blu)
Gas caldo

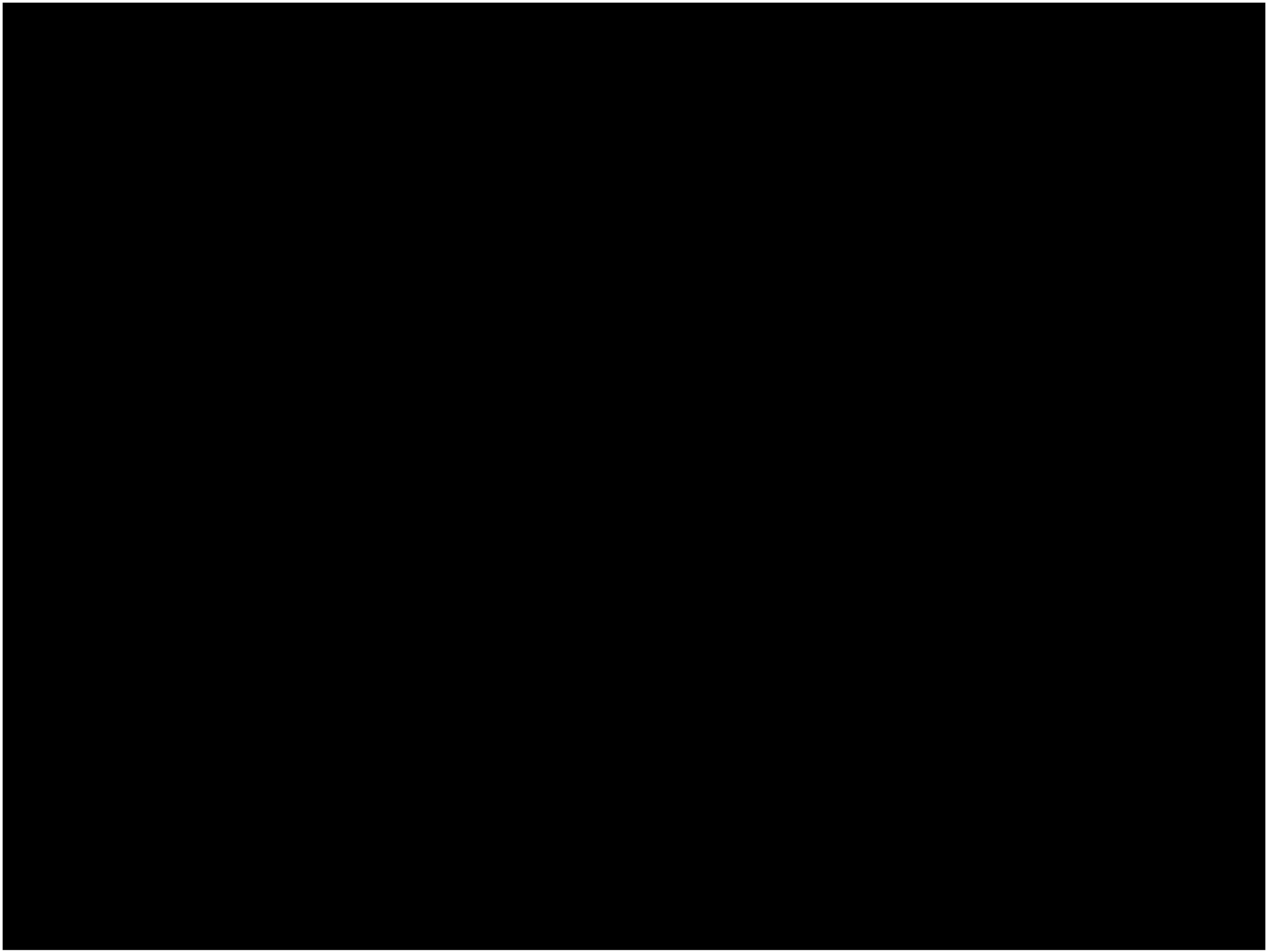
E su scale ancora più grandi cosa succede?



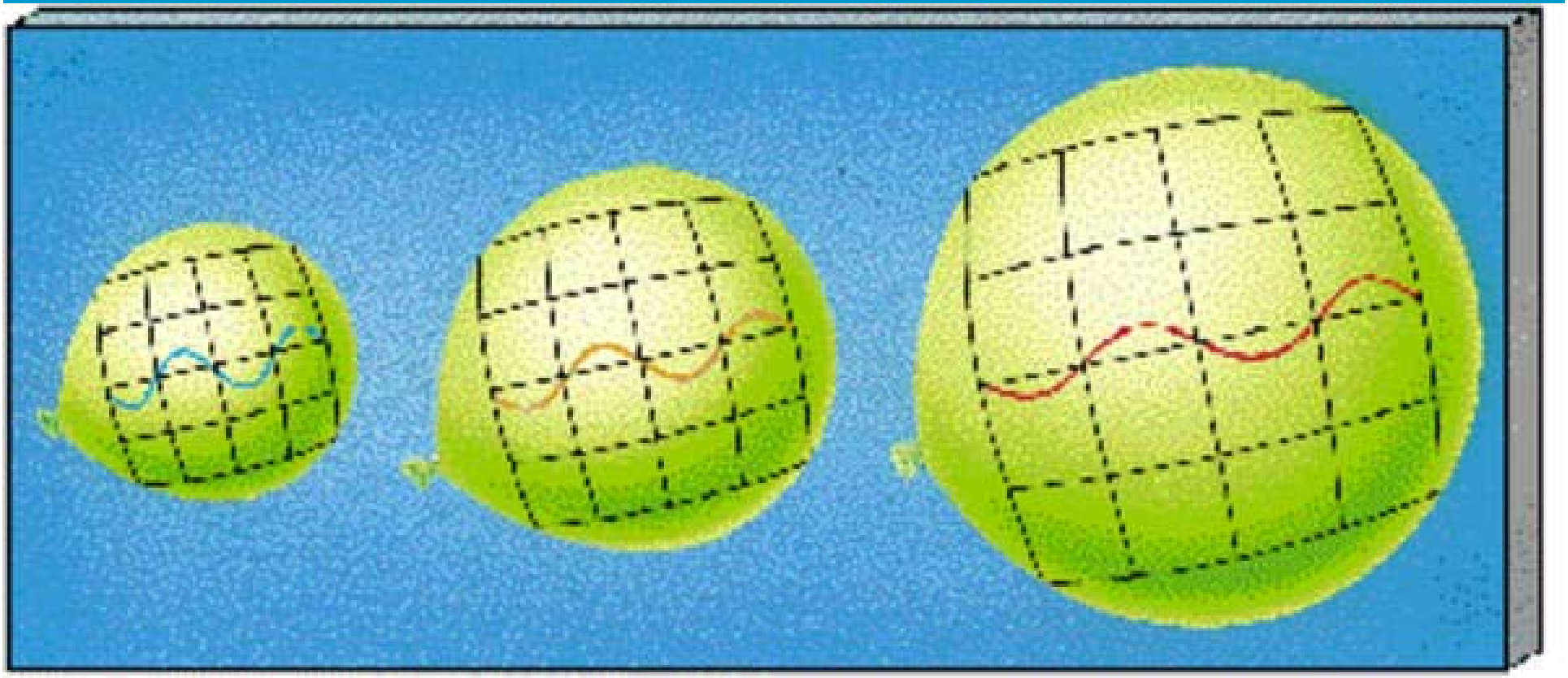



Struttura dell’Universo

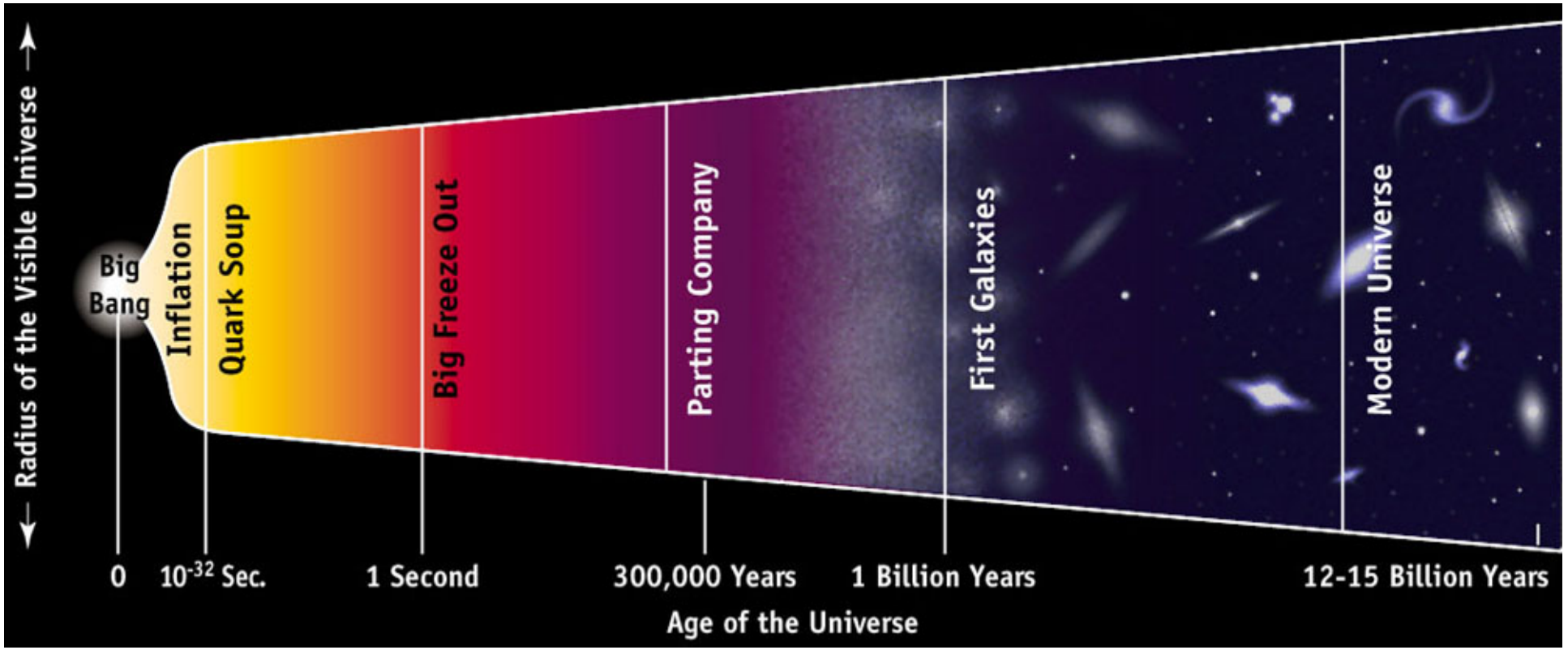



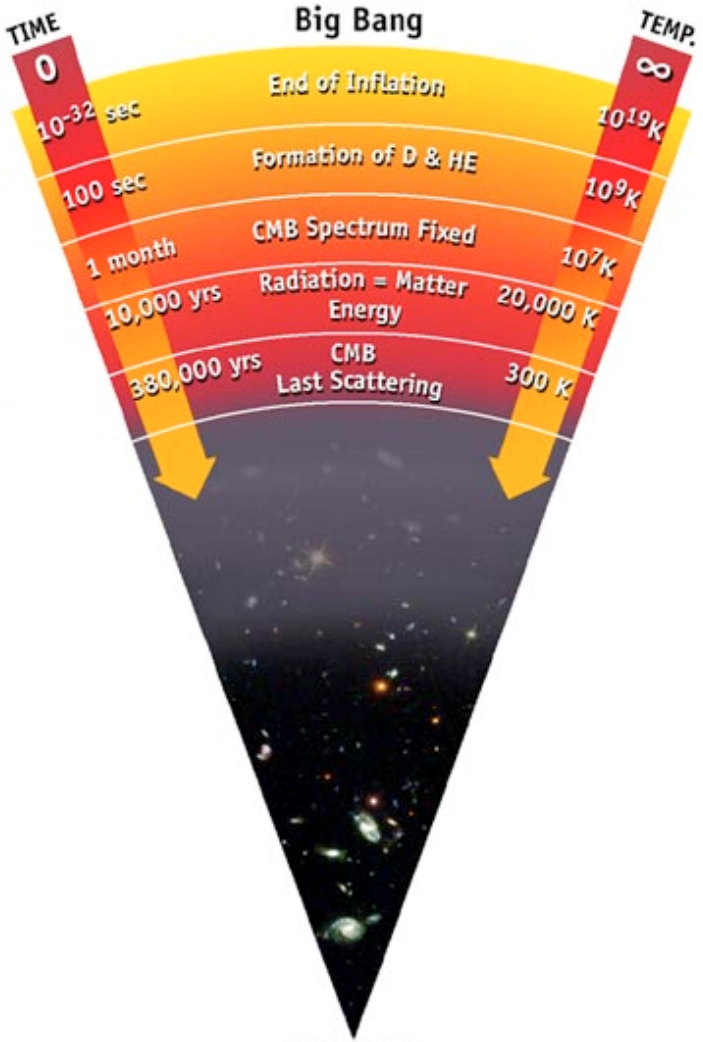


Simulazione al computer di formazione delle strutture

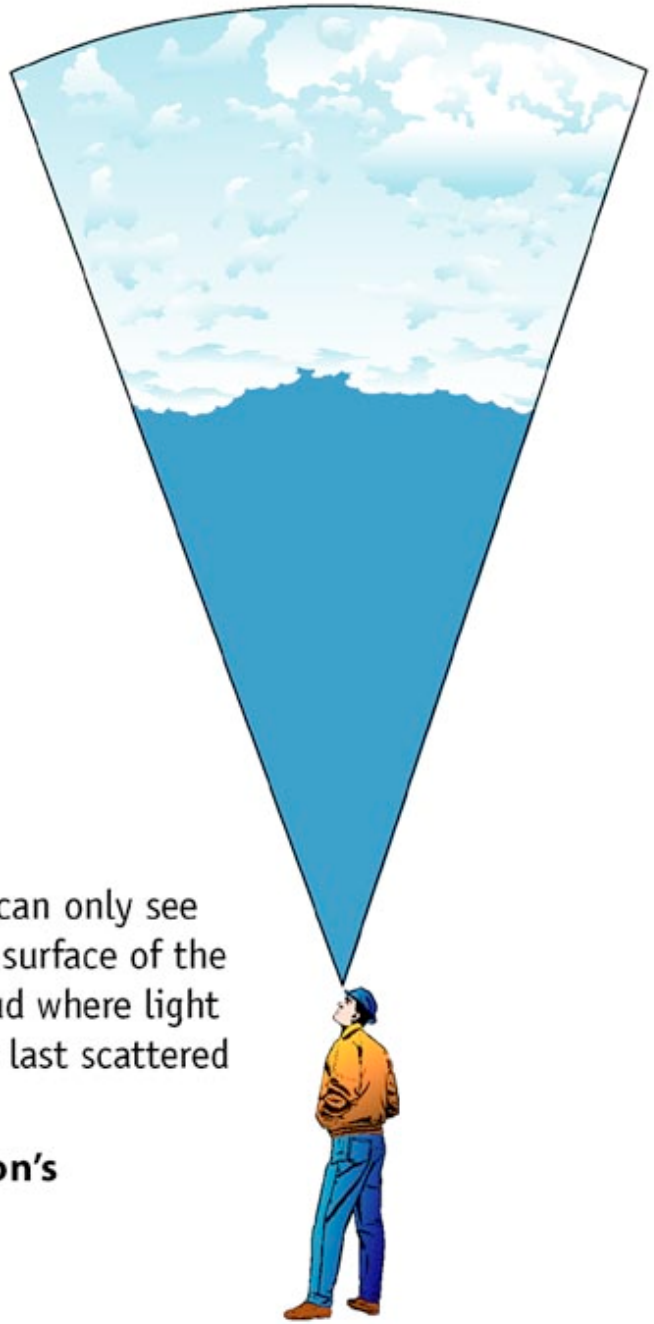


Evoluzione cosmica





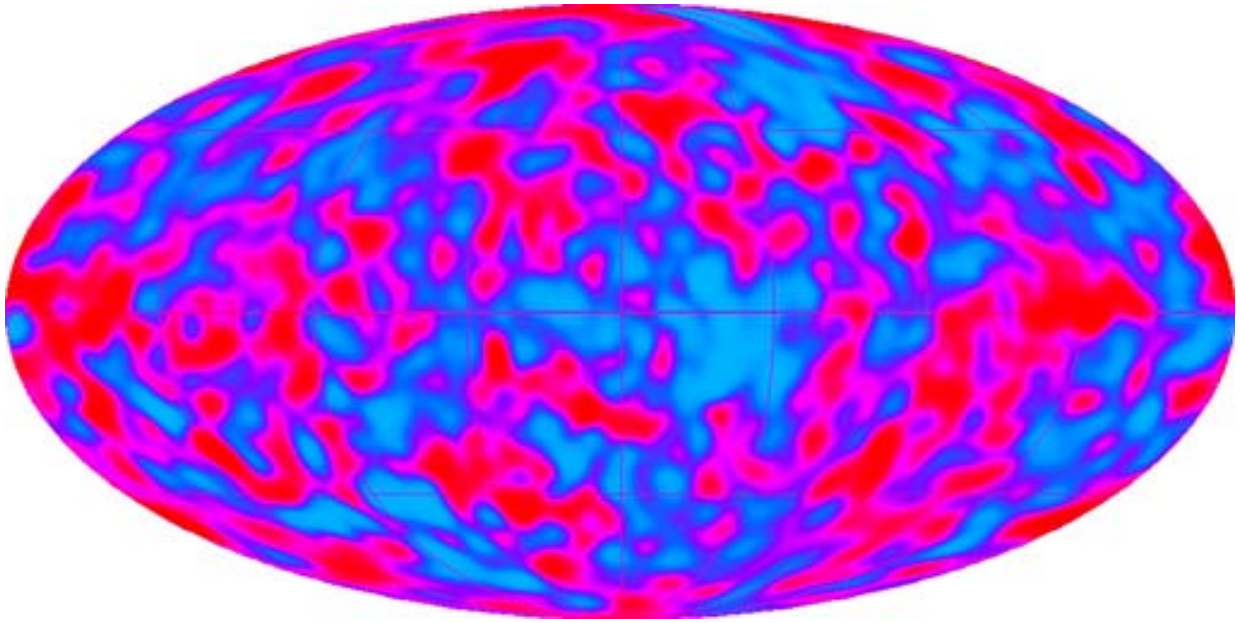
PRESENT
13.7 Billion Years
after the Big Bang



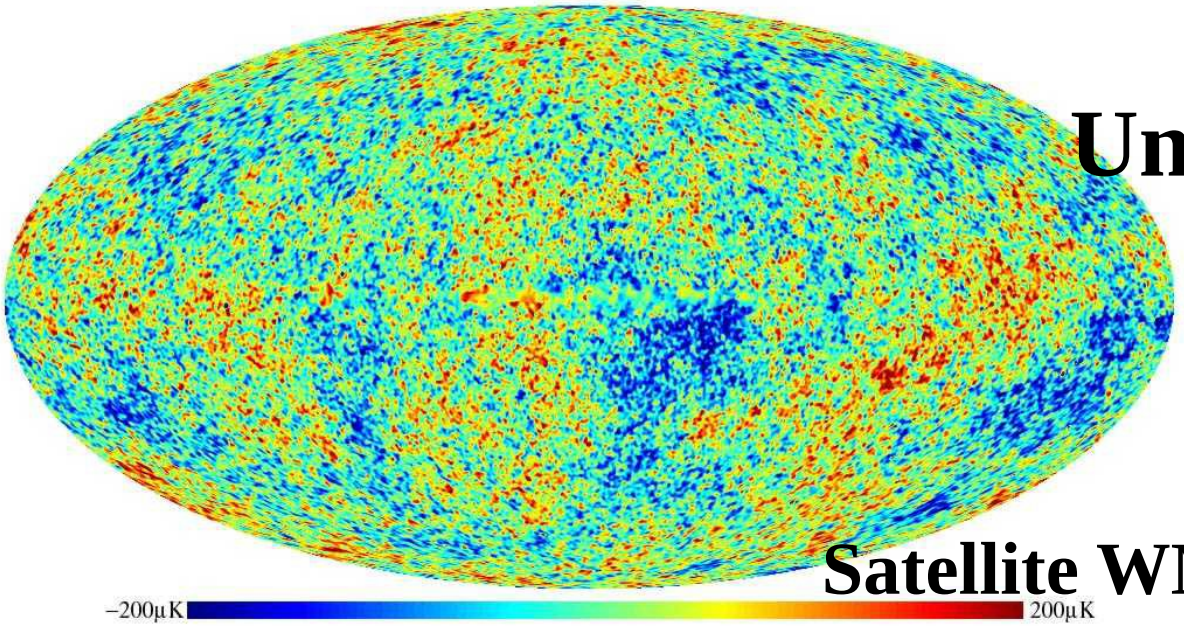
We can only see the surface of the cloud where light was last scattered

The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.

Mappa dell'Universo primordiale 380mila anni dopo il Big Bang (satellite COBE)



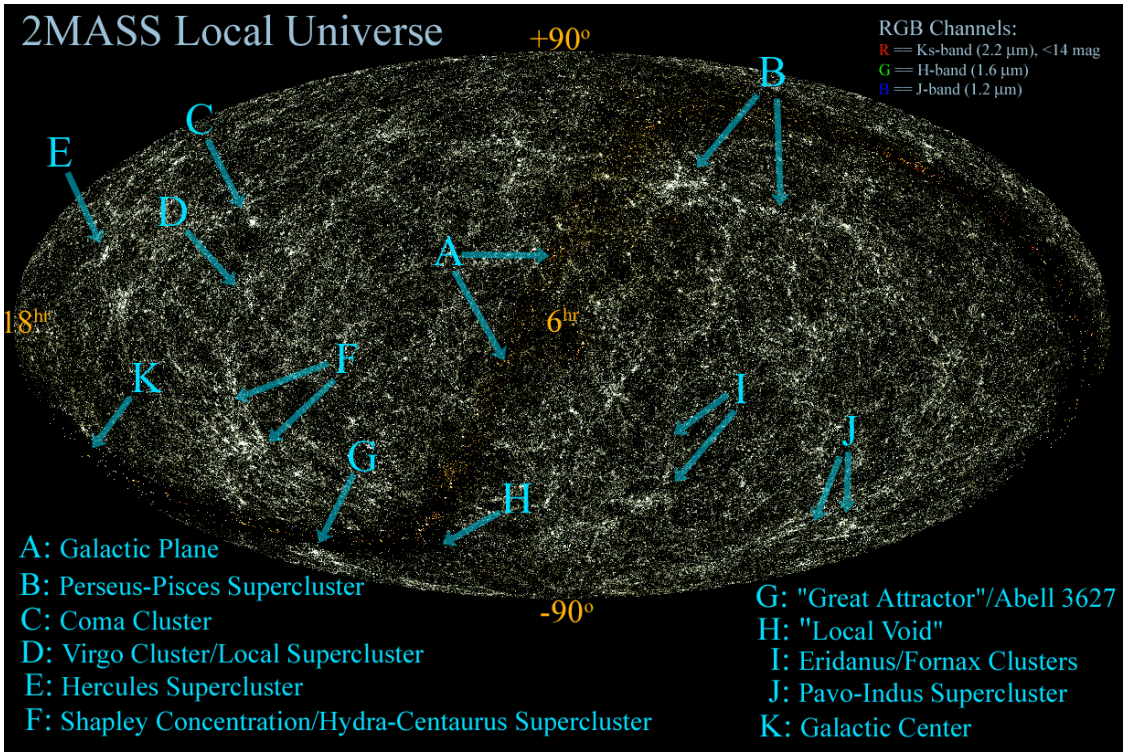
Le macchie rosse sono le strutture cosmiche in formazione

