Dr PANTELIS DELIBALTAS

# MEGA BANG
## WHAT WILL HAPPEN IN BETWEEN AN EXTINGUISHING OF THE SUN AND ITS RADIANCE ANEW?

THESSALONIKI
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## WHAT WILL HAPPEN IN BETWEEN AN EXTINGUISHING OF THE SUN AND ITS RADIANCE ANEW?

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*Mega Bang:* what will happen in between an extinguishing of the sun and its radiance anew?

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# Preface

During my studies in physics at the University of Munich I was fortunate to attend lectures by the famous Prof. W. Heisenberg. At the Technical University of Munich I attended lectures by the Nobel Prize laureate Prof. R. Mössbauer. During my diploma studies I worked under the guidance and supervision of Prof. N. Riehl at the nuclear reactor in Garching, Munich, on the diffusion of isotope O18 on ice (P. Delibaltas *et al.*). Under the guidance and supervision of Prof. I. Chadzidimitriou and Prof. G. Bozis I found periodic and periodic collision trajectories in the general three-body problem. For these studies I was awarded the title of Doctor of Physics of the Aristotle University of Thessaloniki.

In this book I describe some facts of cosmology. I have tried to make several “challenging” concepts of cosmology more accessible by using a reference volume. I have compared the pressure, expansion, heat and intrinsic energy of the reference volume with the corresponding observable quantities of the universe.

Through the collision of two stars, I describe the increase in their temperature and the subsequent birth of a planet's satellite.

I then present a model, which I call the Mega Bang, of the collision of pairs of galaxies. Through this model I try to describe the big Mega Bang. This description is based on pure physics and mathematics far from any theological approach.

I first encountered the Big Bang topic in about 1963 as a student at the Technical University in Munich, when I attended an open discussion between a Church Representative and Prof. W. Wild – my professor in Mechanics and Quantum Mechanics – in the ceremonial hall of the Technical University on the above topic. The room was crowded forcing the organizers to install loudspeakers in the surrounding area, which was also packed to capacity.

The debate went on until the early morning hours, keeping the audience glued to their seats.

The conclusion of the discussion was that the Church representative had a serious lead on the question of who created the universe. The representative of Science countered that the universe had always existed in some form and that it was only a matter of time before the Big Bang occurred and the universe was brought into its present form. Of course, the audience drew their own conclusions.

Regarding the evolution of the universe, the Steady State and renewal theory of Hoyle, Gold and Bondi has a significant lead in observations over the perennial and unchanging Big Bang model of Lemaitre and Eddington. I then present in an understandable way some of the most recent physics research findings at CERN in Geneva that explain the evolution of the universe. Finally I describe some observable quantities in cosmology.

Part One of the book is addressed to high school graduates, with the encouragement to study the explanations of some physical and mathematical concepts. Part Two is aimed at readers familiar with contemporary Physics.

On my part, I would like to thank Prof. N. Spyrou of the Aristotle University of Thessaloniki for his scientific support, as well as Evan for his technical and critical assistance.

*P. E. Delibaltas*

*Thessaloniki, May 2023*

# Table of contents

# