INTRODUCTION TO COSMOLOGY

(1) From Hubble to Planck : 1929 - 2014





26/04/2014

Aristarque of Samos –310, -230 heliocentrism Copernic 1473, 1543 heliocentrism The Earth is NOT the center of the Universe

Rømer1676finite speed of lightNewton1687gravitation lawNo distance of stars, no galaxiesUniverse is eternal and infinite

Bessel	1838	distance of stars by parallax
Einstein	1905	special relativity general relativity (relativistic gravitation) deviation of light by gravitation
Eddington	1919	
Hubble	1924	galaxy Andromeda measure of distance by Cepheids stars



1 parsec (1" arc) = 3×10^{13} km = 3.262 light years

Hipparcos satellite (1990) up to 100 pc

Cepheids 2 Mpc

General Relativity is based on principle of equivalence



astronaut in freefall

astronaut in inertial frame

frame falling freely in a gravitational field "looks like" inertial frame



astronaut under gravity

astronaut in accelerating frame

gravity looks like acceleration (gravity appears to be a "kinematic force")

non Euclidian geometries

XIX^e century : surfaces (Gauss), parallels postulate (Bolyai, Lobatchevski), manifold differentiation (Riemann), tensor calculus (Christoffel, Ricci)



local curvature of space caused by gravity

Universe can be - finite if positive curvature - infinite if negative or zero curvature





spectroscopy lines : measure of radial speed by Doppler effect,



different interpretation in General Relativity (expansion of Universe)



A new paradigm : Universe is NOT eternal, Universe is AGING

Postulate of Standard Model of cosmology : homogeneity and isotropy



universality of Hubble "constant", in space, not in time

expansion is homolog, nobody is at the center of the Universe



galaxies are motionless in comoving coordinates, except random individual motion

there is a universal scale factor R(t)

A new method to measure very long distances : supernovae la



These explosive stars - have the same characteristics (luminosity, period) everywhere - are very bright, can be seen from very far

Periods of supernovae Ia (Supernovae Cosmology Project 2001)

dilatation of time : an independent proof of the expansion of the Universe !



z/D is not constant in time

Le Nobel de physique pour 3 spécialistes des supernovae

Les supernovae

Étoiles très massives en fin de vie qui s'effondrent brutalement sur elles-mêmes et explosent en libérant d'énormes flashes de lumière.





constituerait plus

de 70% de l'Univers.

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Saul Perlmutter

Prize Nobel 2011

Nobel prize 2006 John Mather & George Smoot

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Photo: Belinda Pratten, Australian

Brian P. Schmidt

National University

Adam G. Riess

Cosmological constant introduced by Einstein in General Relativity so that Universe is static

 \Rightarrow modification of gravitation law

Can be interpreted as a repulsive force proportional to distance

$$F = -\frac{1}{3}\Lambda mr$$

 \Rightarrow accelerating expansion equilibrates the self gravity of matter in the Universe

BUT Hubble discovers expansion: Universe is NOT static

The biggest mistake in my life (Einstein)

BUT now there is an accelerating expansion $\Rightarrow \Lambda$ comes back

constant "vacuum density" = "negative pressure"

$$\rho_v = -p_v = \frac{\Lambda}{8\pi G}$$

What is the cause of the expansion ? static state is impossible, due to gravity of matter (could cause only contraction)





Measure of mass in our galaxy Milky Way Oort 1932

Rubin 1970 : idem for other galaxies







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Zwicky, idem for galaxy clusters



DARK MATTER





Measure of masses for very distant objects by light gravitational deviation \Rightarrow dark matter

Gravitational mirages





3D map of dark matter by HST (Hubble Space Telescope)



red shifts measured by terrestrial telescopes

HOT BIG BANG

When the Universe was much smaller

First theory by George Gamow, Ralph Alpher, Robert Herman, around 1940

Understand stellar evolution, with the help of nuclear physics, around 1950

Assume the initial ultradense state is hot, like a compressed gas : application of statistical physics

- nuclear synthesis when the temperature is higher than 10⁸ K
- thermal equilibrium of matter and light when T > 3000 K

HOT BIG BANG



What was the abundance in the Universe before stellar nucleosynthesis?

Primordial nucleosynthesis ?

HOT BIG BANG

production of deuterium, helium 3, helium 4, lithium 7 => 4 independent measurements

disintegration of neutrons and expansion of the Universe stops the synthesis after 3 minutes

is a measure of the density of Universe by the ratio : baryon (neutron + proton) / photon

BBN (Big Bang Nucleosynthesis)

Baryonic matter ≈ 4 times luminous matter (stars)

Total dark matter \approx 5 times baryonic matter



Main prediction of the hot big bang model







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millimetric radiation, isotropic at 10⁻⁵ (after correction due to Earth movement)



Predicted by Gamow a early as 1946 (nucleosynthesis) at 10 kelvins, almost seen by McKellar en 1941 and by Dicke, Peebles, Roll, Wilkinson en 1965

Measured on Earth par Penzias et Wilson at 7.35 cm

energy density divided by λ (Planck law)

$$\frac{du}{d\lambda} = \frac{8\pi h c}{\lambda^5 \left(\exp\left(\frac{h c}{\lambda k T}\right) - 1 \right)}$$

If the spatial dimensions and the wavelength are multiplied by a scale factor

$$f = \frac{\lambda'}{\lambda}$$

the spectral shape is not modified, number of photons is constant ($E = h c / \lambda$), but T becomes T'



galaxies are scattered while keeping their size

analogy of an inflated balloon (2D finite universe)



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WMAP

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gravity (baryons) and pressure (photons) create oscillations in photon-baryon fluid

sound waves

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Filtering the data

Before Planck

After Planck

Latest results (March 2014) from BICEP2 at the South Pole Background Imaging of Cosmic Galactic Polarization

Generated in thermal equilibrium, the CMB is not polarized

In General Relativity, gravitational waves are tensors → polarized If produced by inflation 10⁻³⁵ s after the Big Bang, they distort the CMB

Waiting from Planck results, which will measure polarization in the whole sky

What are the constituents of the baryonic dark matter ?

What are the constituents of the non baryonic dark matter ? Can we explain it by new particles, can we produce them in laboratory ?

Is dark energy due to a cosmological constant ? or is this "constant" variable ?

How did a uniform universe became non uniform (structure formation) ?

How an exponential dilatation happened at the beginning "inflation" ?

What theory can we use for instant zero (Planck era) when quantum effect cannot be neglected in gravitation ?