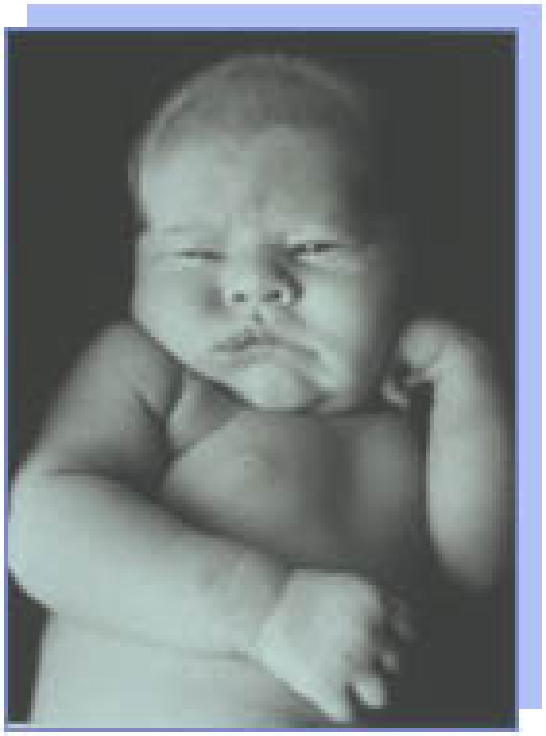


Universo a 380.000 anni

Satellite WMAP

Universo a 14.7 miliardi di anni





Uomo a tre mesi di eta’

Uomo a 40 anni di eta’

Uomo a 40 anni di eta’ con materia oscura “accelerazione della crescita”

Le strutture si sono formate più velocemente di quanto atteso: è necessaria la presenza di materia oscura in quantità circa 10 volte maggiore di quella luminosa

Richieste per la materia oscura

La materia normale e` rallentata dalla fase calda

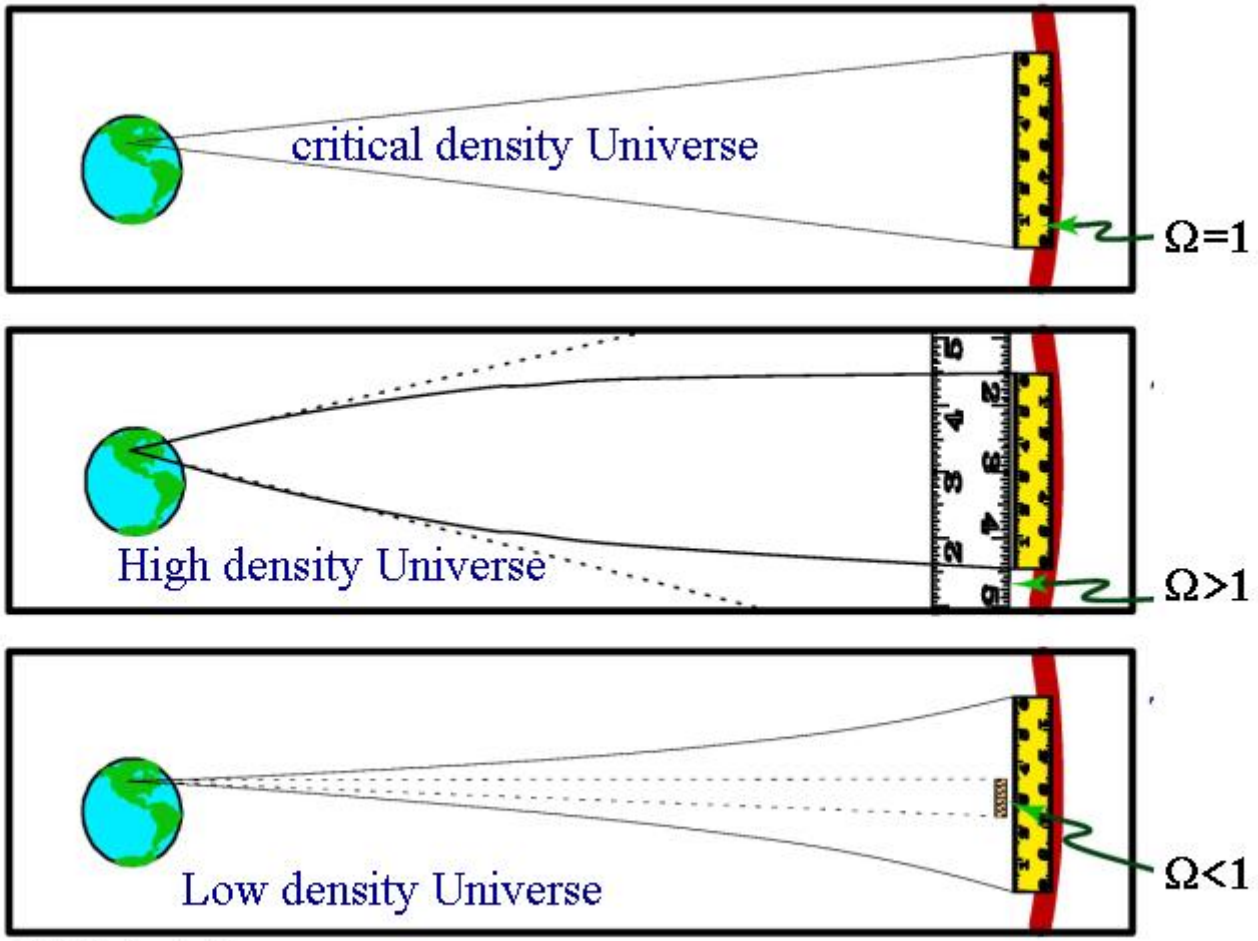
La materia oscura non interagisce con la materia normale e la radiazione e deve essere “fredda” (Scenari di materia oscura fredda CDM)

La materia oscura forma le buche di potenziale dentro cui cade la materia normale (agisce da accelerante non visibile)

Ma non e` finita qui…..

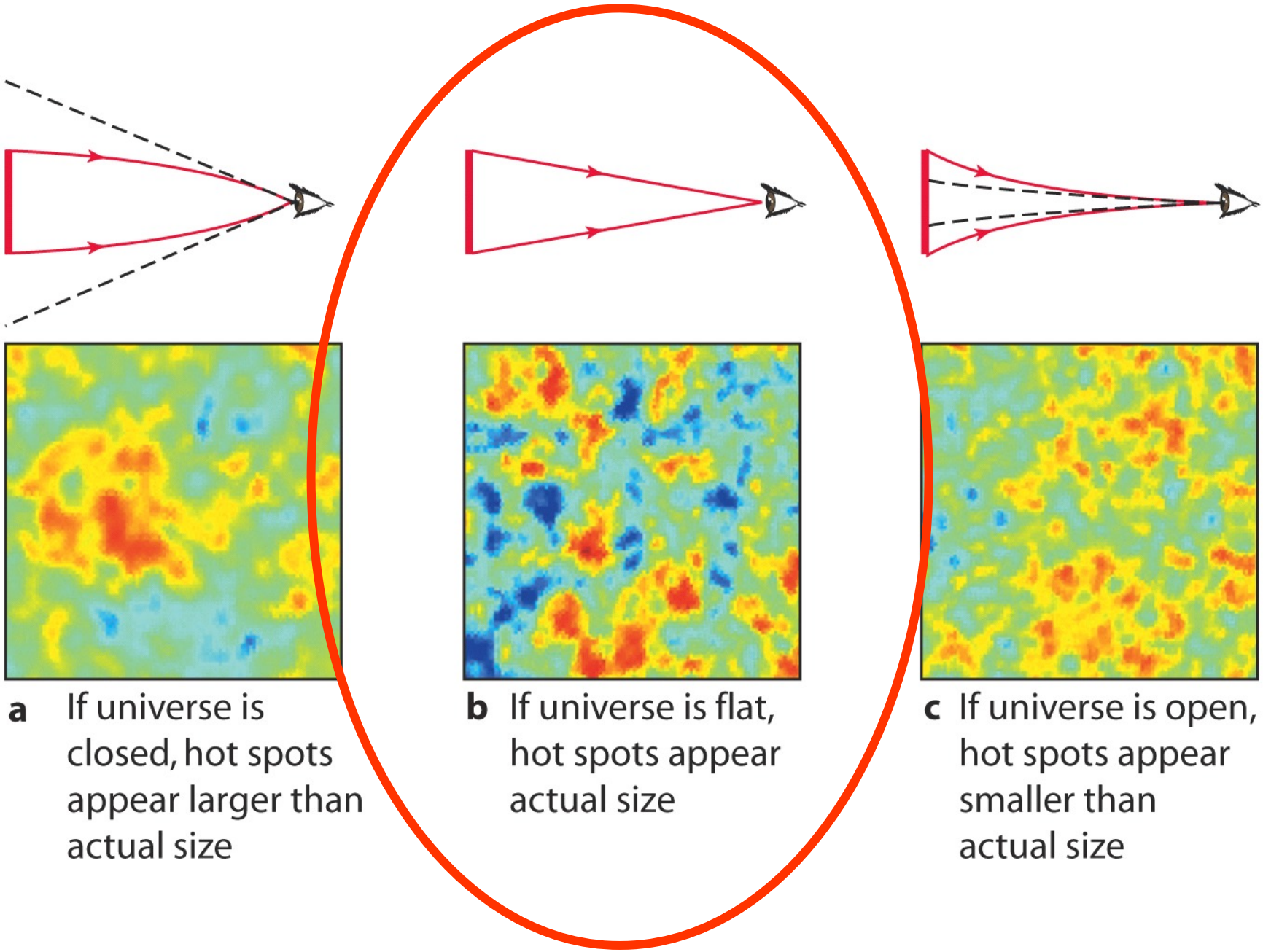
ENERGIA OSCURA

Esperimento Boomerang



C.B.Netterfield

P. de Bernardis Oct. 2000

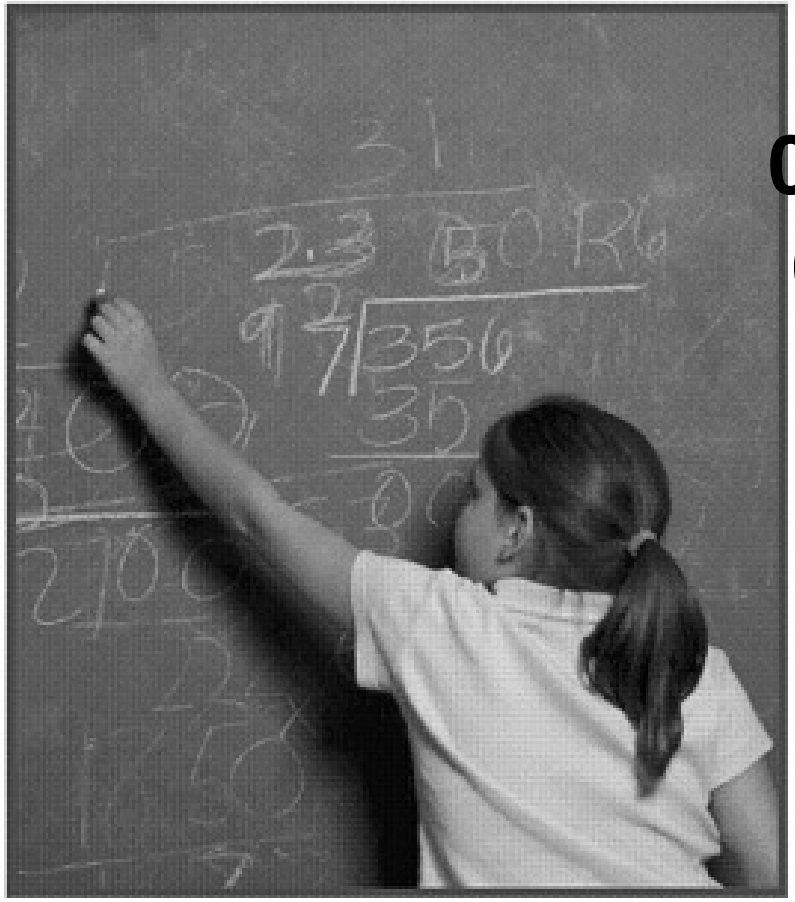


a If universe is closed, hot spots appear larger than actual size

b If universe is flat, hot spots appear actual size

c If universe is open, hot spots appear smaller than actual size

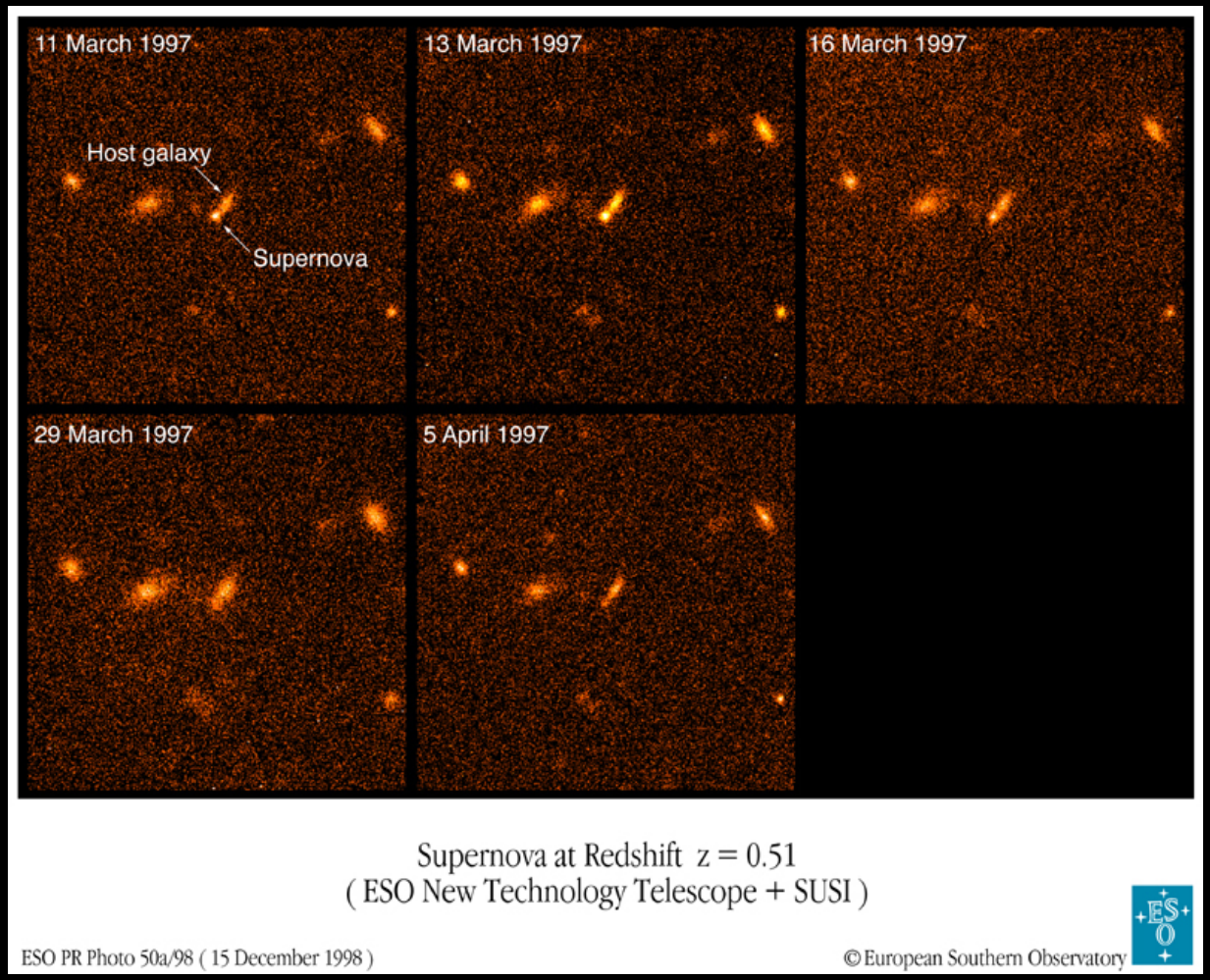
Energia oscura

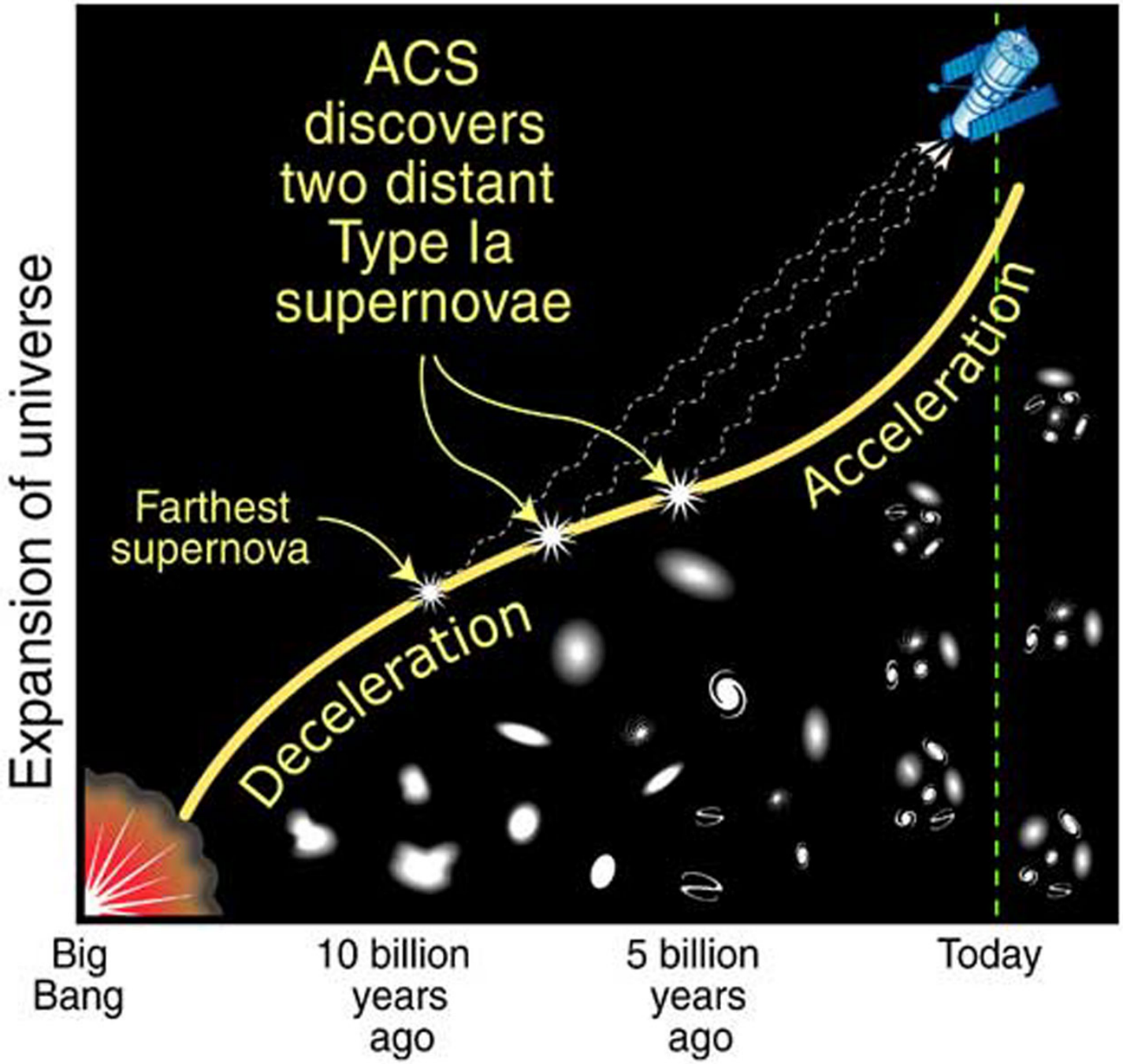


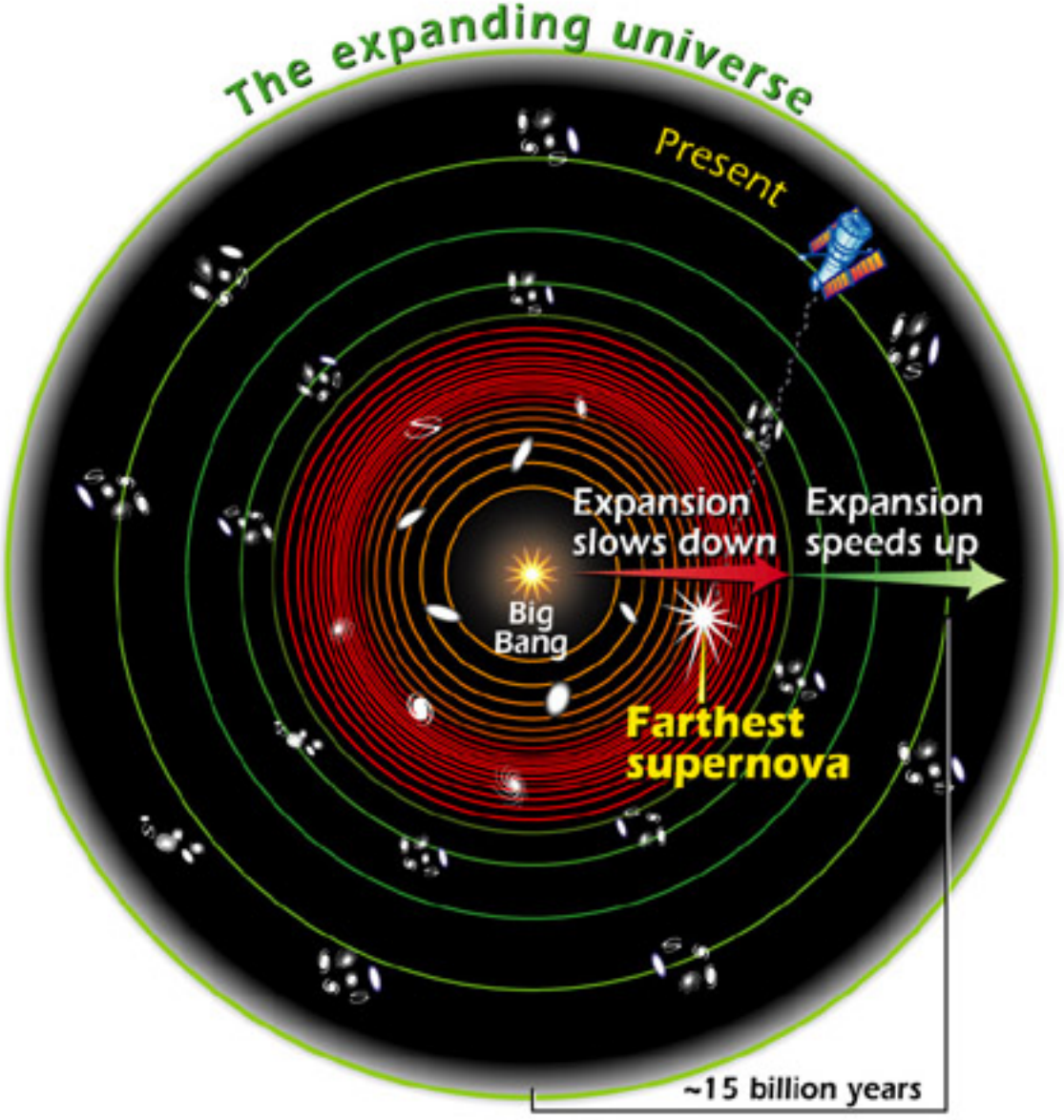
0.25 (materia oscura)+
0.05 (materia ordinaria)+
???? =
1

