Particles in the Universe

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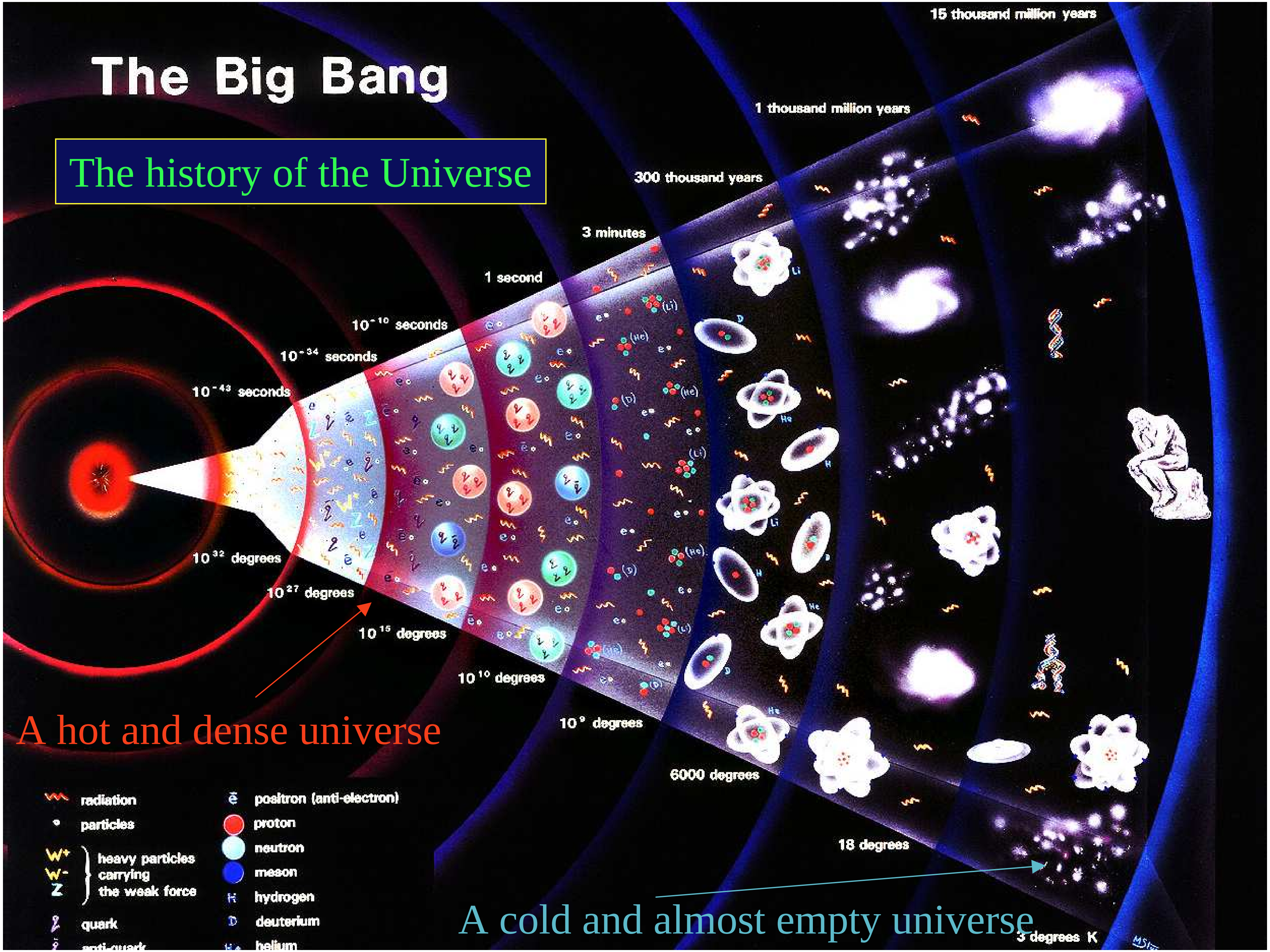
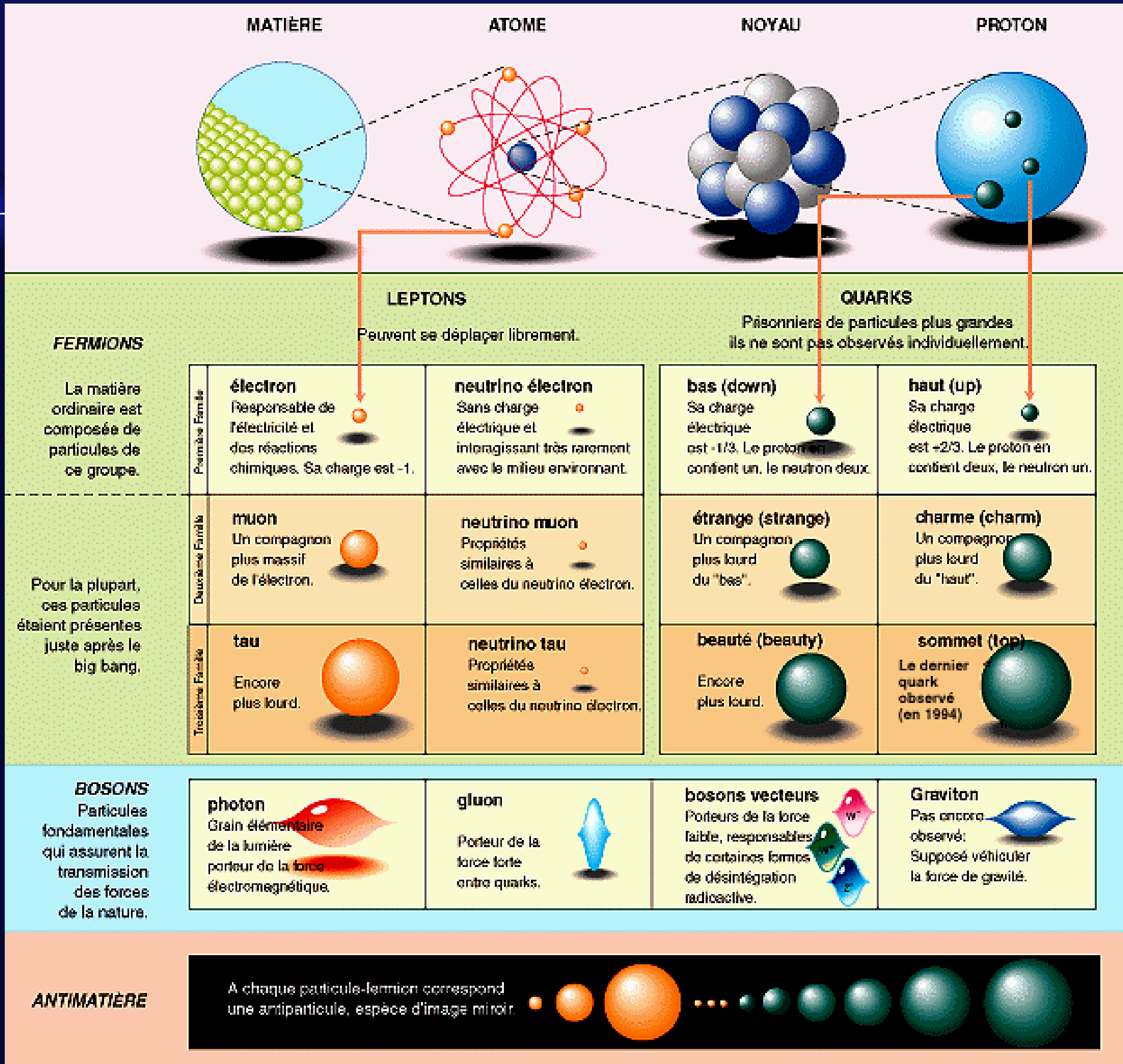
CERN : where the conditions of the big bang are reproduced

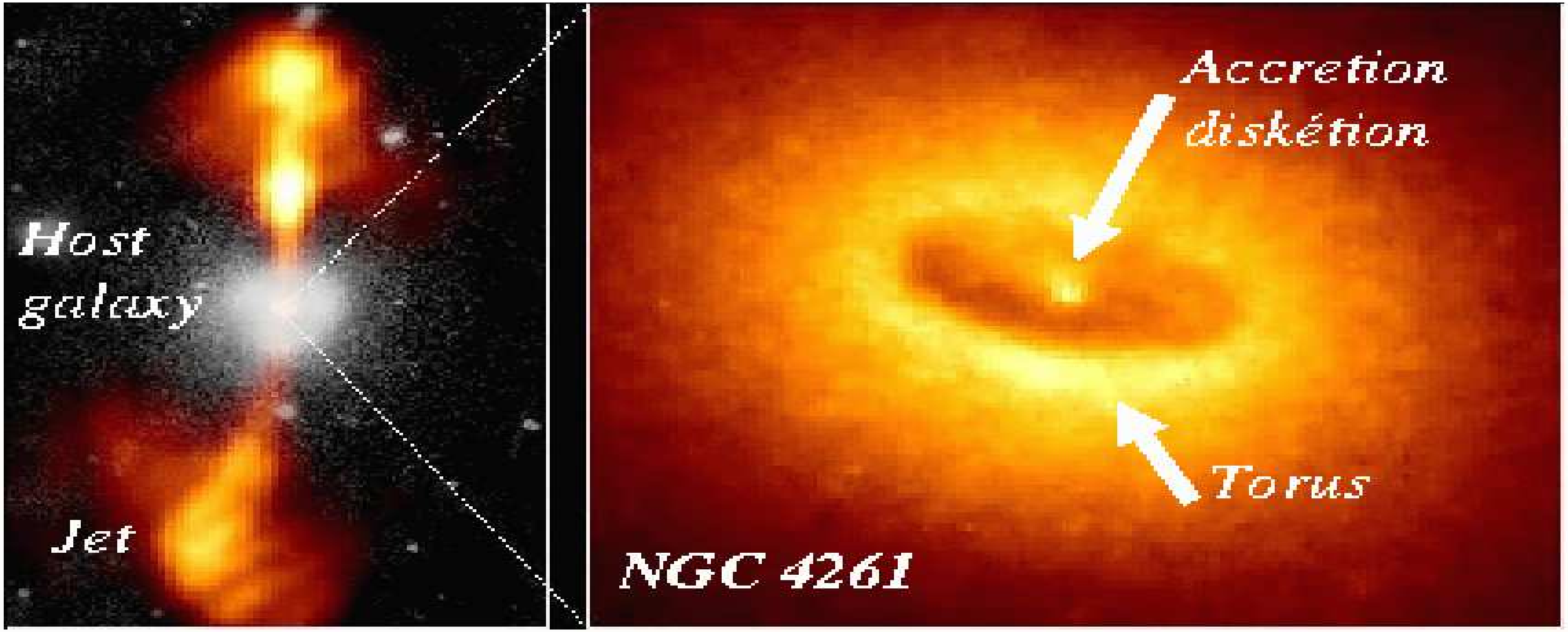
The history of the Universe



A hot and dense universe

A cold and almost empty universe


MATIÈRE
ATOME
NOYAU
PROTON
LEPTONS
Peuvent se déplacer librement.
QUARKS
Prisonniers de particules plus grandes
ils ne sont pas observés individuellement.
FERMIONS
La matière ordinaire est composée de particules de ce groupe.
Première Famille
électron
Responsable de l'électricité et des réactions chimiques. Sa charge est -1.
neutrino électron
Sans charge électrique et interagissant très rarement avec le milieu environnant.
bas (down)
Sa charge électrique est -1/3. Le proton en contient un, le neutron deux.
haut (up)
Sa charge électrique est +2/3. Le proton en contient deux, le neutron un.
Pour la plupart, ces particules étaient présentes juste après le big bang.
Deuxième Famille
muon
Un compagnon plus massif de l'électron.
neutrino muon
Propriétés similaires à celles du neutrino électron.
étrange (strange)
Un compagnon plus lourd du "bas".
charme (charm)
Un compagnon plus lourd du "haut".
Troisième Famille
tau
Encore plus lourd.
neutrino tau
Propriétés similaires à celles du neutrino électron.
beauté (beauty)
Encore plus lourd.
sommet (top)
Le dernier quark observé (en 1994)
BOSONS
Particules fondamentales qui assurent la transmission des forces de la nature.
photon
Grain élémentaire de la lumière porteur de la force électromagnétique.
gluon
Porteur de la force forte entre quarks.
bosons vecteurs
Porteurs de la force faible, responsables de certaines formes de désintégration radioactive.
Graviton
Pas encore observé. Supposé véhiculer la force de gravité.
ANTIMATIÈRE
A chaque particule-fermion correspond une antiparticule, espèce d'image miroir.



The Universe is the place of violent phenomena which are sources of high energy particles.

Cosmic accelerators

CERN vs Universe

Particle accelerators :

- Pro: experiments can be prepared and repeated
- Con : energy range is limited by technology and funds

The Universe :

- Pro : energy available is enormous
  (temperature increases as one goes back to the big bang)
- Con : experiment was only made once and we were not
  present (well…)

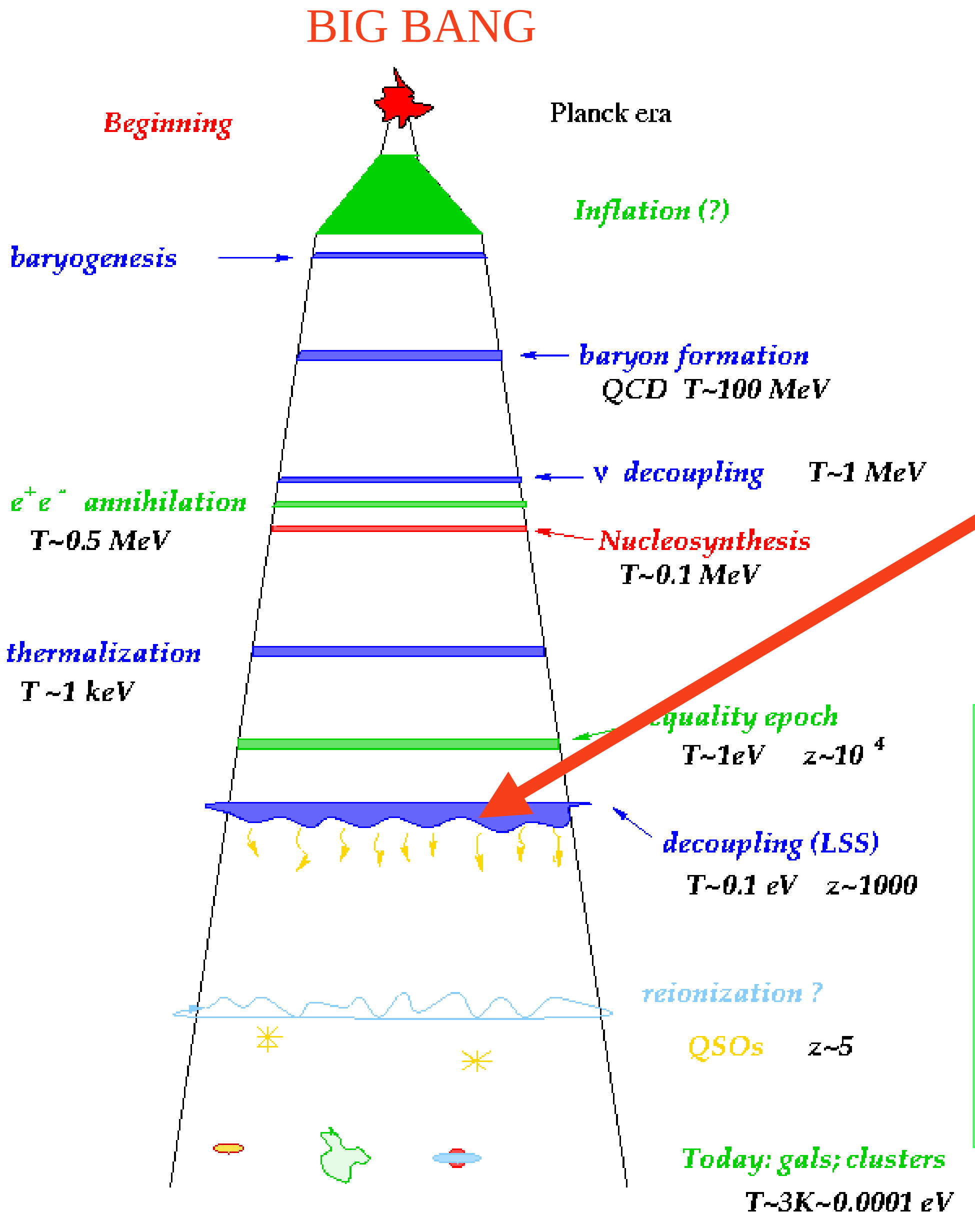
How to study the history of the Universe?

By searching for the fingerprints of past eras in the evolution of the Universe

cosmological microwave background

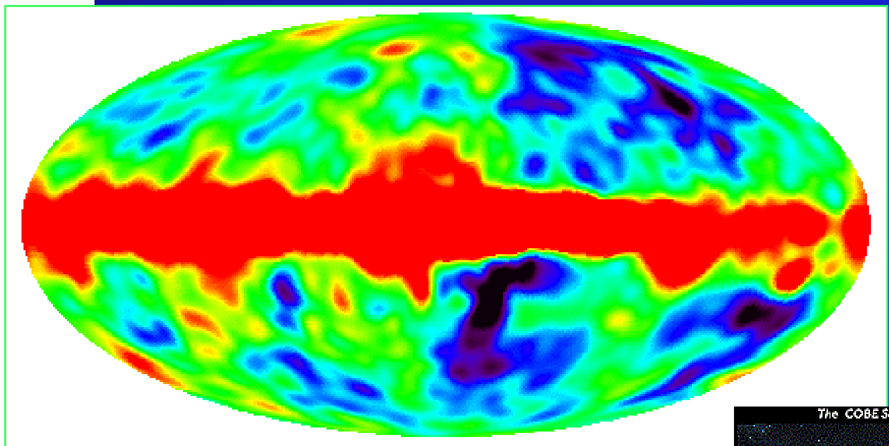
By identifying and understanding the present content of the Universe at large scale

geometry, topology, energetic budget

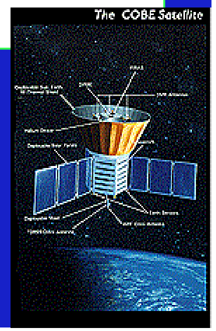


At t = 400 000 yrs, the Universe becomes transparent: photons no longer interact with matter

Cosmological background
T = 3 K = - 270 °C



COBE satellite



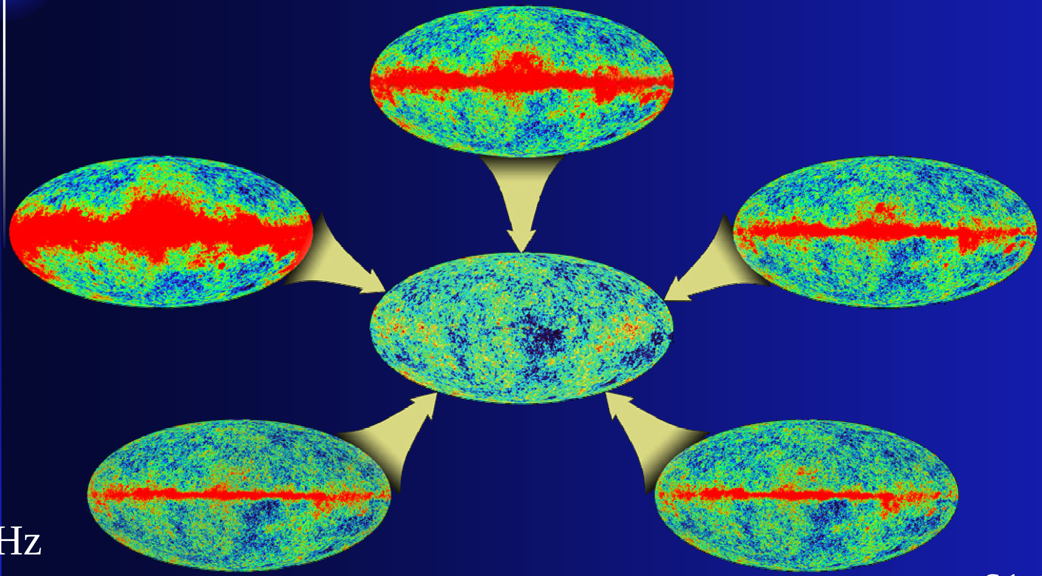
WMAP satellite

2002

33 GHz

23 GHz

41 GHz



94 GHz

61 GHz

$\Omega_{tot} = 1.02^{+0.02}_{-0.02}$

$w < -0.78$ (95% CL)

$\Omega_\Lambda = 0.73^{+0.04}_{-0.04}$

$\Omega_b h^2 = 0.0224^{+0.0009}_{-0.0009}$

$\Omega_b = 0.044^{+0.004}_{-0.004}$

$n_b = 2.5 \text{ x } 10^{-7}{}^{+0.1\text{x}10^{-7}}_{-0.1\text{x}10^{-7}}$ cm^{-3}

$\Omega_m h^2 = 0.135^{+0.008}_{-0.009}$

$\Omega_m = 0.27^{+0.04}_{-0.04}$

$\Omega_\nu h^2 < 0.0076$ (95%CL)

$m_\nu < 0.23$ eV (95% CL)

$T_{cmb} = 2.725^{+0.002}_{-0.002}$ K

$n_\gamma = 410.4^{+0.9}_{-0.9}$ cm^{-3}

$\eta = 6.1 \text{ x } 10^{-10}{}^{+0.3\text{x}10^{-10}}_{-0.2\text{x}10^{-10}}$

$\Omega_b \Omega_m^{-1} = 0.17^{+0.01}_{-0.01}$

$\sigma_8 = 0.84^{+0.04}_{-0.04}$ Mpc

$\sigma_8 \Omega_m^{0.5} = 0.44^{+0.04}_{-0.05}$

$A = 0.833^{+0.086}_{-0.083}$

$n_s = 0.93^{+0.03}_{-0.03}$

$dn_s/d \ln k = -0.031^{+0.016}_{-0.018}$

$r < 0.71$ (95% CL)

$z_{dec} = 1089^{+1}_{-1}$

$\Delta z_{dec} = 195^{+2}_{-2}$

$h = 0.71^{+0.04}_{-0.03}$

$t_0 = 13.7^{+0.2}_{-0.2}$ Gyr

$t_{dec} = 379^{+8}_{-7}$ kyr

$t_r = 180^{+220}_{-80}$ Myr (95% CL)

$\Delta t_{dec} = 118^{+3}_{-2}$ kyr

$z_{eq} = 3233^{+194}_{-210}$

$\tau = 0.17^{+0.04}_{-0.04}$

$z_r = 20^{+10}_{-9}$ (95% CL)

$\theta_A = 0^\circ.598^{+0.002}_{-0.002}$

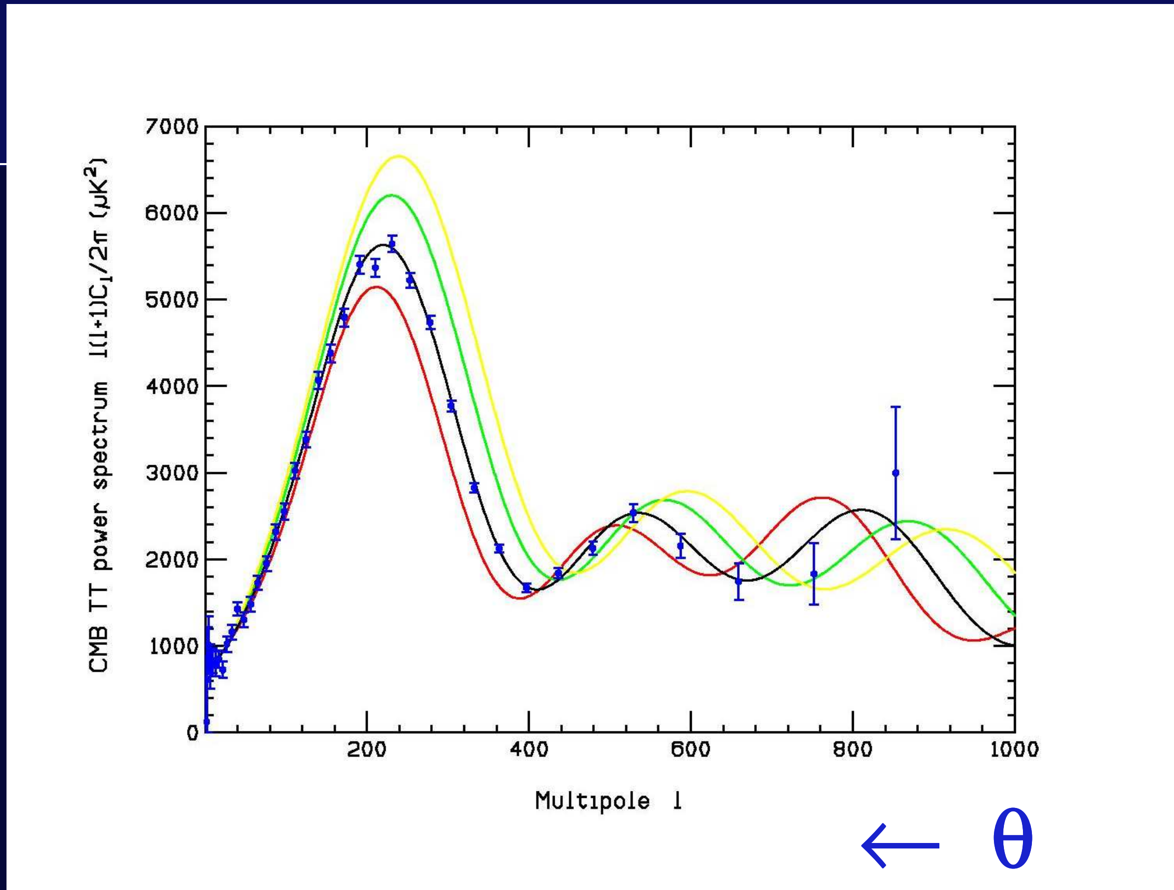
$d_A = 14.0^{+0.2}_{-0.3}$ Gpc

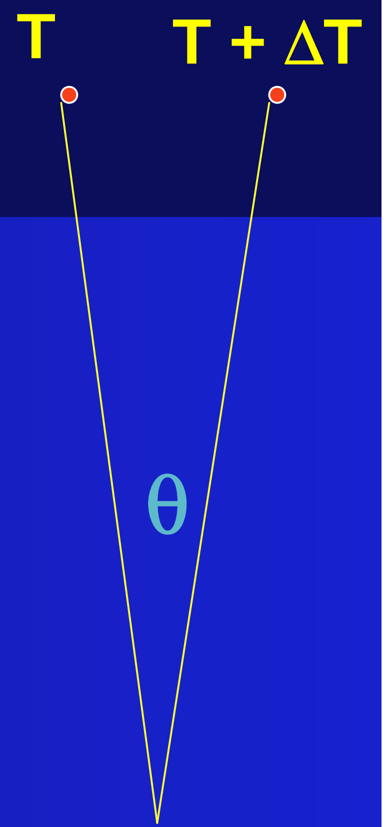
$l_A = 301^{+1}_{-1}$

$r_s = 147^{+2}_{-2}$ Mpc

Spectrum of temperature anisotropies

ΔT ↑



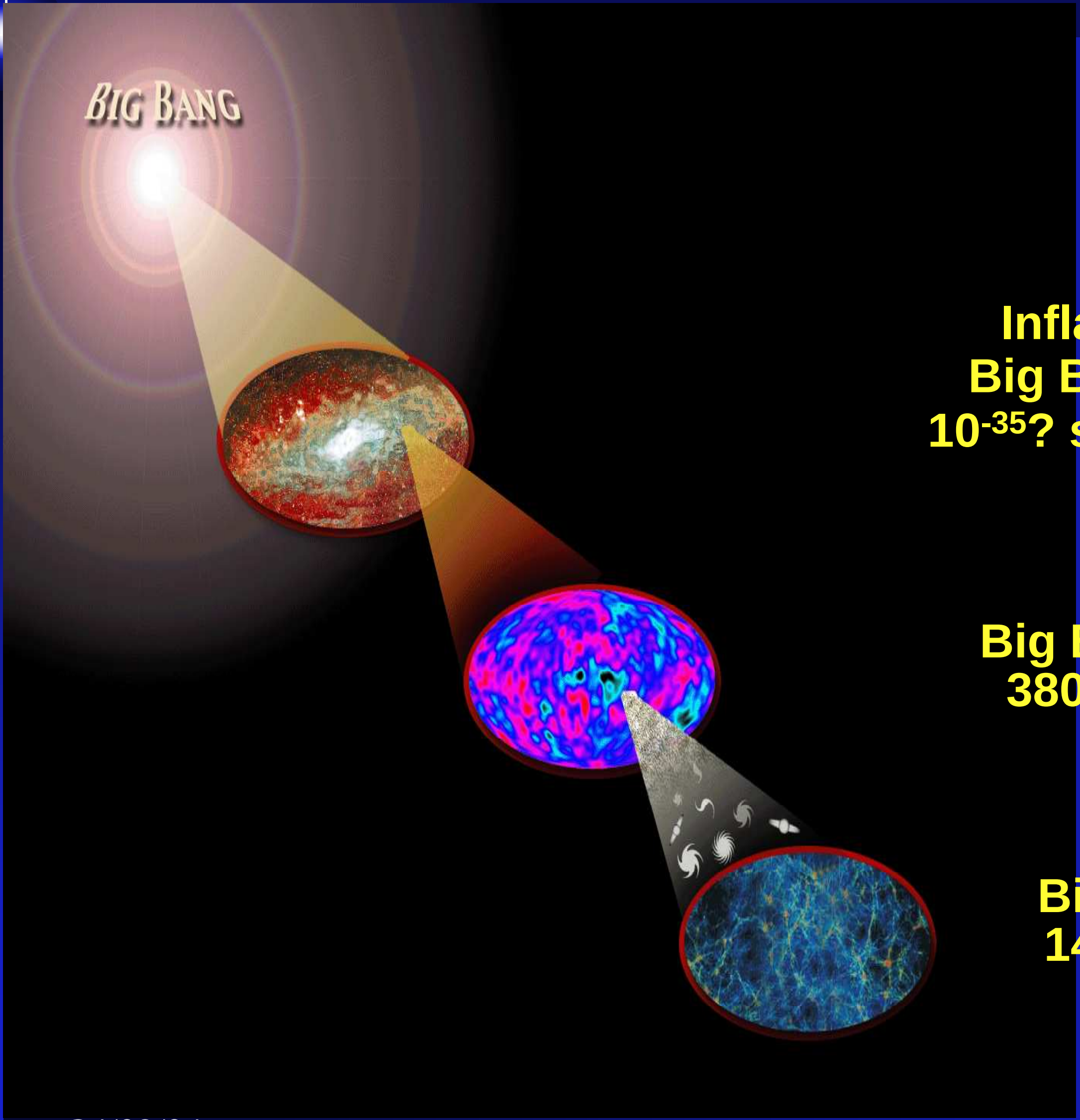


The position of the first peak gives indications on the total energy density in the Universe and on its geometry : it is spatially flat.

Energy density $\rho \bullet \rho_c = 10^{-29}$ g/cm^3

$\Omega = \rho/\rho_c \bullet\ 1$

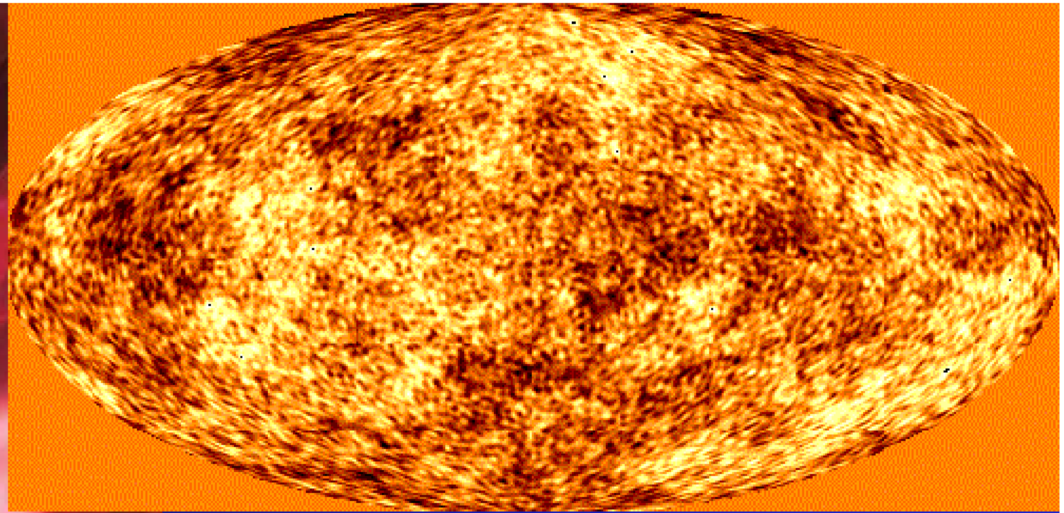
Why should the Universe be spatially flat? Inflation scenario



Inflation
Big Bang plus
10^{-35}? secondes

Big Bang plus
380,000 ans

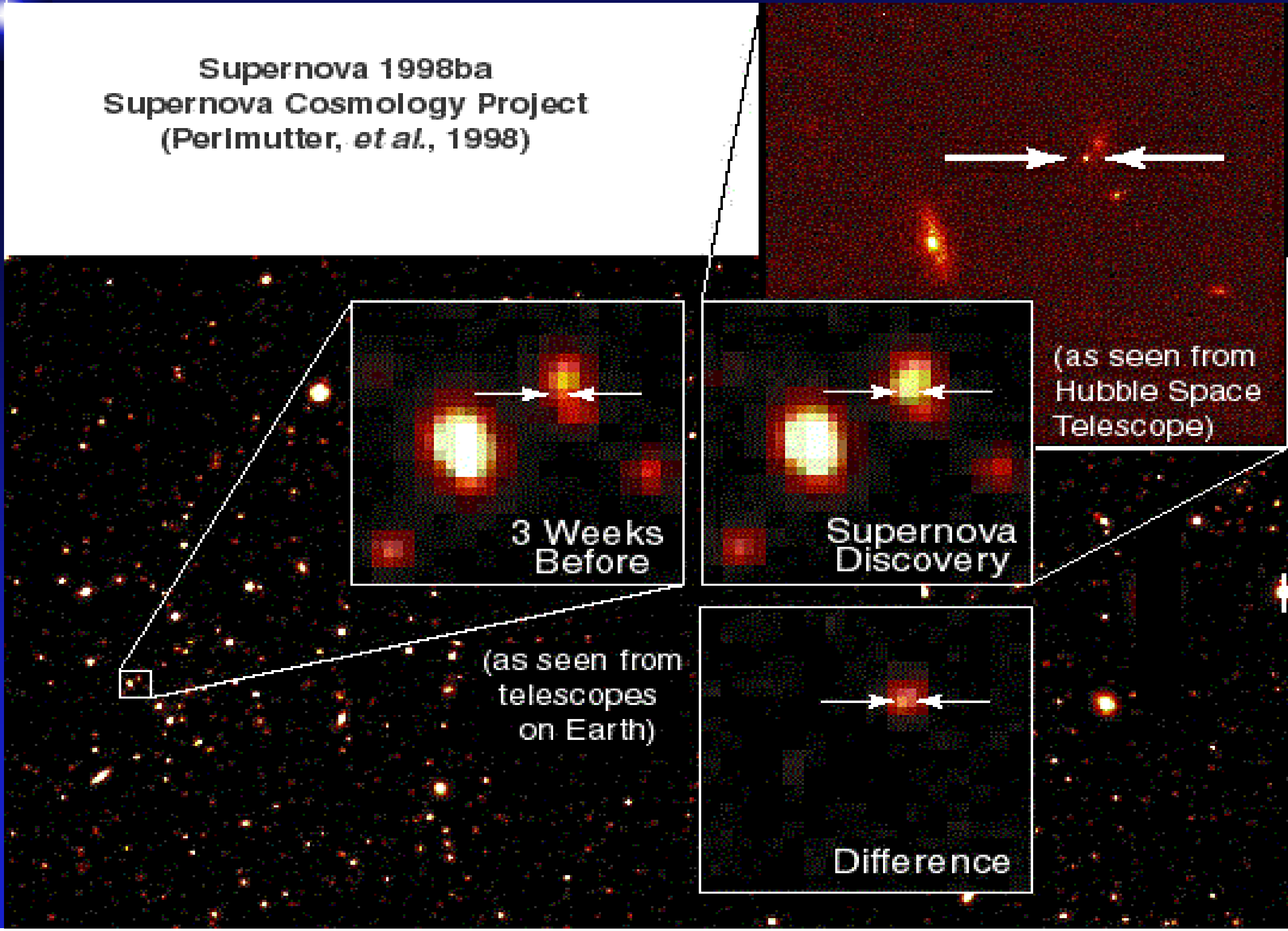
Big Bang plus
14 Billion ans



Planck satellite will be launched in 2007

50th anniversary

The study of supernovae explosions has helped us to identify a new component of the Universe

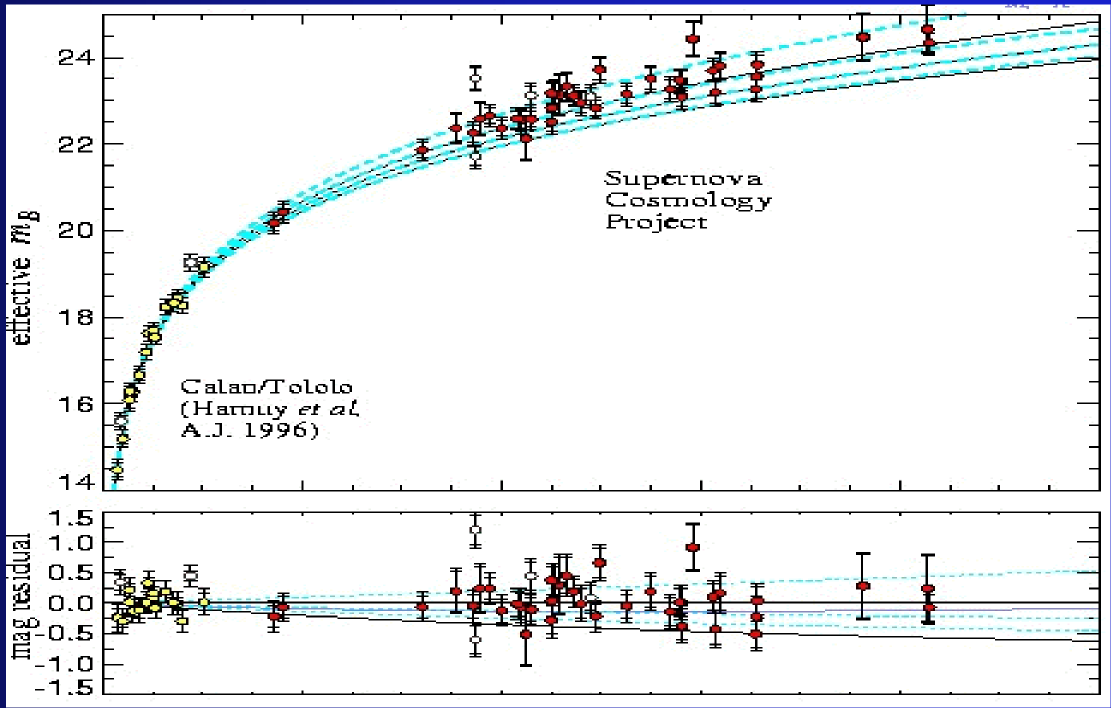


QuickTime™ et un
décompresseur codec YUV420
sont requis pour visionner cette image.

Supernovae of type Ia are used as standard candles to test the geometry of spacetime

Distant supernovae appear less bright than in an expanding universe

➔ accelerated expansion



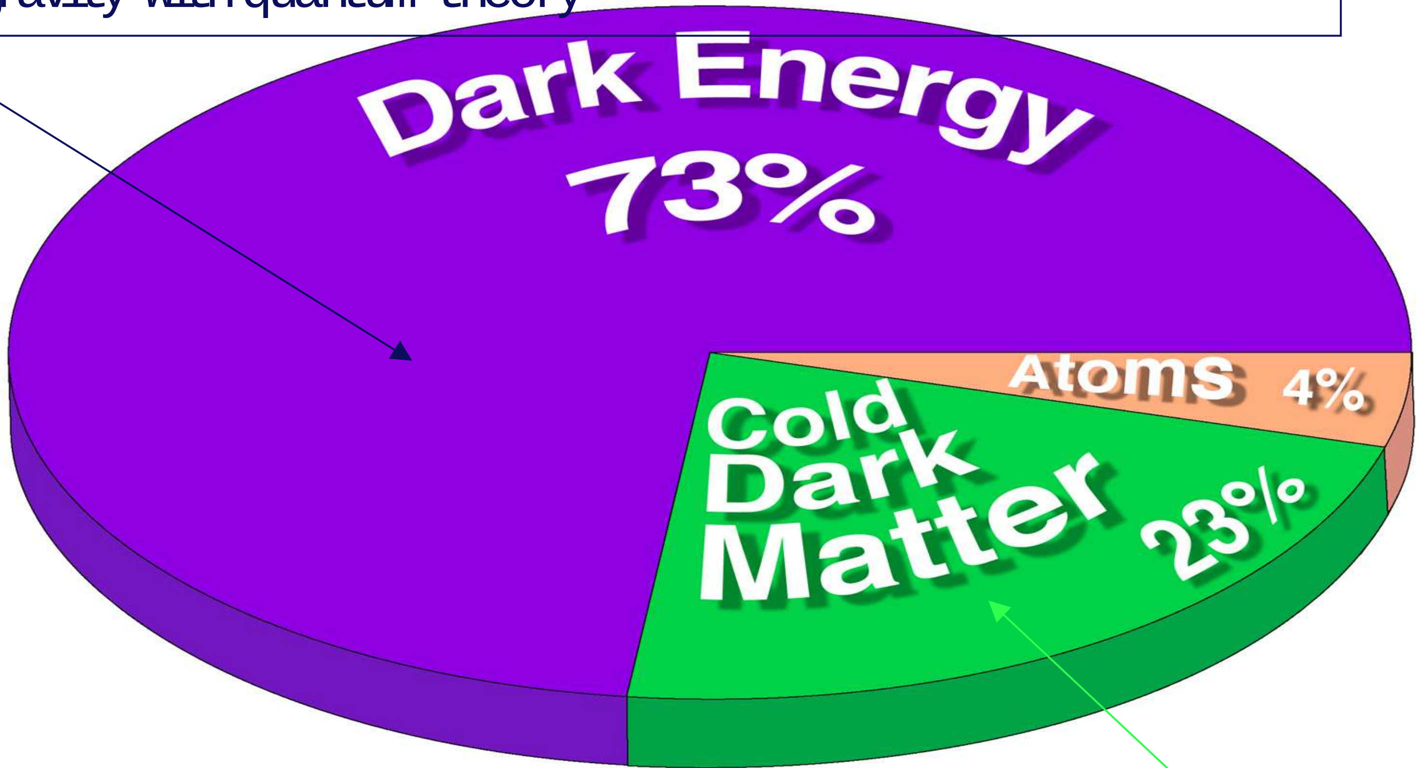
Matter tends to decelerate the expansion

→ a new form of energy is responsible of this acceleration

DARK ENERGY

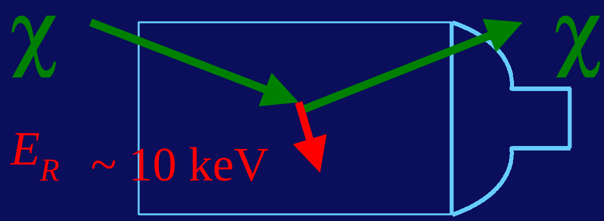
The energetic budget of the Universe

Connected with a fundamental problem of high energy theory to reconcile gravity with quantum theory

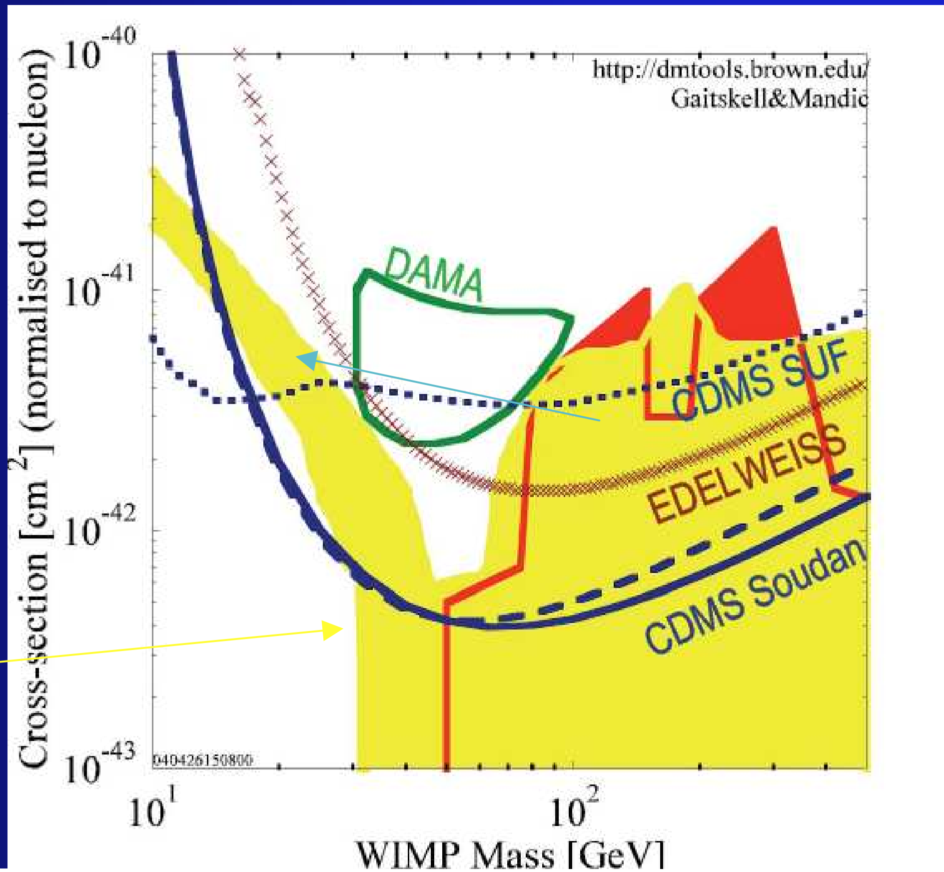


Complementary to experimental searches in particle accelerators

Dark matter : direct detection



Go to underground sites (mines, tunnels…)



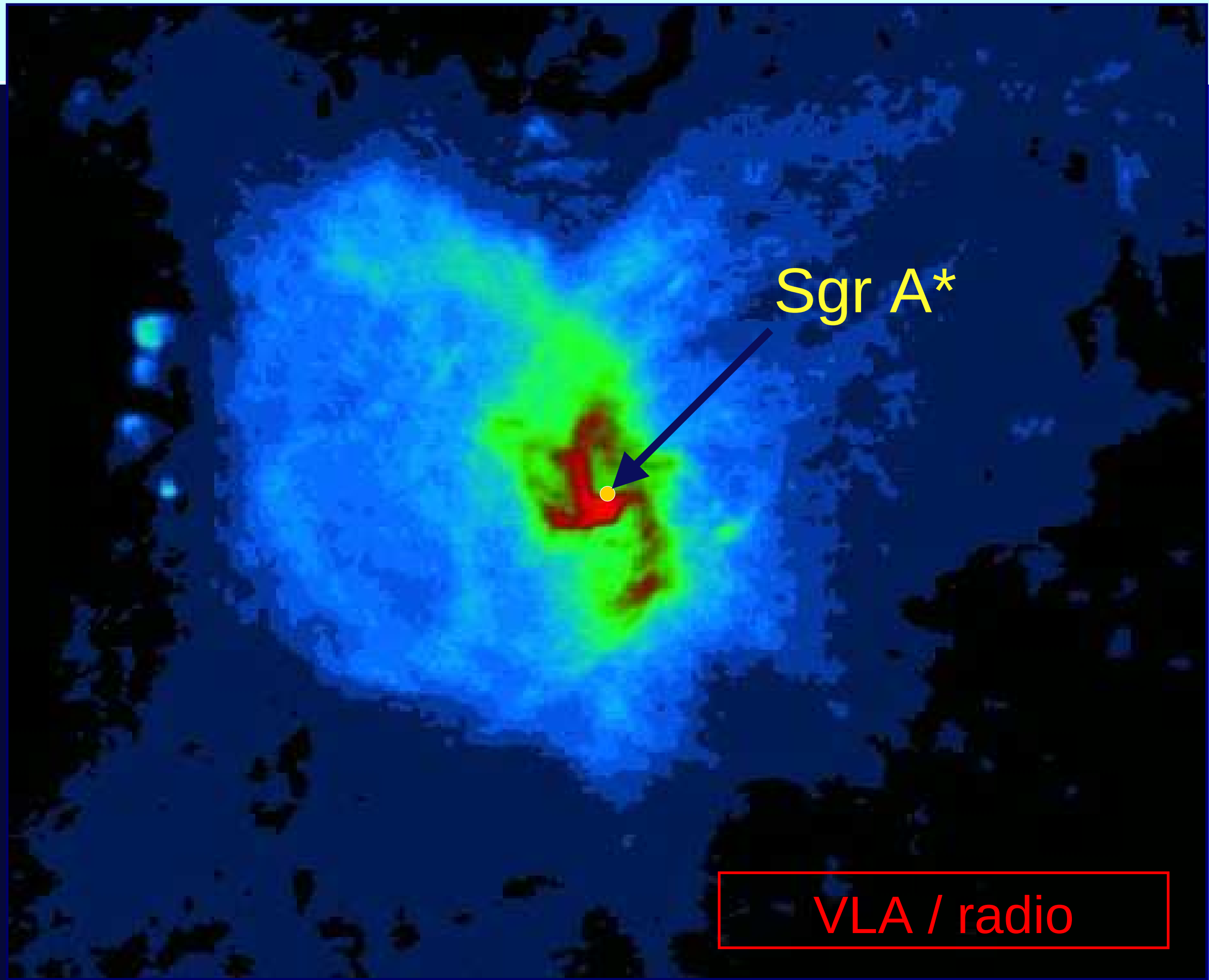
favored by particle theories (supersymmetry)

The main questions of this field

Was there a big bang?
If there was inflation, what was its dynamics?
What is the origin of the matter-antimatter asymmetry?
What were the first luminous objects, and when did they appear?
How to detect and identify dark matter?
What is the geometry and content of the Universe at large scale?
How to check or disprove the recent acceleration of the expansion?
Is there a dark energy? Why is the vacuum energy so small?
What are the limits of validity of general relativity ?

Black holes, sources of high energy particles

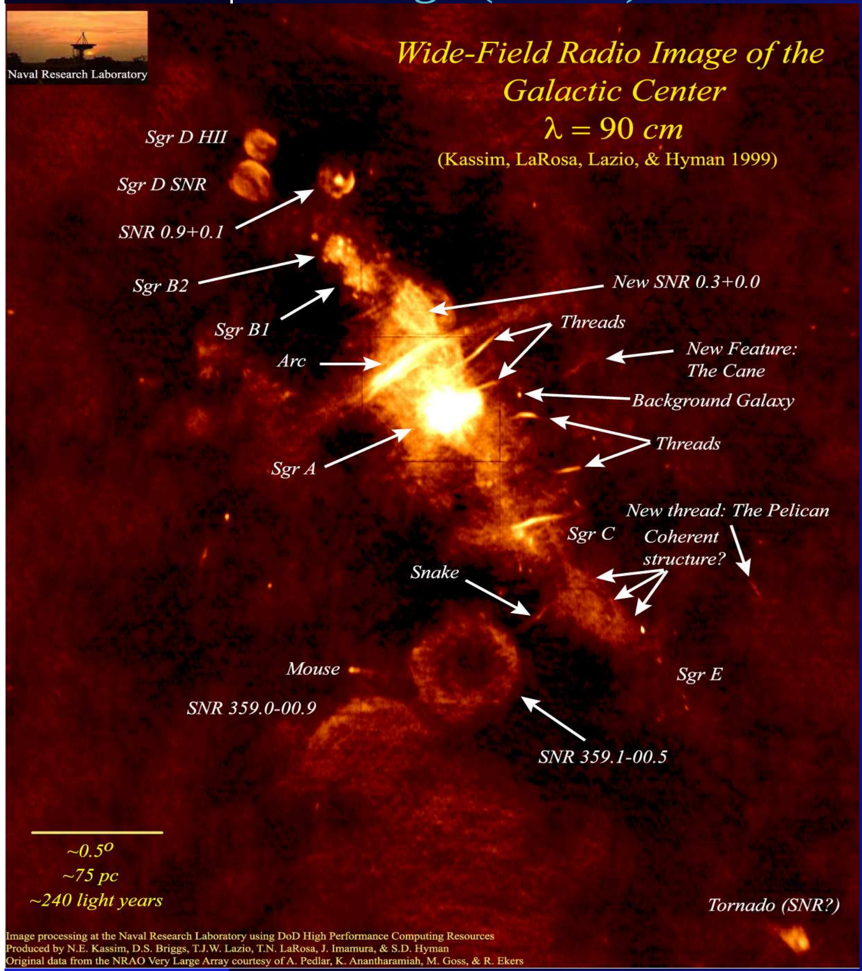
A black hole in your neighbourhood ?



In the vicinity of the galactic centre…

A closer look at the galactic center

Radio image (90 cm)



Infrared (1.6 µm <λ <3.5µm)
NAOS/CONICA

QuickTime™ et un
décompresseur GIF
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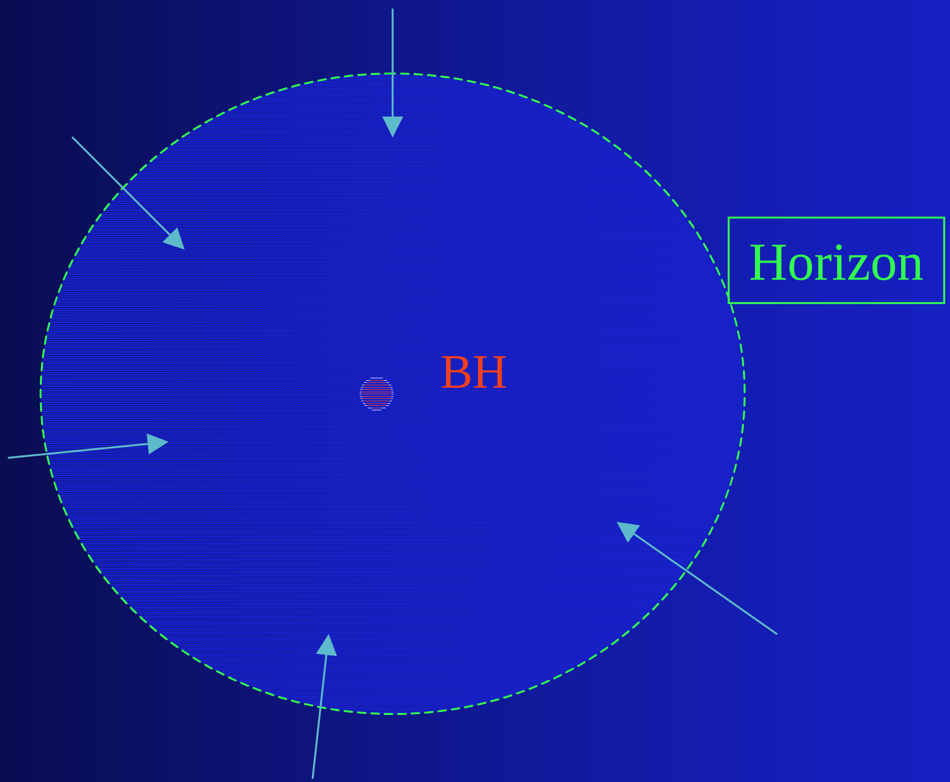
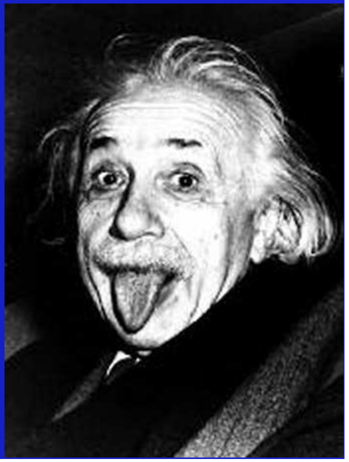
Black hole of mass of the order of 3 million solar mass

Black holes are singularities of spacetime predicted by the theory of general relativity :





In fact, a black hole is surrounded by a region of intense activity

QuickTime™ et un
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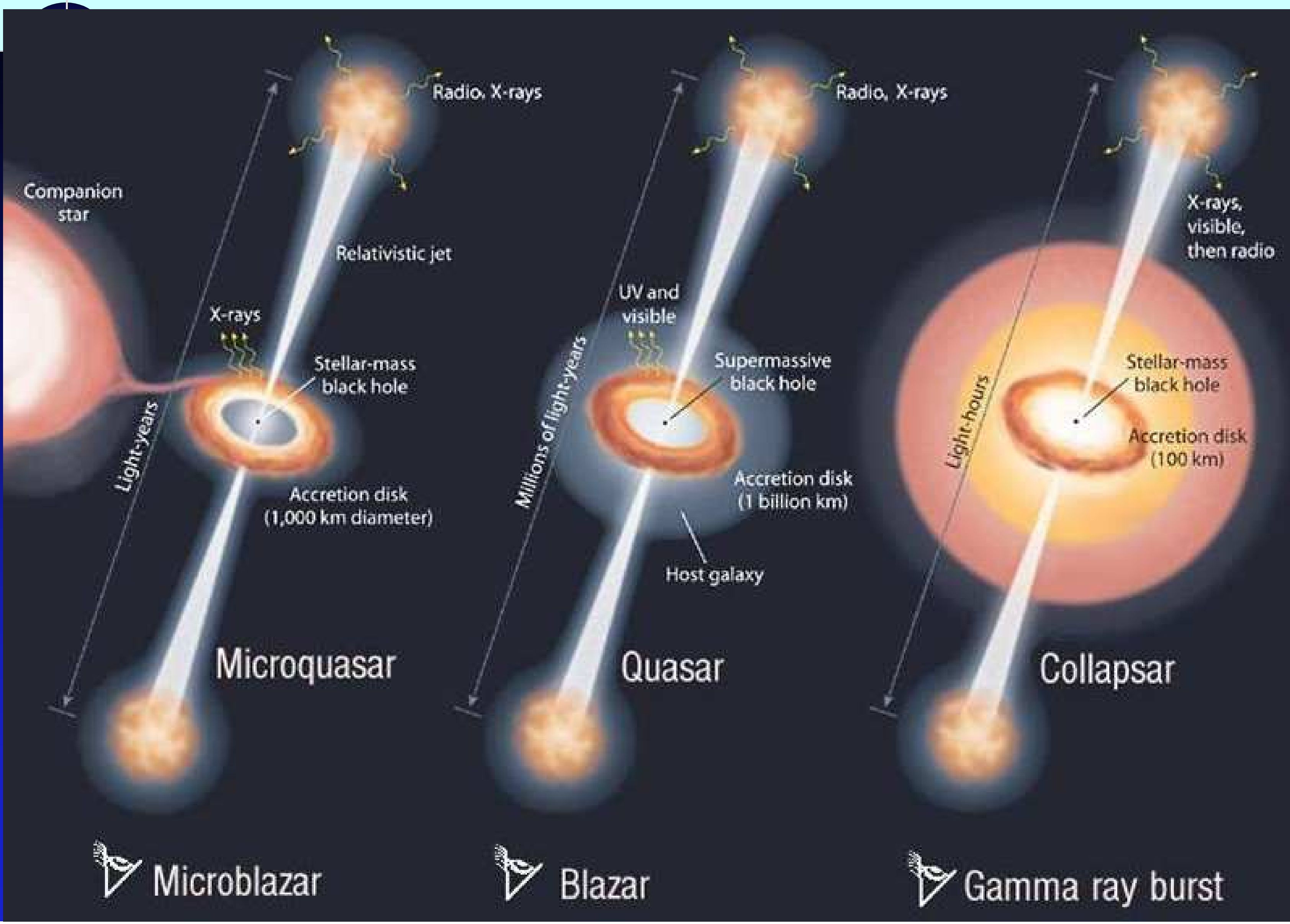
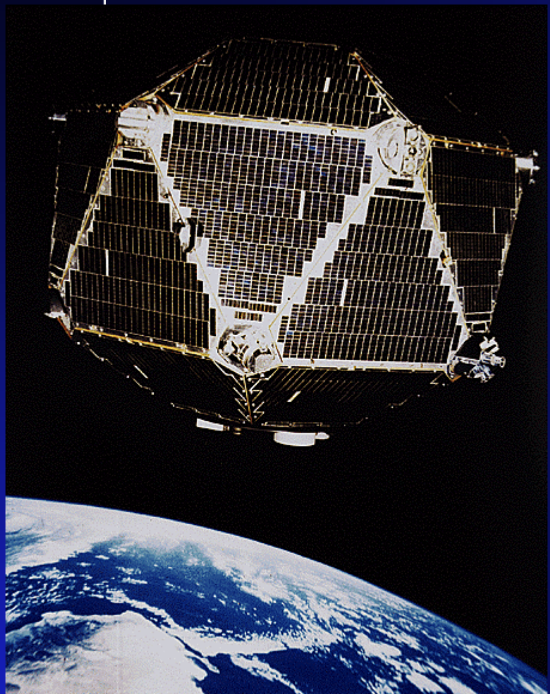
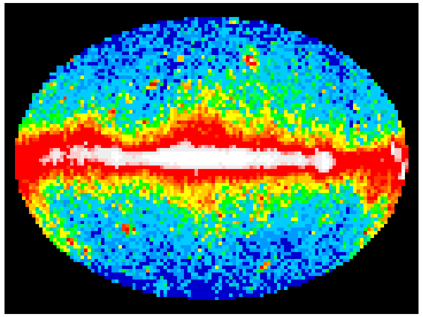
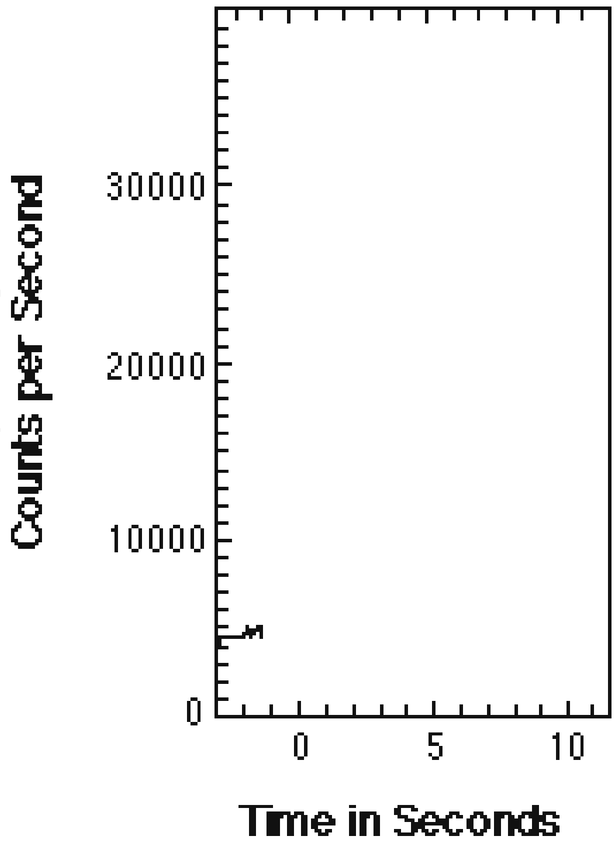
Black holes (and neutron stars) are the building blocks of the violent universe



The example of the gamma ray bursts : the most luminous events known → the most distant probes!

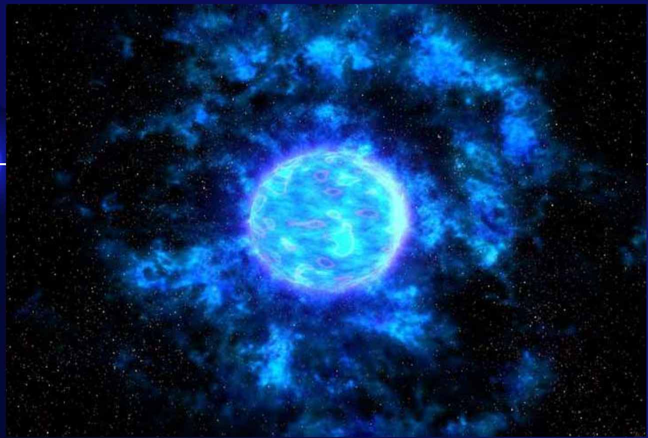




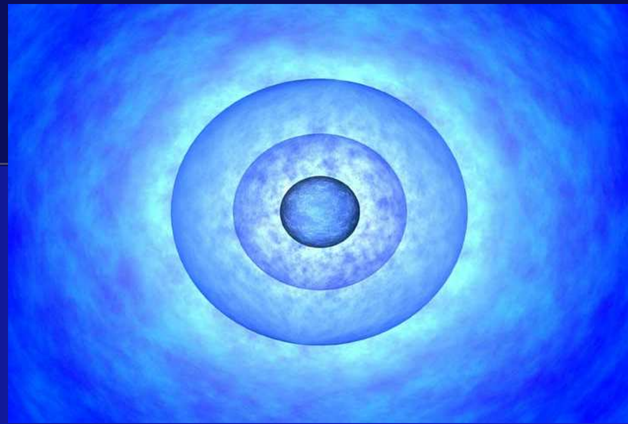


Vela US military satellite
Probing the gamma emission
due to soviet nuclear explosions

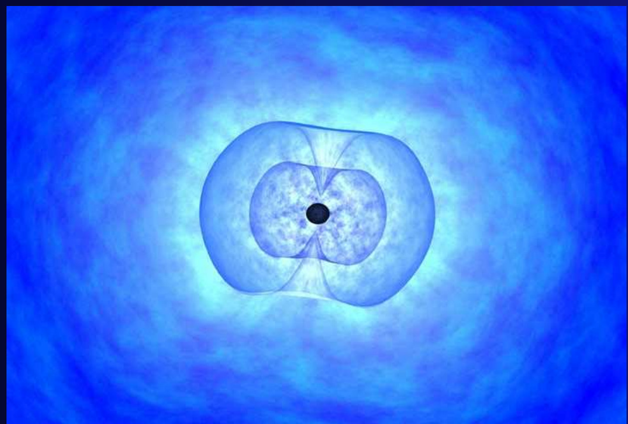
A model for gamma ray bursts : the fireball.



A very massive star ends its existence with an explosion



Its inner core undergoes a collapse into a black hole



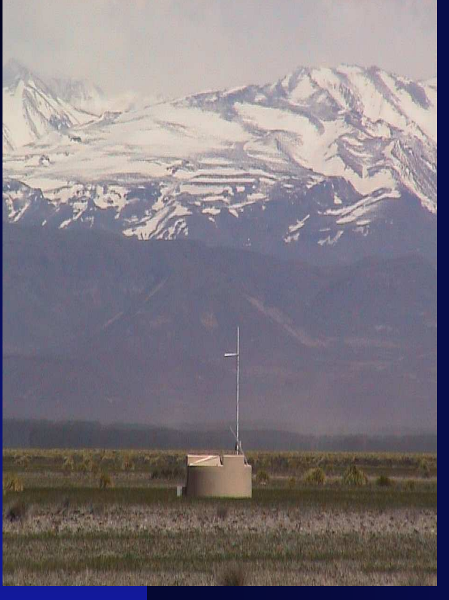
The collapse is non-uniform. There is creation of a jet of particles

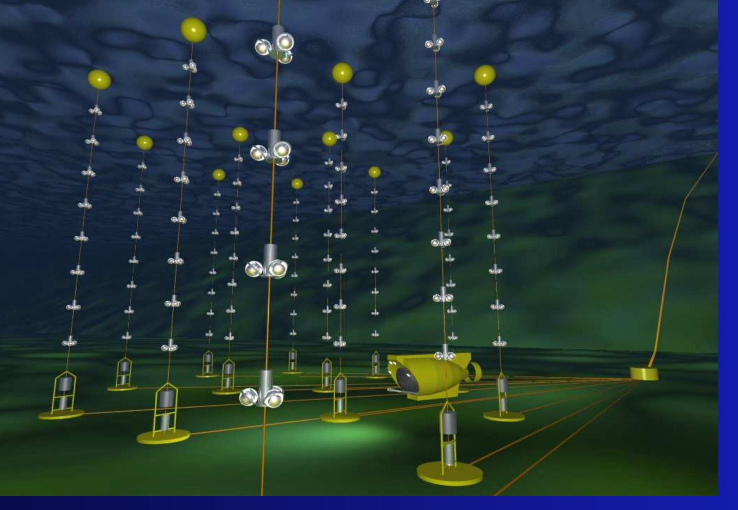
This jet interacts with outer layers; this accelerates its particles.

The main questions of the field

How do cosmic accelerators function?
What can we learn from the study of energetic sources on the laws of physics?
How are black holes formed?
Are there new states of matter at extreme energies or densities?
How do supernovae explode?
How are formed heavy elements?

How to detect high energy cosmic particles ?

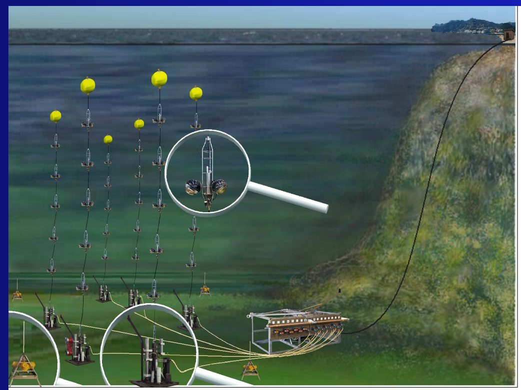




A new frontier

Three fields at the heart of particle astrophysics represent a new window open on the sky:

- Ultra-high energy cosmic rays



- High energy neutrinos

Nobel Prize 2002 to
R. Davis and M. Koshiba

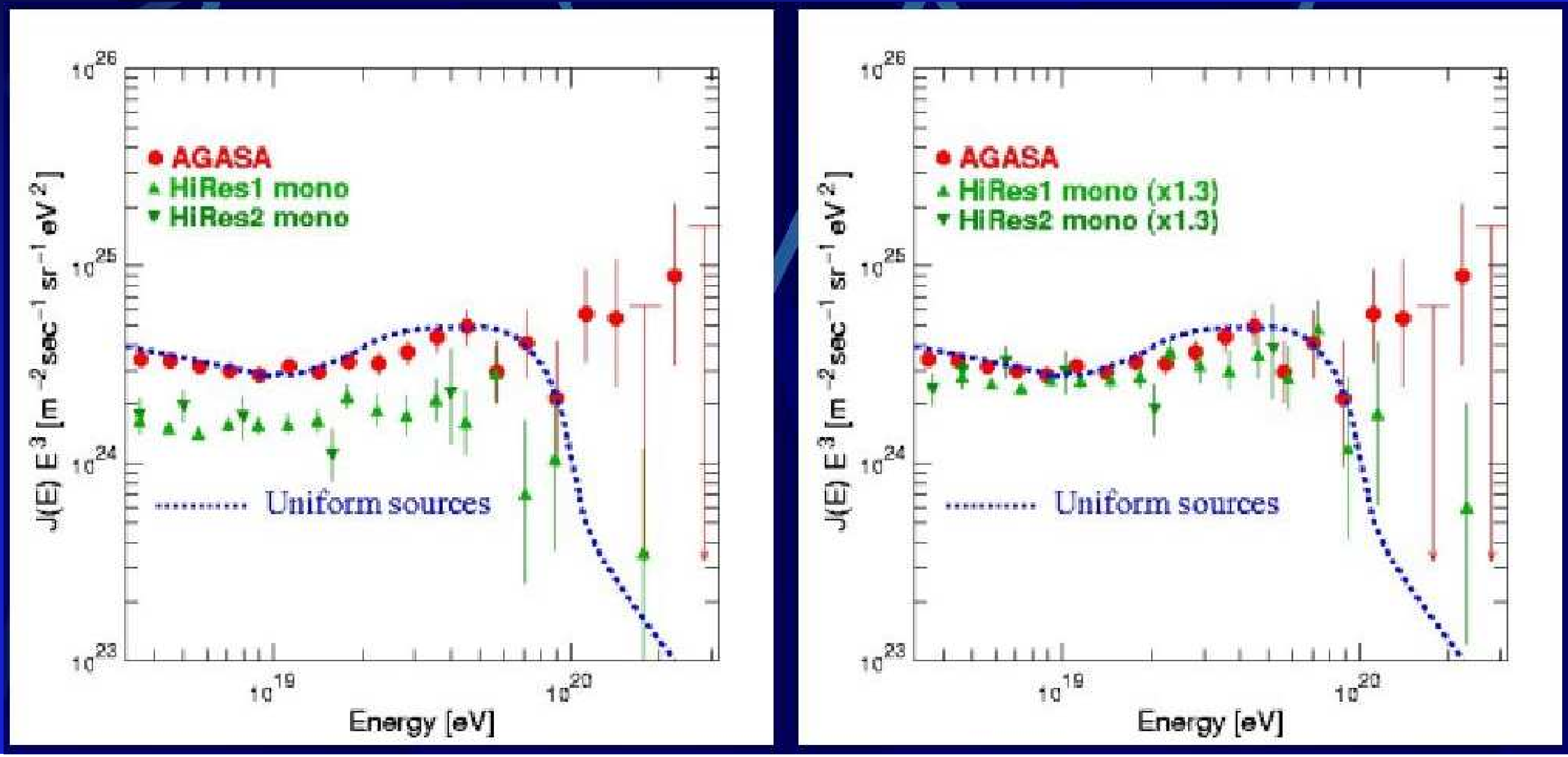
- Gravitational waves

The Enigma of Extreme Energy Cosmic Rays

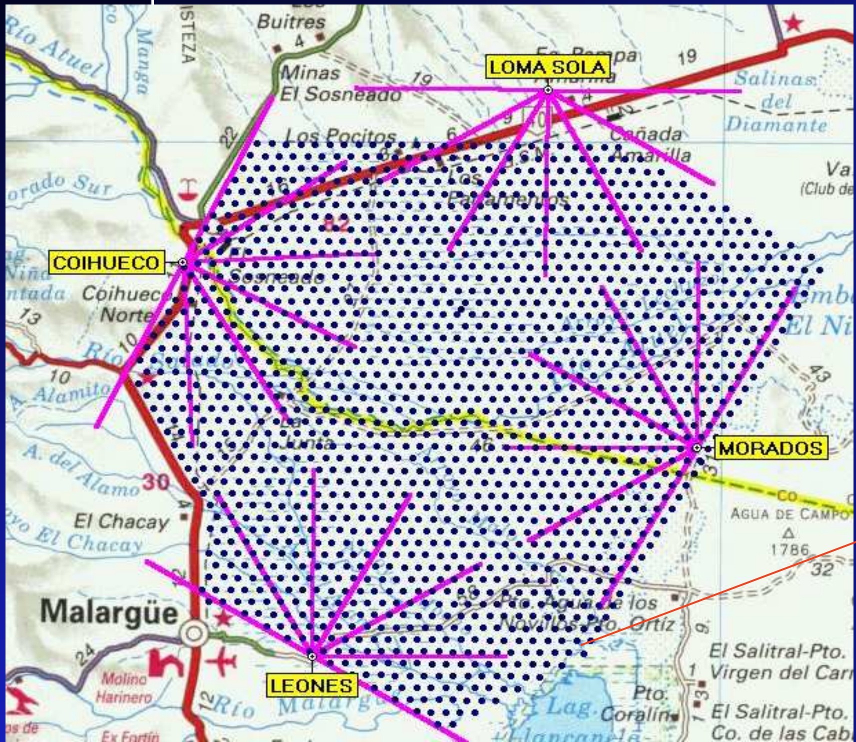
The GZK effect

The cosmic microwave background (3°K) limits the distance at which can be found sources of ultra high energy cosmic rays visible from the earth :

- 50 Mpc, for protons of energy > 5 10^{19}eV

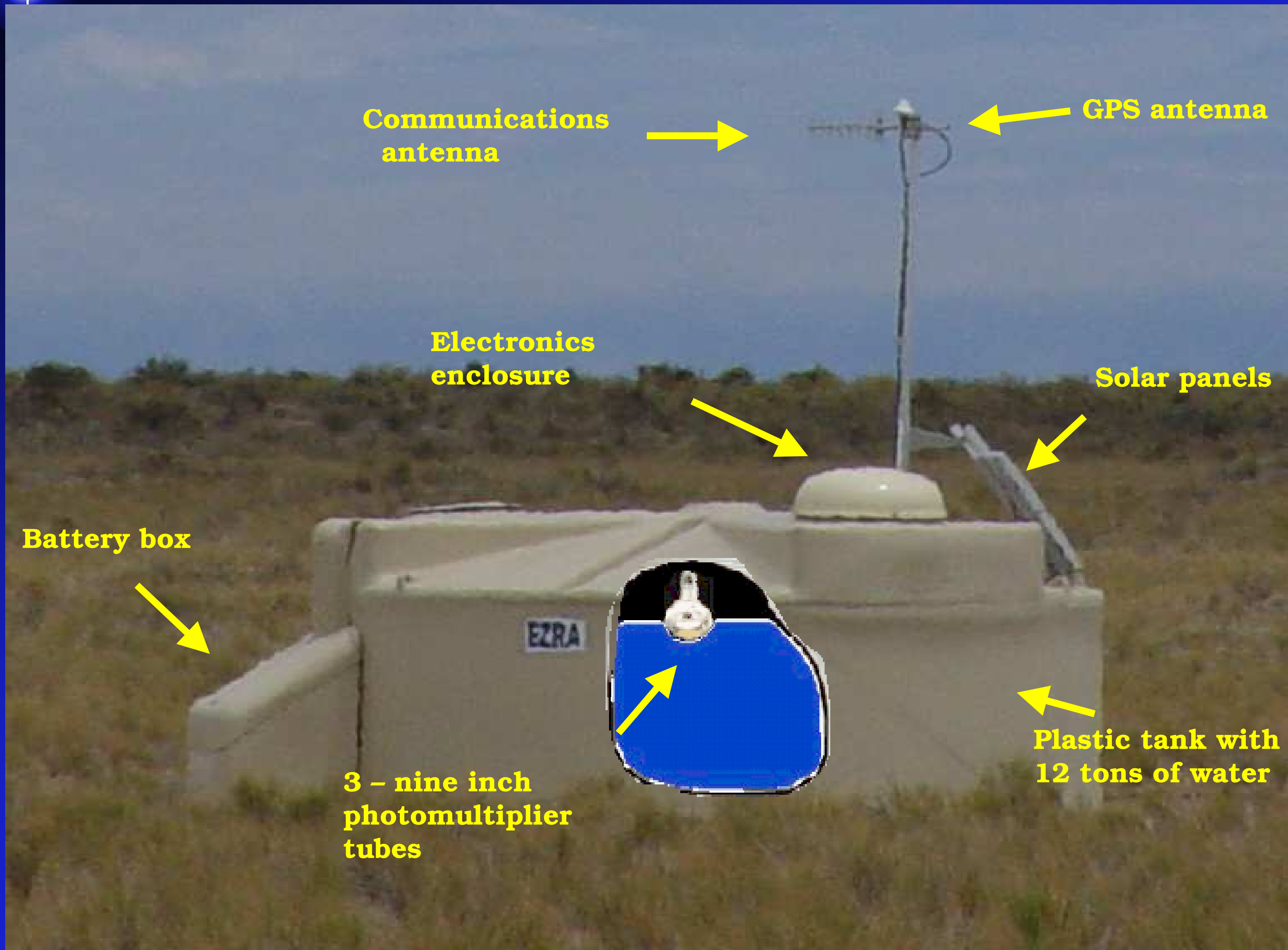


The Pierre Auger observatory
(Argentina)

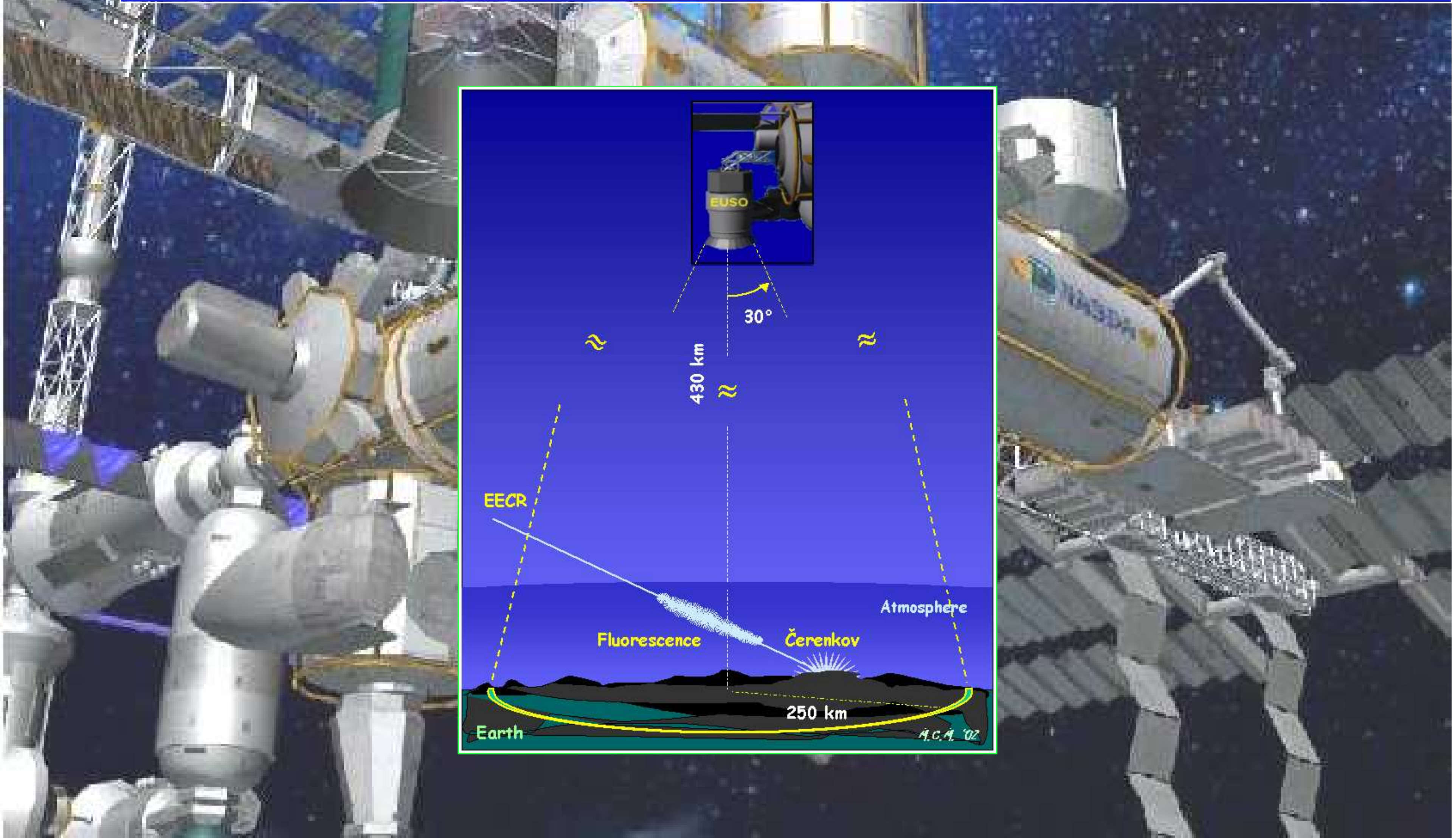


Array of 1600 detectors which cover an area of 3000km^2

A tank of Auger



Euso : detecting cosmic rays by looking from above…



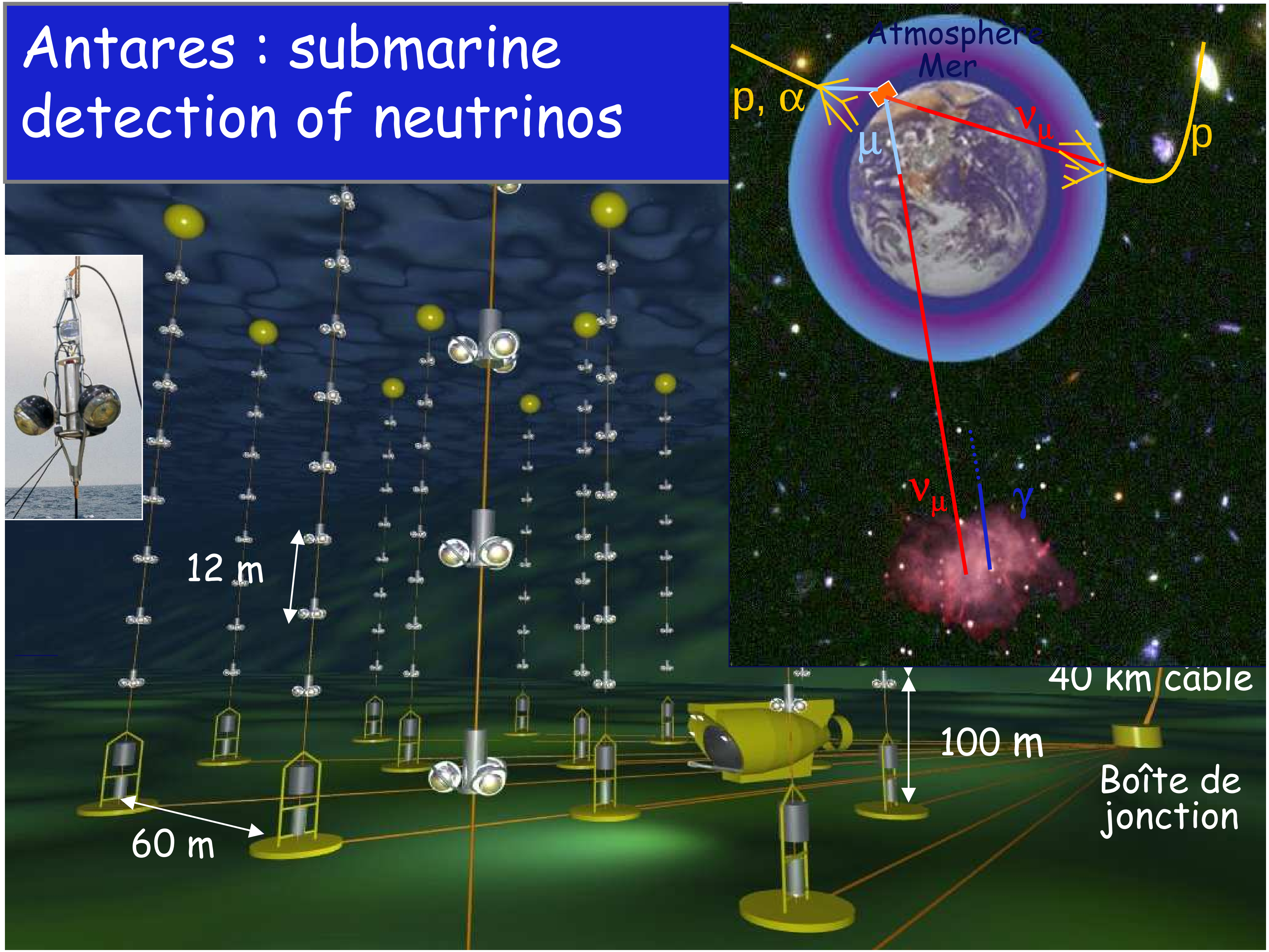
Neutrino: very light particle , interacting very weakly with matter, produced in nuclear reactions which take place in stars (sun) and astrophysical sources

Detector SuperKamioka in Japan;

10 000 tons of water to study neutrinos from the sun or the atmosphere.

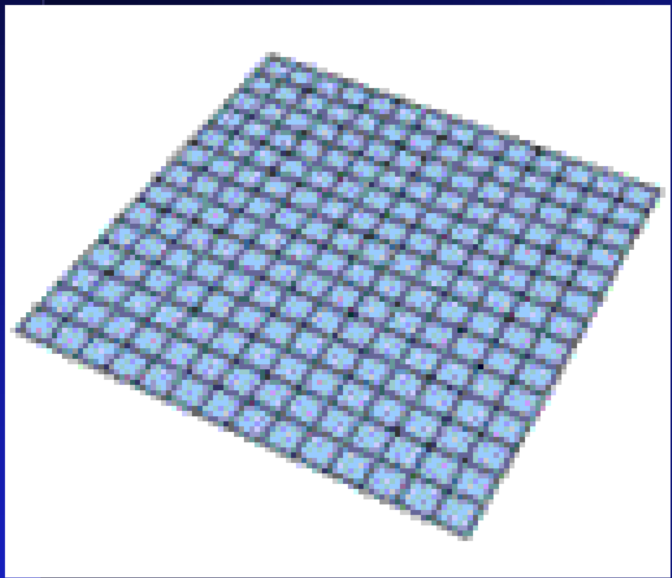
Rich neutrino program at CERN

Antares : submarine detection of neutrinos



Gravitational waves

Space-time (4D) is « elastic »,
any mass ou localized energy disturbs it and curves it…
as does the wind on the surface of water…



… waves can also propagate …

LISA
launched in 2012
ESA/NASA mission

Three satellites forming a triangle of 5 millions km side length

Conclusions

A new field at the interface between high energy physics and astrophysics.

Cosmology and particle astrophysics provide ways to address fundamental questions which are very complementary to particle physics.

New windows open on the Universe : neutrinos, gravitational waves, ultra-high energy cosmic rays.
Might change our understanding of some of the crucial issues.

Particle accelerators such as CERN remain the places where one can make the experiments that will provide confirmation in a decisive way.

CERN

Particle astrophysics and Cosmology

ESA

ESO