Le TEMPS dans l'UNIVERS

19 décembre 2014

CICAF Ambassade Argentine en France

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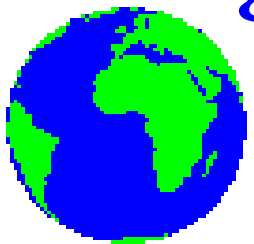
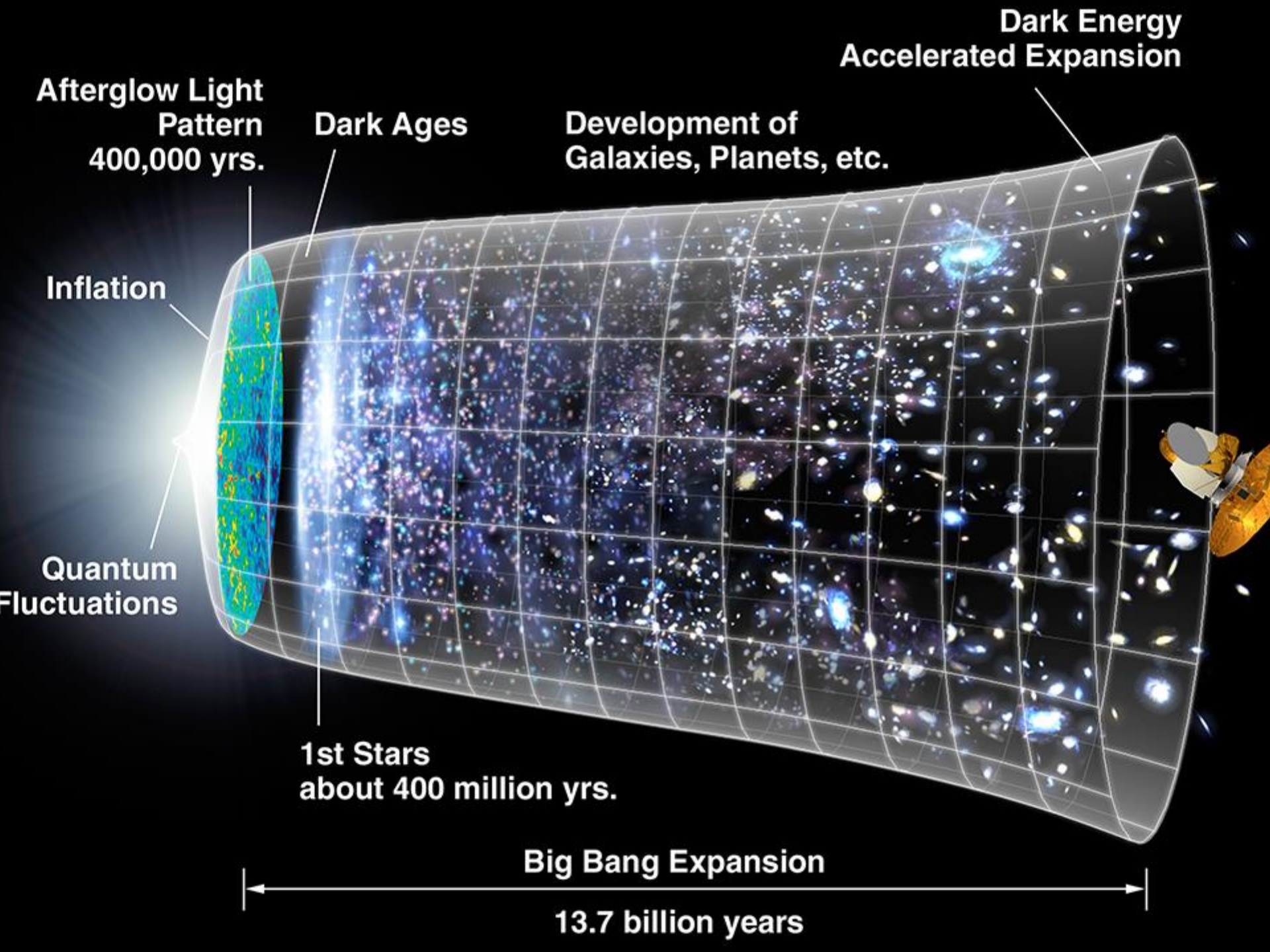
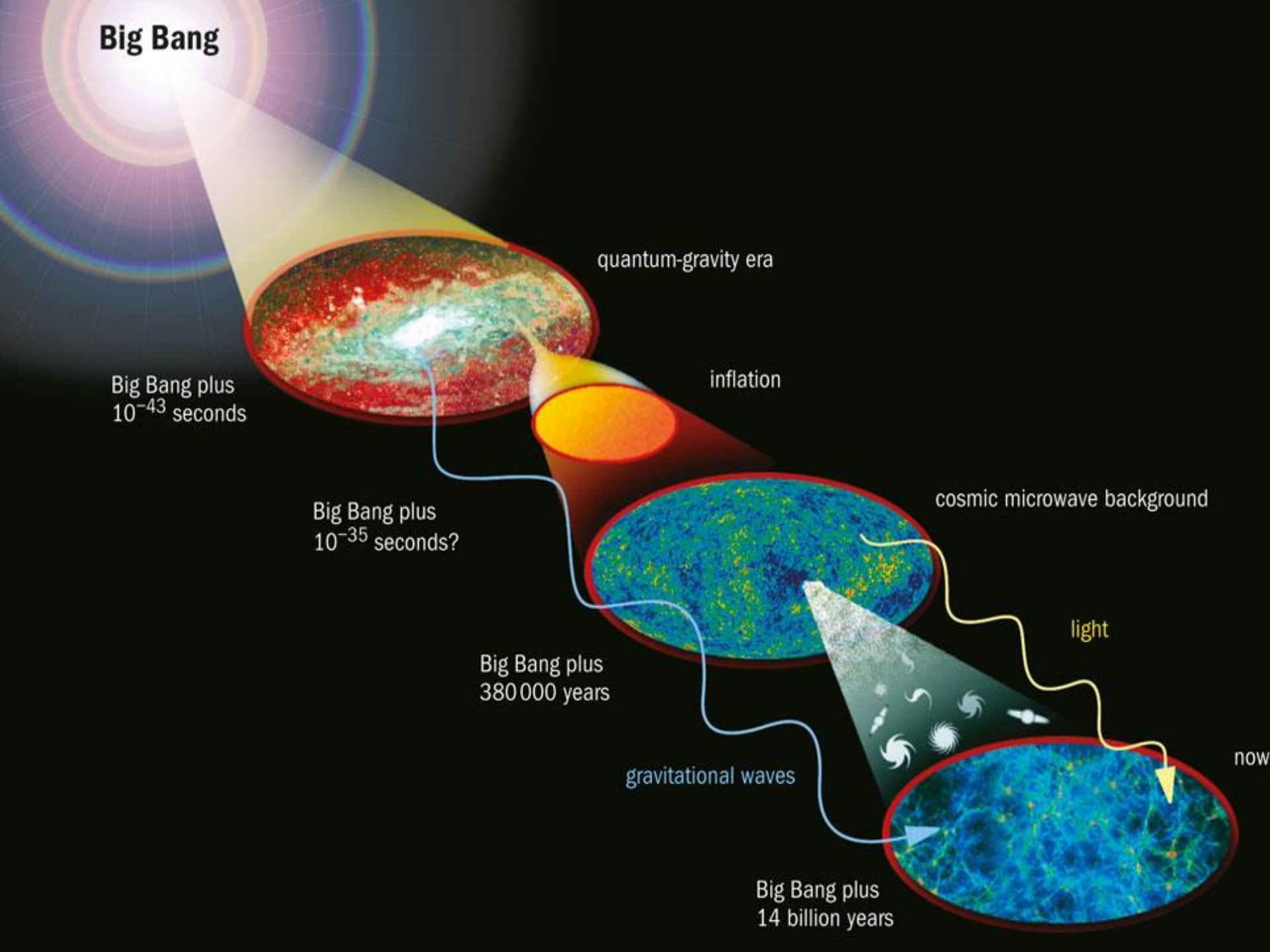



Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years


Big Bang
quantum-gravity era
Big Bang plus
10^{-43} seconds
inflation
Big Bang plus
10^{-35} seconds?
cosmic microwave background
light
Big Bang plus
380 000 years
gravitational waves
now
Big Bang plus
14 billion years

LE TEMPS: CONCEPTS

- **CAUSALITE, VITESSE MAXIMALE: c. PASSE, PRESENT, FUTURE: CONE DE LUMIERE**

- **IRREVERSIBILITE : LA FLECHE DU TEMPS**
- **→→→**

- **L'UNIVERS évolue DU DESORDRE VERS l'ORDRE (DU CHAOS VERS l'STRUCTURATION): => ENTROPY, toujours CROIT**

- **LA GRAVITATION ESPACE-TEMPS**

- **CLASSIQUE vs QUANTIQUE**

- **LE TEMPS est un concept CLASSIQUE**
- **EMERGE a partir du QUANTIQUE**
- **ORIGIN DU TEMPS**
- **VIDE (RIEN) : VIDE QUANTIQUE (pas de temps)=>**
- **EMERGENCE du TEMPS**

THE HISTORY OF THE UNIVERSE IS A HISTORY of EXPANSION and COOLING DOWN

THE EXPANSION OF THE UNIVERSE IS THE MOST POWERFUL REFRIGERATOR

INFLATION PRODUCES THE MOST POWERFUL STRETCHING OF LENGTHS

THE EVOLUTION OF THE UNIVERSE IS FROM QUANTUM TO SEMICLASSICAL TO CLASSICAL

From Very Quantum (Quantum Gravity) state to Semiclassical Gravity (Inflation) stage (Accelerated Expansion) to Classical Radiation dominated Era followed by Matter dominated Era (Deccelerated expansion) to Today Era (again Accelerated Expansion)

THE EXPANSION CLASSICALIZES THE UNIVERSE

THE EXPANSION OF THE UNIVERSE IS THE MOST POWERFUL QUANTUM DECOHERENCE MECHANISM

The History of the Universe

It is a history of EXPANSION and cooling down.

EXPANSION: the space itself expands with the time. All lengths grow as time goes on: wavelengths, distances between objects. Atoms and elementary particle sizes remain unchanged.

Cooling: temperature decreases as lenghts increase.

The expansion of the Universe started explosively fast: the Big Bang !! The Big Bang has no center. The Universe expands similarly at all space points. Homogeneous and isotropic expansion at all times.

This is very different to supernova explosions, atomic bombs or firecrackers.

Universe homogeneous and isotropic during 80 Myr. Since then, structures (galaxies) form via dynamical gravitational processes.

Inflation and subsequent eras of the Universe

Main Events since the Big Bang	Time from beginning	Tempe-rature	Expansion since B B
Inflation - DED	10^{-36} sec	10^{29} K	10^{28}
Protons & neutrons form - RD	10^{-5} sec	10^{12} K	10^{45}
D, He, Li form - RD	20 sec	10^{9} K	10^{48}
Non-relativistic ($v \ll c$) particles dominate - MD	57000 yr	8000 K	3×10^{53}
Atoms and CMB form	370000 yr	3000 K	10^{54}
Galaxies and Stars start to form - MD	80 Myr	90 K	10^{55}
Today - DED	13.7 Gyr	3 K	10^{57}

ED: DE dominated, RD: radiation dom, MD, matter dom.

CONTENT OF THE UNIVERSE

ATOMS, the building blocks of stars and planets: represent only the 4.6%

DARK MATTER comprises 23.4 % of the universe. This matter, different from atoms, does not emit or absorb light. It has only been detected indirectly by its gravity.

72% of the Universe, is composed of DARK ENERGY that acts as a sort of an anti-gravity. This energy, distinct from dark matter, is responsible for the present-day acceleration of the universal expansion, compatible with cosmological constant

Standard Cosmological Model:

Ordinary Matter + Dark Matter + Cosmological Constant

- Begins by the inflationary era.
- Gravity is described by Einstein's General Relativity. Matter determines the spacetime geometry.
- Ordinary Matter described by the Standard Model of Particle Physics: $SU(3) \otimes SU(2) \otimes U(1) =$ qcd+electroweak model. Strong, electromagnetic and weak interactions involving quarks, gluons, protons, electrons, photons and neutrinos.
- Dark matter plays a crucial role in galaxy and structures formation. DM could be a sterile neutrino which does not interact through the SM and has mass $\sim$ keV.
- Dark energy uniformly distributed in space. Repulsive gravitational force. Described by the cosmological constant Λ

The Universe Today is Essentially Empty

Inter galactic distances $\sim$ Mpc. (pc = 3.0857×10^{13} kms.)

Galaxy sizes $\sim 0.0001 - 0.1$ Mpc. (pc = 3.262 light years.)

99.9 % of the universe volume is the intergalactic space with an average energy density of 5 proton masses per m (cosmological constant).

Galaxy masses: $10^6 - 10^{12}\ M_\odot$ from dwarf compact galaxies to (diluted) big galaxies spirals.

Galaxy density:

$\sim 4000 - 40000$ proton masses per m^3 for big galaxies.

$\sim 4 \times 10^6$ proton masses per m^3 for small compact galaxie

For comparison: air density at the atmospheric pressure and 0^o C $\sim 3.9 \times 10^{26}$ proton masses per m^3.

e Fossil Cosmic Microwave bkg and Primordial Gravito

Cosmic microwave background almost homogeneous and isotropic plus small inhomogeneities $\sim 10^{-4}$.

Inflation is the only explanation for the CMB including these small fluctuations of quantum origin $\sim 10^{-4}$.

Density CMB anisotropies first detected in 1992 by COBE.

Einstein's General Relativity predicts the existence of gravitational waves. Oscillations of the space-time itself.

Primordial gravitons are produced during inflation. They appear as tensor fluctuations in the CMB anisotropies.

Primordial gravitons first detected in the CMB by BICEP in March 2014. Detected ratio r of gravitons to density fluctuations $r \sim 0.15 - 0.20$

This detection show two important results: a) the existence of gravitational waves, b) their existence as quantized gravitons.

How the Universe took its present aspect?

The Universe was homogeneous and isotropic after inflation thanks to the fast and gigantic expansion stretching lenghts by a factor $e^{64} \simeq 10^{28}$.

The universe by the end of inflation is a extraordinarily hot plasma at $T \sim 10^{14}$ GeV $\sim 10^{27}$ K.

However, small ($\sim 10^{-5}$) quantum fluctuations were of course present.

These inflationary quantum fluctuations are the seeds of

- the structure formation in the universe: galaxies, clusters, stars, planets (and all on them), ...
- the CMB anisotropies today.

That is, our present universe (including ourselves) was built out of inflationary quantum fluctuations.

Universe Inventory Today

The universe is spatially flat.
Curvature is present in the space-time geometry.

Today: Dark Energy (Λ): 73 % , Dark Matter: 22 %

Baryons + electrons: 4.5 % , Radiation ($\gamma + \nu$): 0.0085%

83 % of the matter in the Universe is DARK.

Total average energy density today (very dilute!):

$\rho(\text{today}) = 0.947\ 10^{-29}\ \frac{\text{g}}{\text{cm}^3} \simeq$ 5 proton masses per m^3

DM dominates in the halos of galaxies (external part).
Ordinary matter dominates around the center of galaxies.

Most galaxies exhibit a gigantic black hole in the center.
Central black hole mass ~ 0.001 galaxy mass.

Galaxies form out of matter collapse via gravitational dynamics.

Recent News on Cosmological Observables

Before 2013: Hubble constant $H_0 = 73.8 \pm 2.4 \ \frac{\text{km}}{\text{s}} \ \frac{1}{\text{Mpc}}$ from direct observations of Cepheids by HST, $\Omega_m = 0.27 \pm 0.03$. A G Riess et al. ApJ 730, 119 (2011).

Planck 2013: $H_0 = 67.3 \pm 1.2 \ \frac{\text{km}}{\text{s}} \ \frac{1}{\text{Mpc}}$. $\Omega_m = 0.32 \pm 0.02$.

Planck assumed here only three massless neutrinos and n sterile neutrinos ν_s.

There is today strong evidence for ν_s with $m_s \sim$ eV from short baseline experiments (reactors, MiniBoone, LSND).

Adding one ν_s yields:

$H_0 = 70 \pm 1.2 \ \frac{\text{km}}{\text{s}} \ \frac{1}{\text{Mpc}}$. $\Omega_m = 0.30 \pm 0.01$ for $m_s = 0.4$ eV.

These values for H_0 and Ω_m are compatible with the direct astronomical measurements.

M. Wyman et al. PRL. 112, 051302 (2014), J. Hamann & J Haserkamp, JCAP,10,044H (2013) R. Battye & A. Moss, PRL. 112. 051303 (2014), S. Gariazzo et al. JHEP 1311

What is the nature of the Dark Matter?

83% of the matter in the universe is Dark.

Only the DM gravitational effects are noticed and they are necessary to explain the present structure of the Universe.

DM (dark matter) particles are neutral and so weakly interacting that no effects are so far detectable.