Tutte le supernovae hanno la stessa luminosità

Studio di supernovae lontane

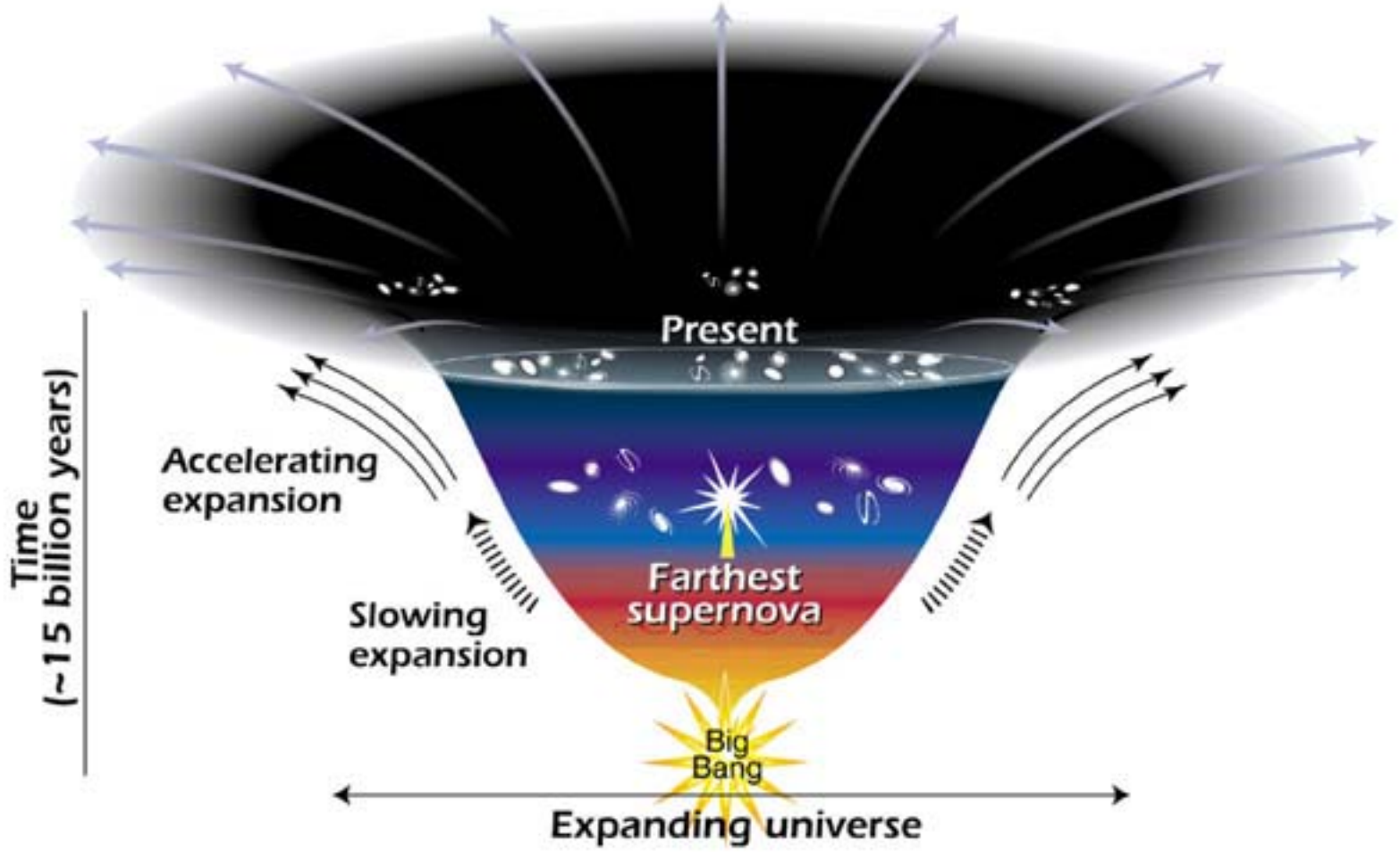


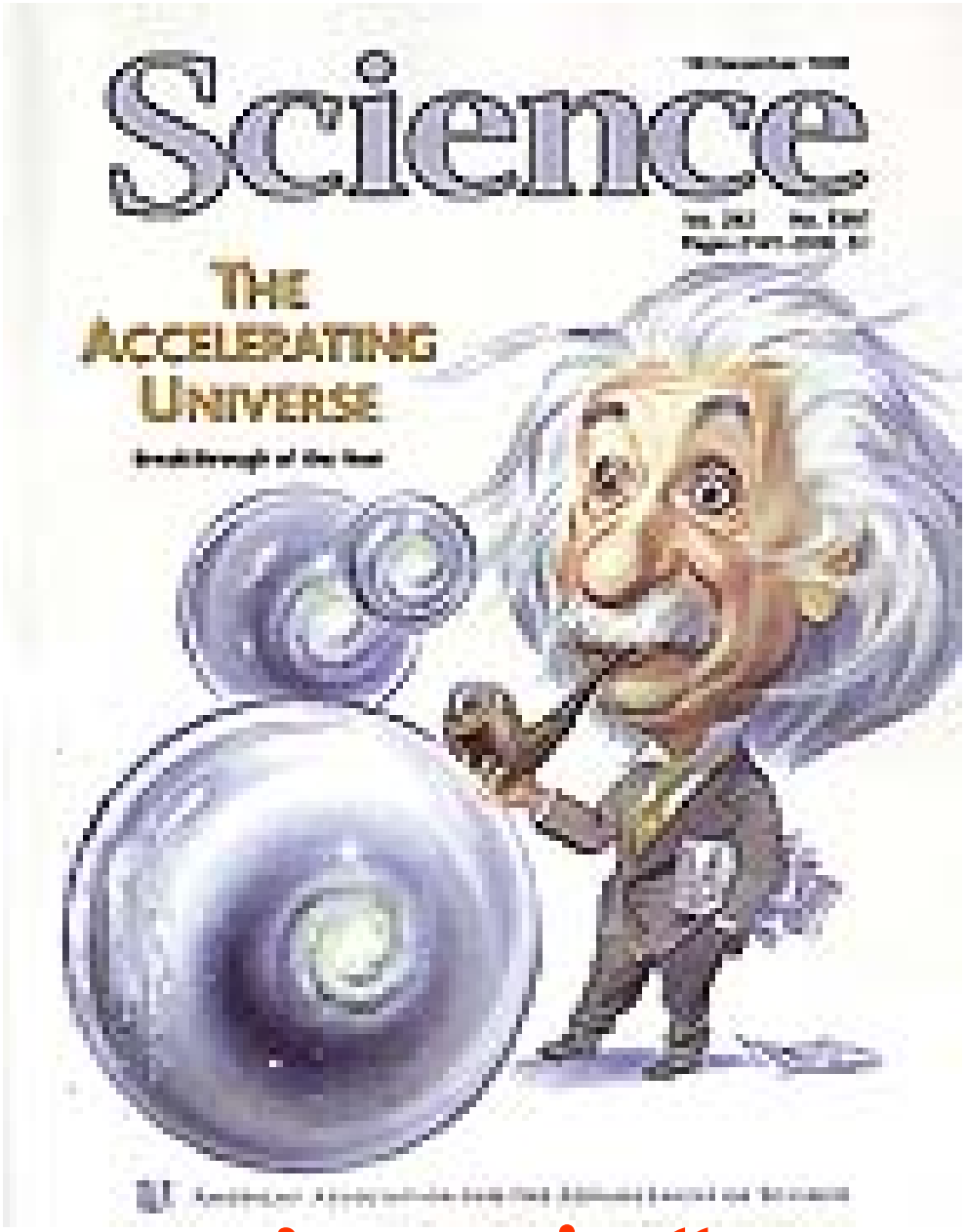

ACS
discovers
two distant
Type Ia
supernovae
Farthest
supernova
Deceleration
Acceleration
Expansion of universe
Big
Bang
10 billion
years
ago
5 billion
years
ago
Today



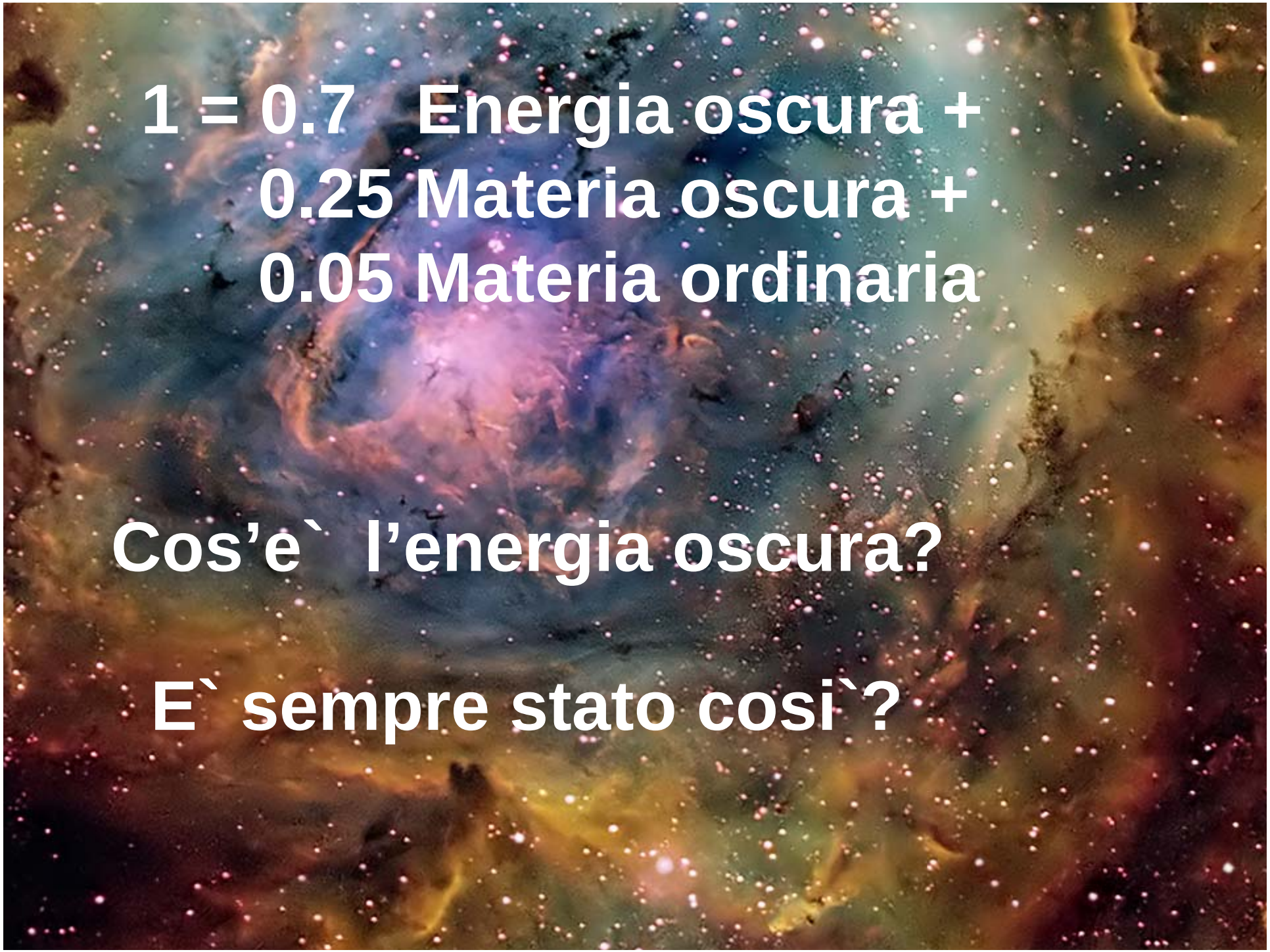
This diagram shows how the universe slowed down and then revved up since the Big Bang. The concentric red circles denote that galaxies are migrating apart at a slower rate during the first half of the cosmos. Then a mysterious, dark force overcame gravity and began pushing galaxies apart at an ever-faster rate, signified by the green circles. Astronomers found evidence of the universe's deceleration when they observed the farthest supernova ever seen, which detonated so long ago that the universe was still slowing down.

L'Universo sta accelerando la sua espansione!





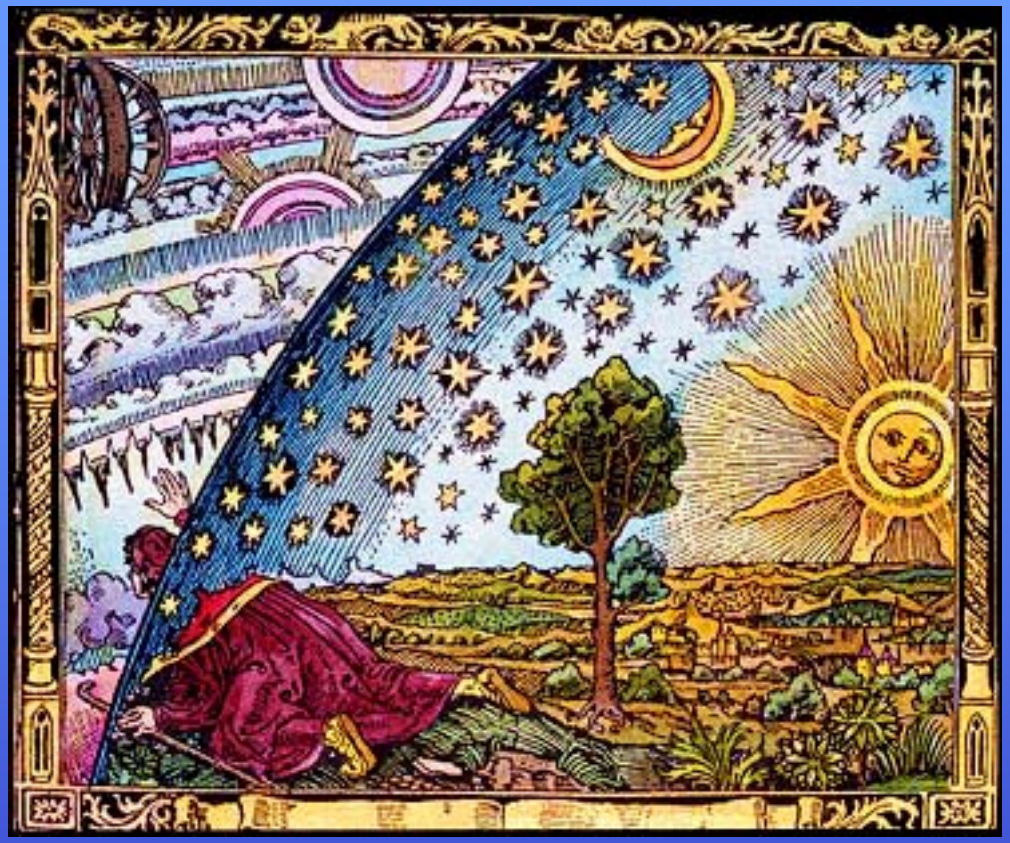
Esiste un’energia “oscura”


1 = 0.7 Energia oscura +
0.25 Materia oscura +
0.05 Materia ordinaria
Cos'e` l'energia oscura?
E` sempre stato cosi`?

I costituenti dell'Universo:

- 5% materia ordinaria
  luminosa e oscura
- 25% materia oscura
  non ordinaria
- 70% energia oscura

Cosa abbiamo imparato?



Cosa sono la materia e l'energia oscura?

collegamento con la microfisica

È tutto un falso problema?

estrapolazione delle leggi fisiche a tutto l'Universo

… la ricerca continua …