Theoretical analysis combined with astrophysical data from galaxy observations as:

- Observed galaxy densities and velocity dispersions.
- Observed galaxy density profiles are cored.
- Acceleration of gravity in the surface of DM dominated galaxies is universal
  $g \simeq 1.7 \times 10^{-11}\, m/s^2 \ = 540\ \mathrm{kpc}/(\mathrm{Gyr})^2$.

points towards a DM particle mass in the keV scale called warm dark matter (WDM). 2 keV = 1/250 electron mass.

Quantum Fluctuations During Inflation and after

The Universe is homogeneous and isotropic after inflation thanks to the fast and gigantic expansion stretching lenghts by a factor $e^{62} \simeq 10^{27}$. By the end of inflation: $T \sim 10^{14}$ GeV.

Quantum fluctuations around the classical inflaton and FRW geometry were of course present.

These inflationary quantum fluctuations are the seeds of the structure formation and of the CMB anisotropies today: galaxies, clusters, stars, planets, ...

That is, our present universe was built out of inflationary quantum fluctuations. CMB anisotropies spectrum:

$3 \times 10^{-32}\text{cm} < \lambda_{begin\,inflation} < 3 \times 10^{-28}\text{cm}$

$M_{Planck} \gtrsim 10^{18}$ GeV $> \lambda^{-1}_{begin\,inflation} > 10^{14}$ GeV.

total redshift since inflation begins till today $= 10^{56}$:

0.1 Mpc $< \lambda_{today} <$ 1 Gpc , 1 pc = 3×10^{18} cm $= 200000$ AU

Two key observable numbers :
associated to the primordial density and primordial gravitons :

$$n_s = 0.9608 \, , \quad r$$

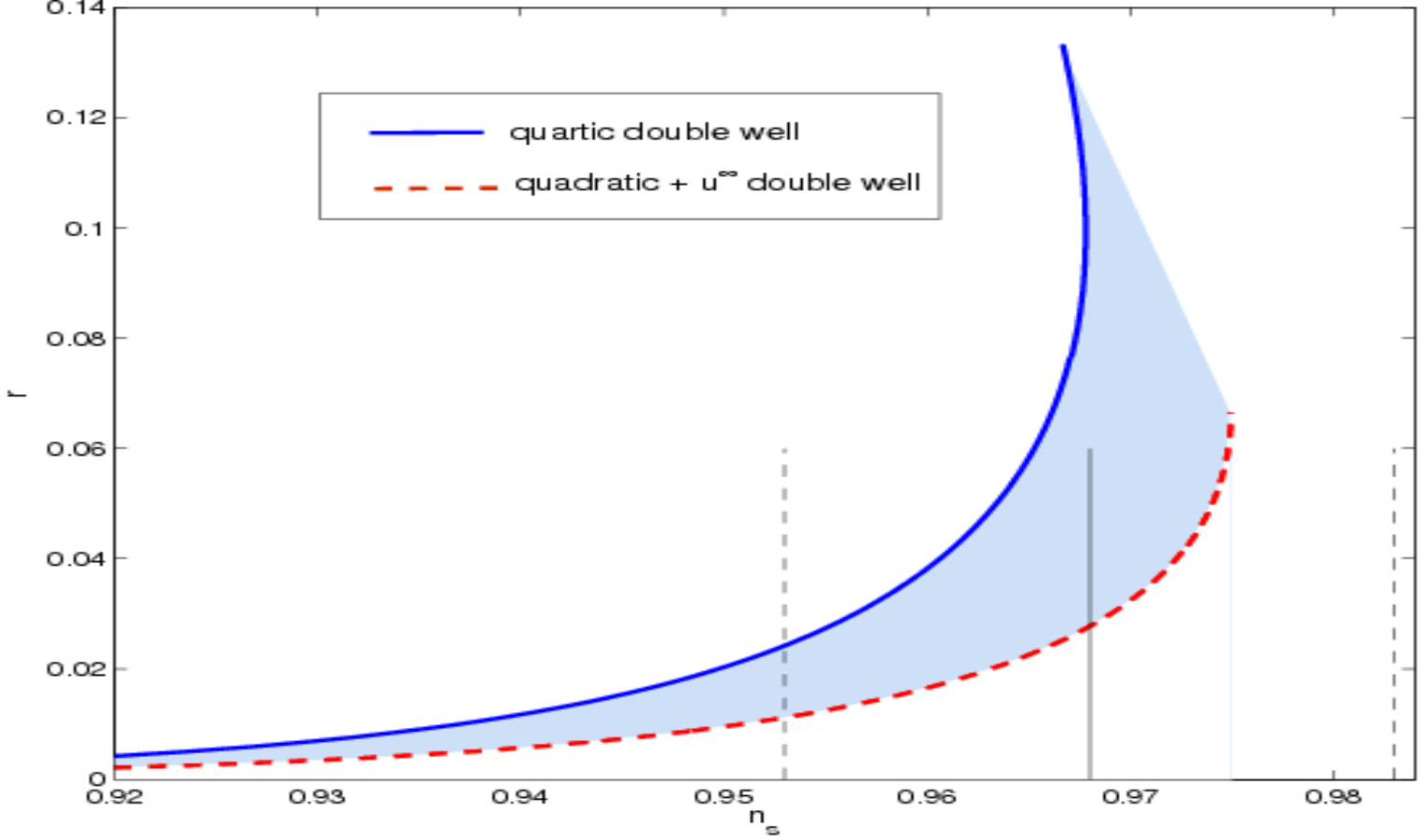
PREDICTIONS

$$r < 0.053$$

$$r > 0.021$$

$$0.021 < r < 0.053$$

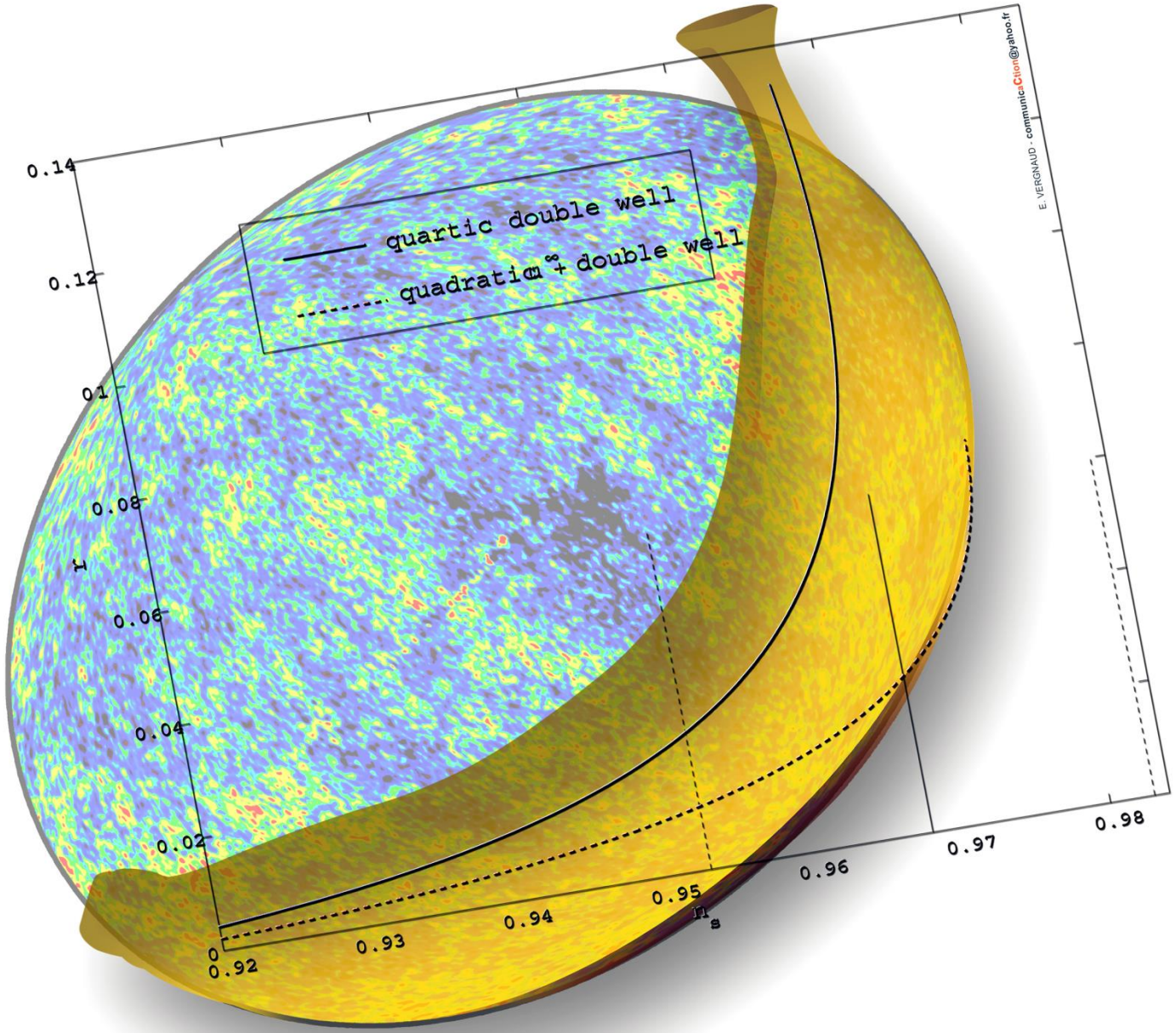
Most probable value: r ~ 0.051



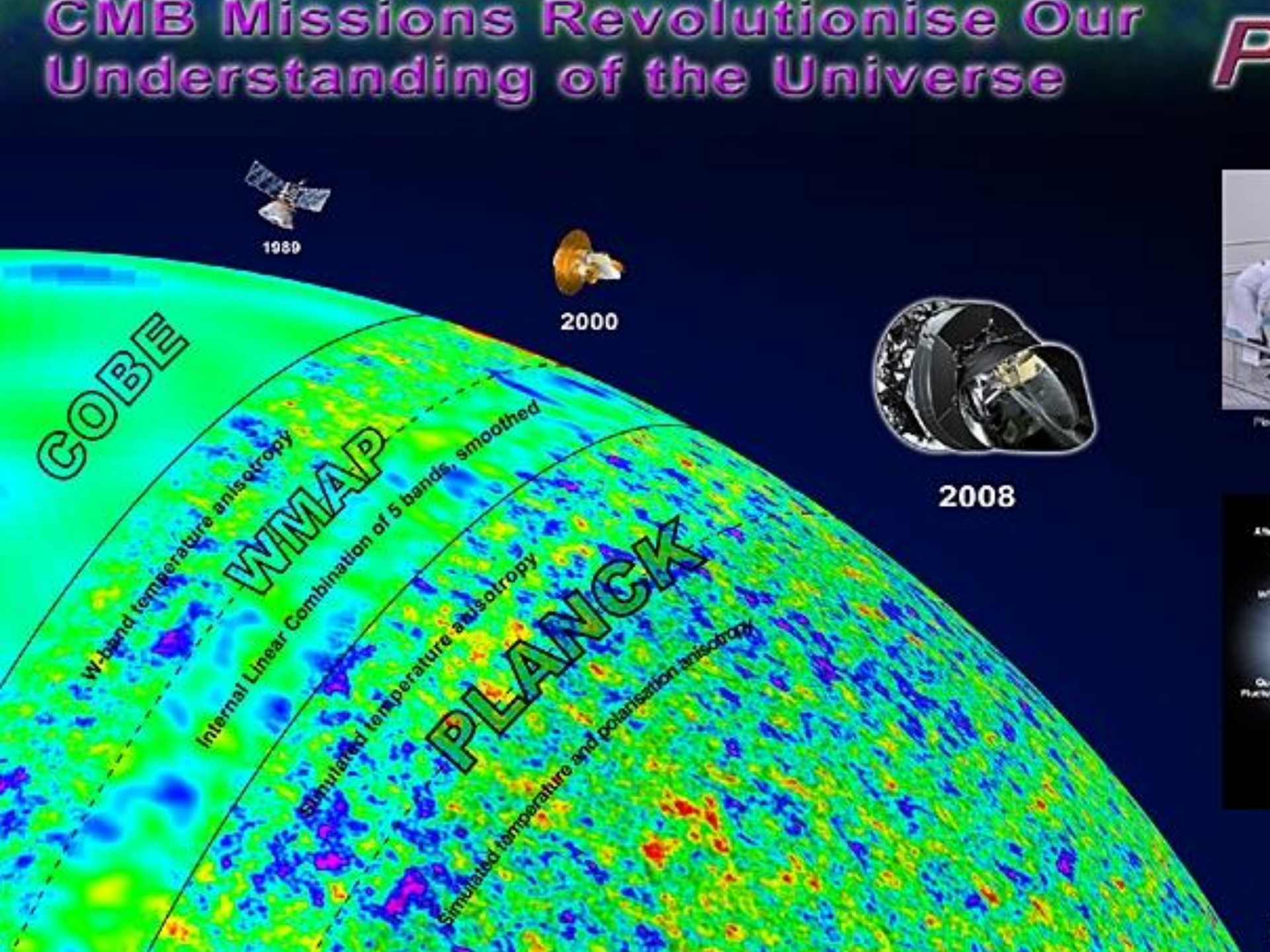
THE PRIMORDIAL COSMIC BANANA

The tensor to scalar ratio r (primordial gravitons) versus the scalar spectral index n_s. The amount of r is always non zero

H.J. de Vega, C. Destri, N.G. Sanchez, Annals Phys 326, 578(2011)


quartic double well
quadratic + double well
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
T
0.92
0.93
0.94
0.95
0.96
0.97
0.98
η_s
E. VERGNAUD - communicCtion@yahoo.fr

CMB Missions Revolutionise Our Understanding of the Universe



THE ENERGY SCALE OF INFLATION IS THE

THE SCALE OF GRAVITY IN ITS SEMICLASSICAL REGIME

(OR THE SEMICLASSICAL GRAVITY TEMPERATURE)

(EQUIVALENT TO THE HAWKING TEMPERATURE)

The CMB allows to observe it

(while is not possible to observe for Black Holes)

BLACK HOLE EVAPORATION DOES THE INVERSE EVOLUTION :

BLACK HOLE EVAPORATION GOES FROM CLASSICAL/SEMICLASSICAL STAGE TO A QUANTUM (QUANTUM GRAVITY) STATE,

Through this evolution, the Black Hole temperature goes from the semiclassical gravity temperature (Hawking Temperature) to the usual temperature (the mass) and the quantum gravity temperature (the Planck temperature).

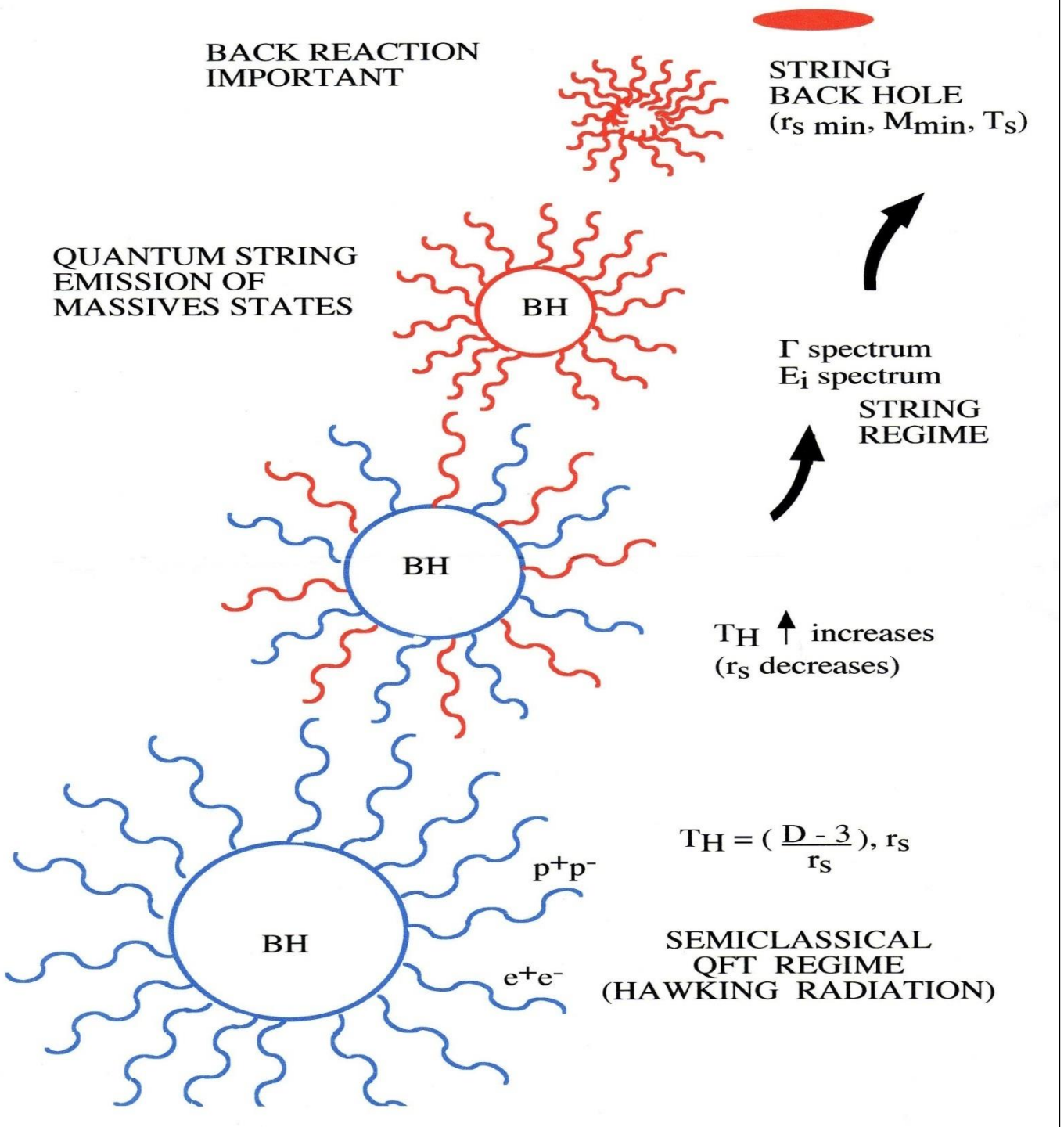
Conceptual unification of quantum black holes, elementary particles and quantum states

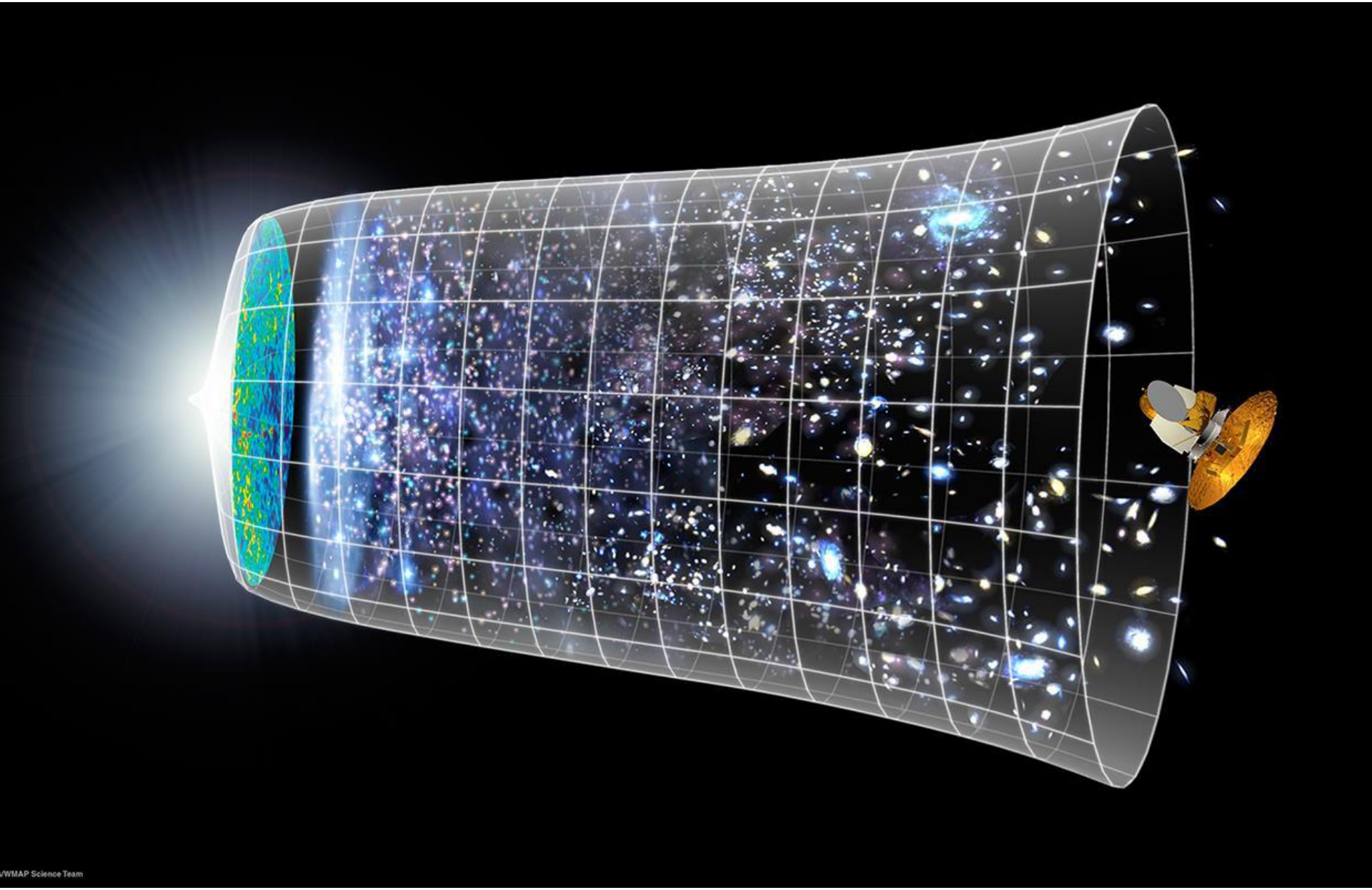
CONCEPTUAL UNIFICATION

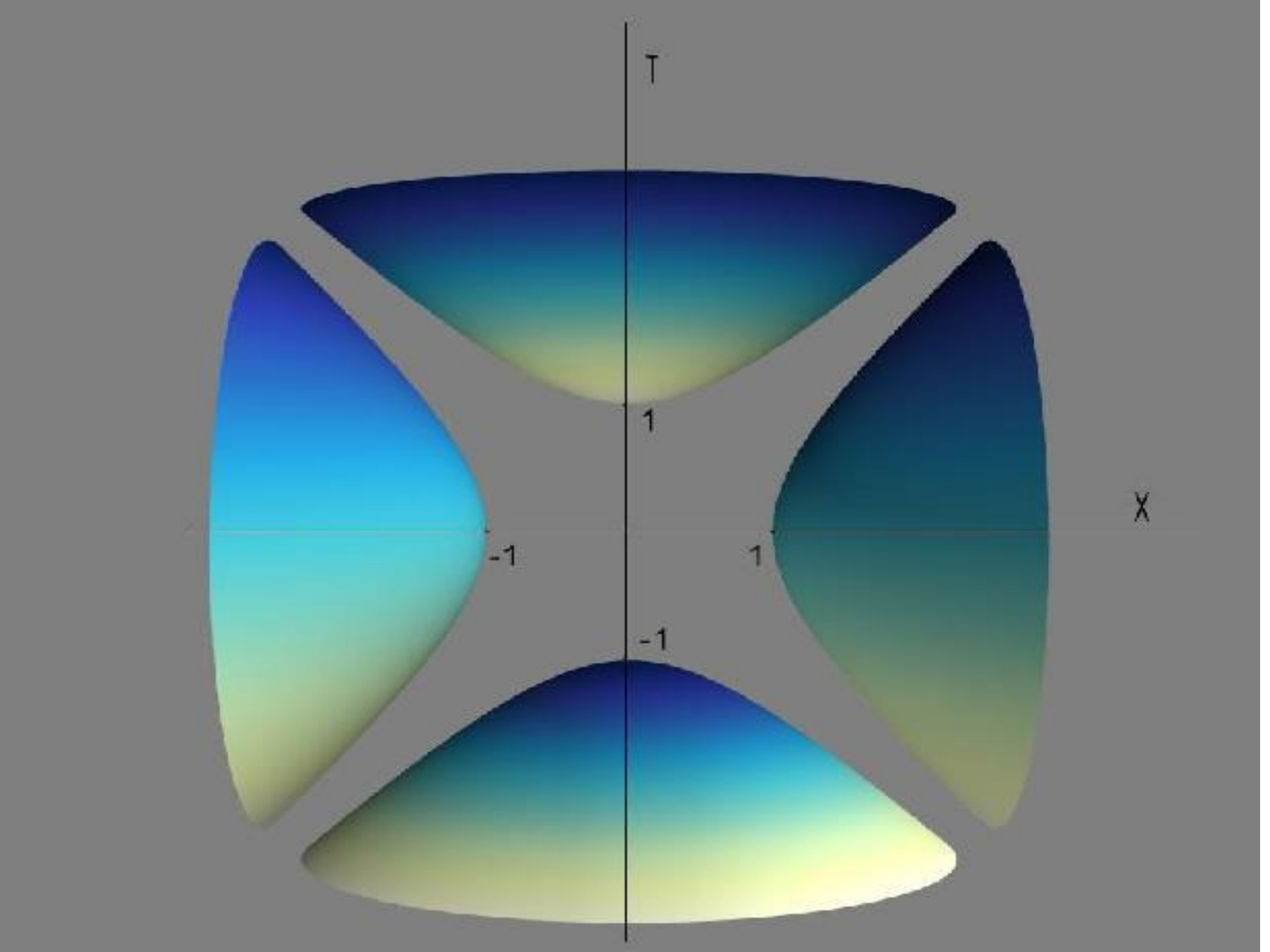
- **Cosmological evolution goes from a quantum gravity phase to a semi-classical phase (inflation) and then to the classical (present cosmological) phase.**

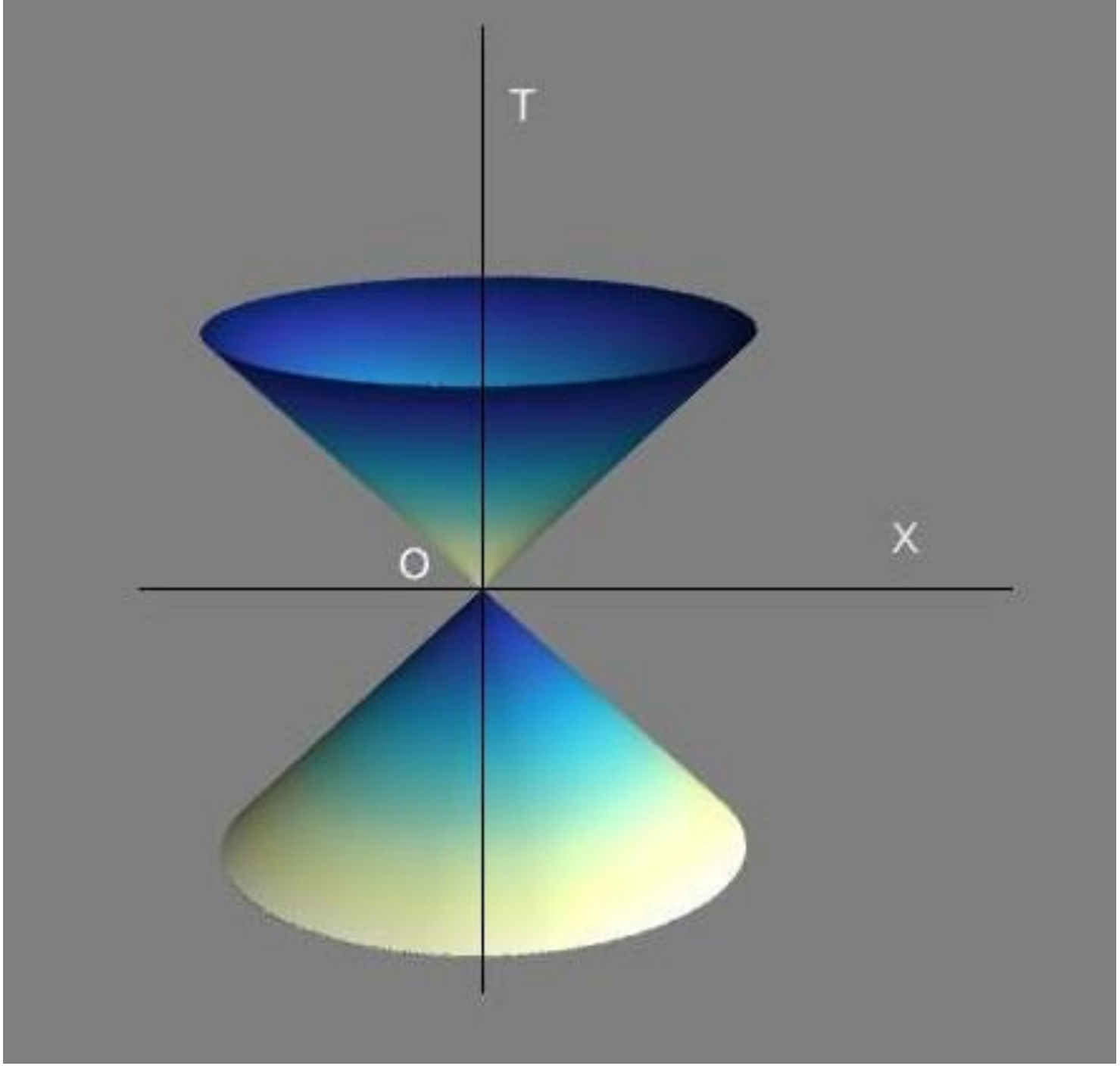
- **Black Hole Evaporation (BH hole decay rate), heavy particles and extended quantum decay rates; black hole evaporation ends as quantum extended decay into pure (non mixed) non thermal radiation.**

- **The Hawking temperature, elementary particle and Hagedorn (string) temperatures are the same concept in different gravity regimes (classical, semiclassical, quantum) and turn out to be the precise classical-quantum duals of each other.**


BACK REACTION
IMPORTANT
STRING
BACK HOLE
($r_{S\,min}$, M_{min}, T_S)
QUANTUM STRING
EMISSION OF
MASSIVES STATES
BH
Γ spectrum
E_i spectrum
STRING
REGIME
BH
T_H ↑ increases
(r_S decreases)
BH
p^+p^-
e^+e^-
$T_H = \left(\frac{D-3}{r_S}\right), r_S$
SEMICLASSICAL
QFT REGIME
(HAWKING RADIATION)

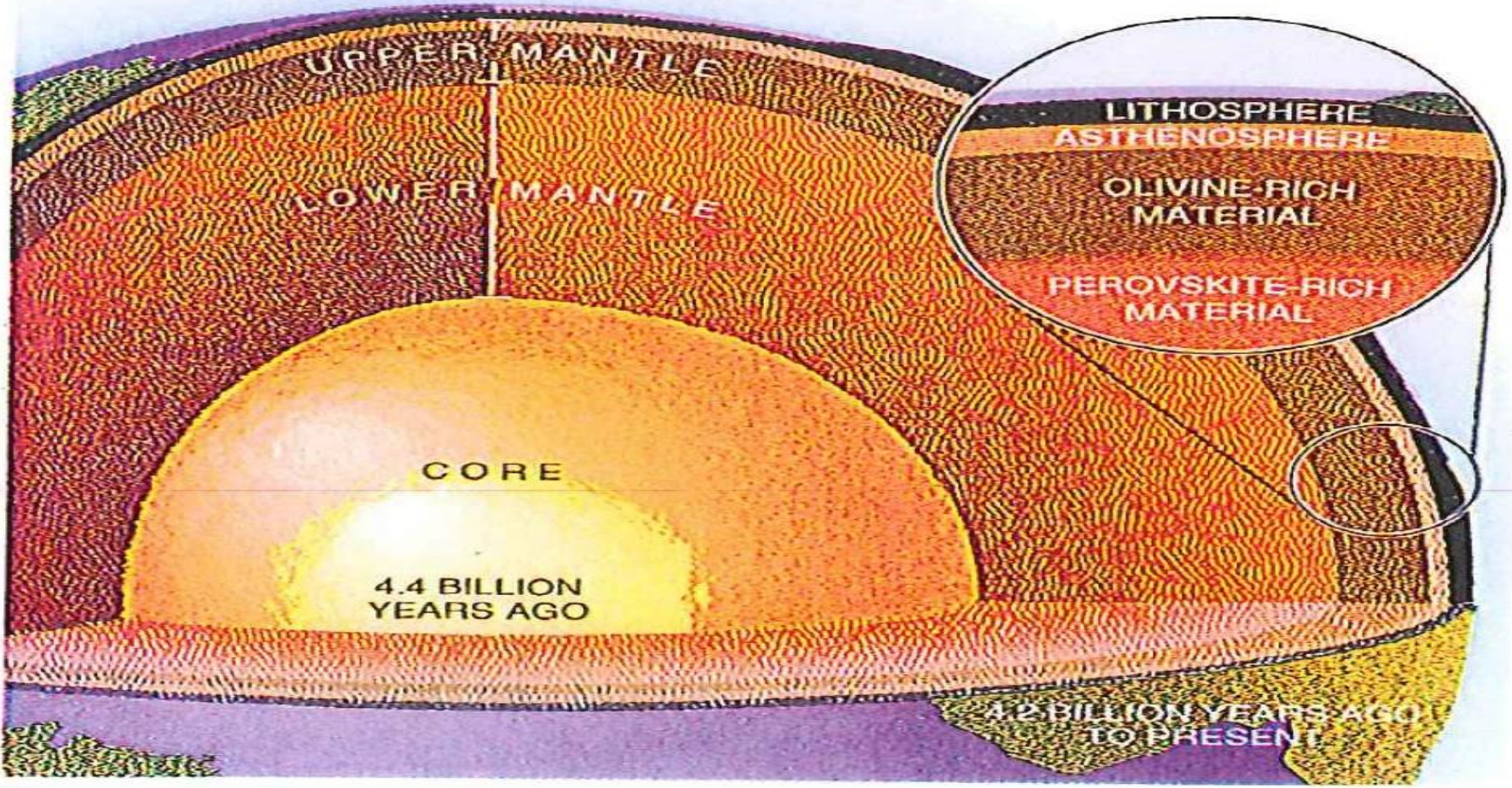

/WMAP Science Team


T
1
-1
1
-1
X

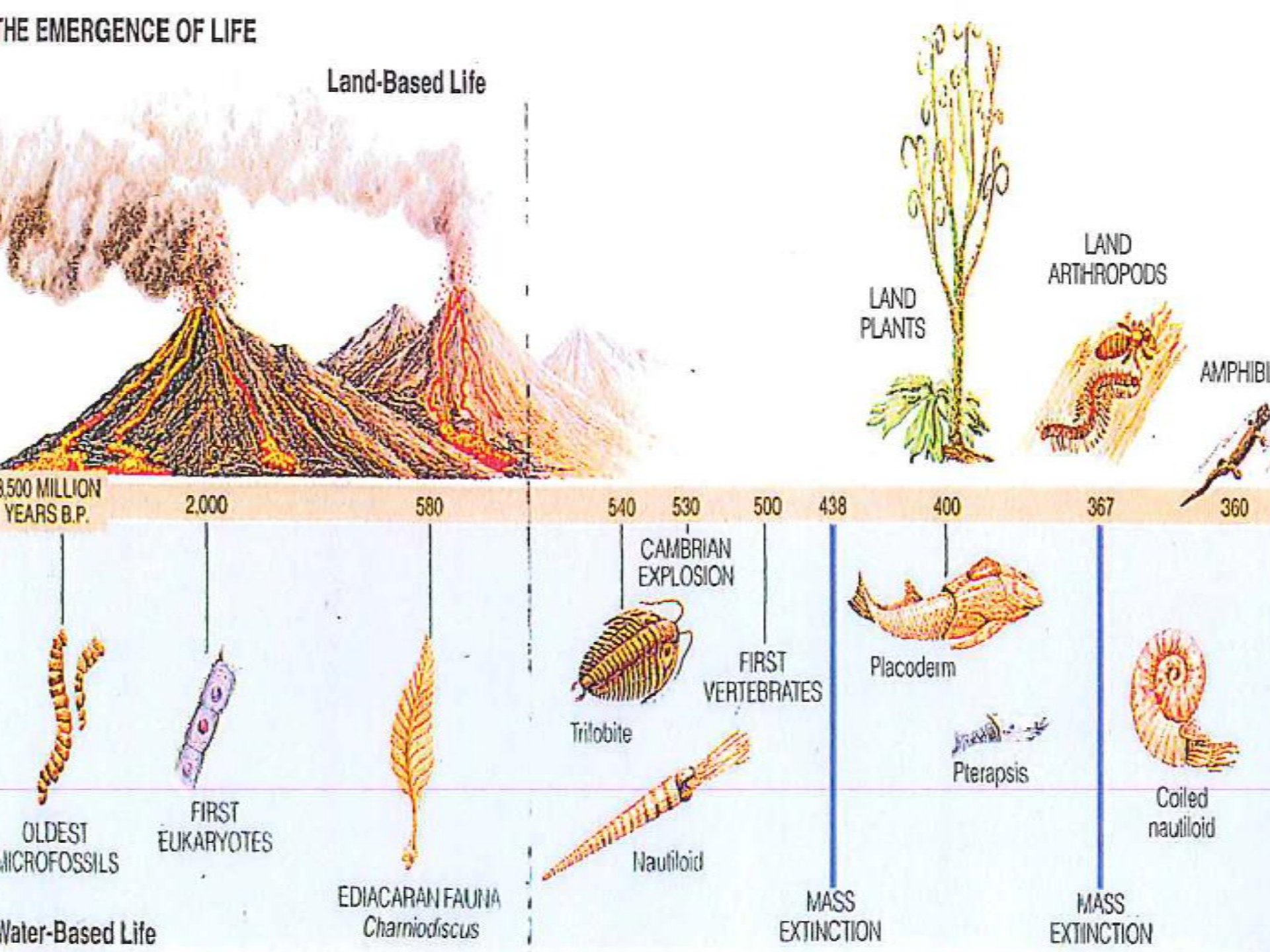

T
X
O

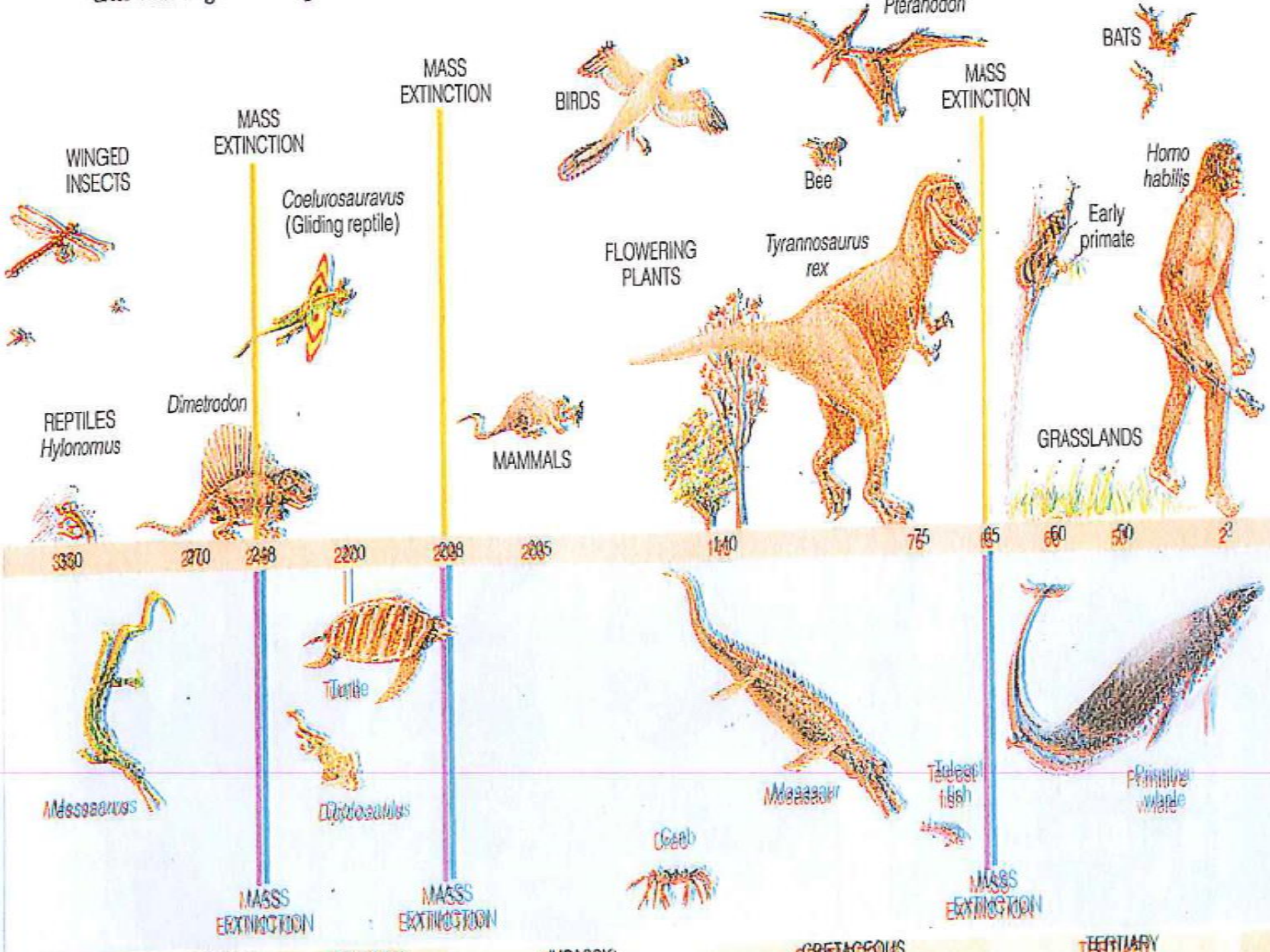
How the Earth Got Its Core

The differentiation of the planet took place quite quickly after the earth was formed by the accretion of cosmic dust and meteorites. About 4.4 billion years ago the core—which, with the mantle, drives the geothermal cycle, including volcanism—appeared; gases emerging from the interior of the planet also gave rise to a nascent atmosphere. Somewhat later, although the issue has not been entirely resolved, it seems that continental crust formed as the various elements segregated into different depths.



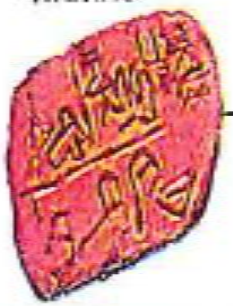
THE EMERGENCE OF LIFE




WINGED INSECTS
MASS EXTINCTION
Coelurosauravus (Gliding reptile)
MASS EXTINCTION
BIRDS
Pteranodon
BATS
MASS EXTINCTION
Bee
Homo habilis
Early primate
FLOWERING PLANTS
Tyrannosaurus rex
REPTILES
Hylonomus
Dimetrodon
MAMMALS
GRASSLANDS
3360
270
248
220
208
205
140
75
65
60
50
2
Tortoise
Messaerus
Diplocaulus
Mosasaur
Teleost fish
Primitive whale
Crab
MASS EXTINCTION
MASS EXTINCTION
MASS EXTINCTION
CRETACEOUS
TERTIARY

THE EMERGENCE OF INTELLIGENCE

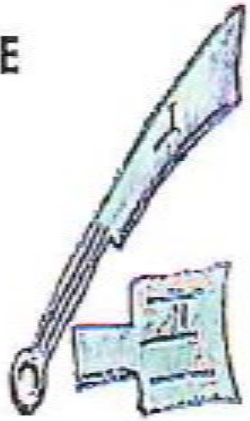
IRST STONE TOOLS



WRITING

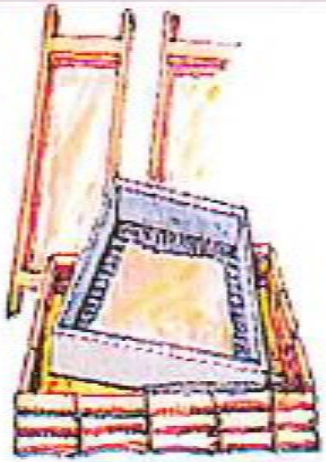
ROCK ENGRAVING

EARLIEST FARMING

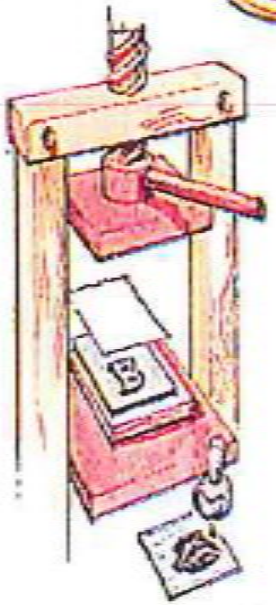


FIRST COINS

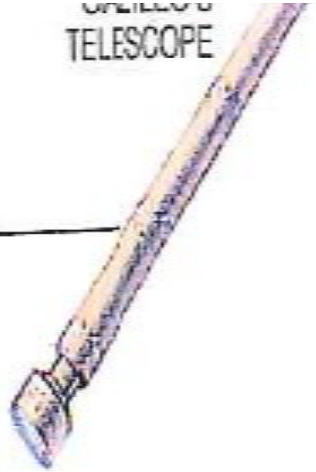
ASTROLABE



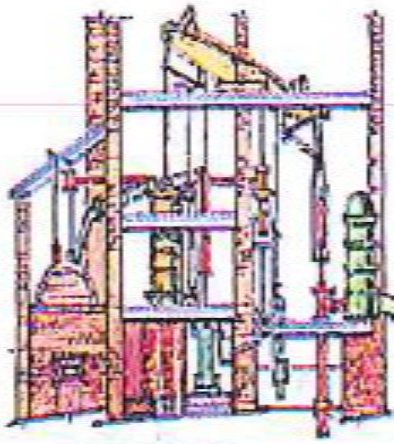
PAPER INVENTED IN CHINA



GUTENBERG PRESS



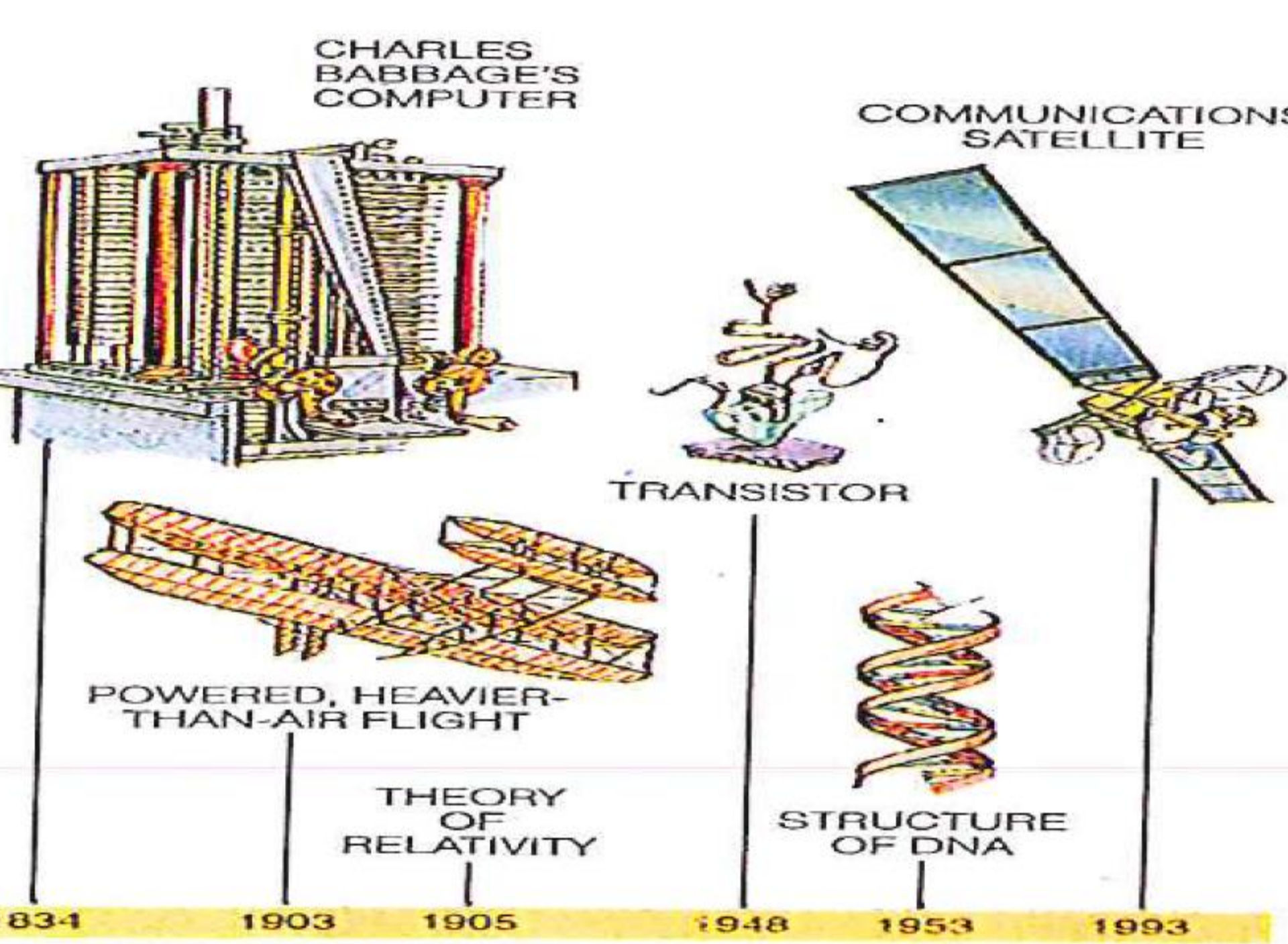
TELESCOPE



JAMES WATT'S STEAM ENGINE

FIRST CAS IRON BRID

1.9 MILLION YEARS B.P. | 35,000 | 9,000 | 3,500 B.C. | 700 B.C. | A.D. 100 | 500 | 1440 | 1590 | 1609 | 1765 | 1779


CHARLES BABBAGE'S COMPUTER
COMMUNICATIONS SATELLITE
TRANSISTOR
POWERED, HEAVIER-THAN-AIR FLIGHT
THEORY OF RELATIVITY
STRUCTURE OF DNA
834
1903
1905
1948
1953
1993

FIN…

THE END….

MUCHISIMAS GRACIAS

por vuestra ATENCION !!!

MERCI beaucoup pour votre ATTENTION !!

THANK YOU very much for your ATTENTION !!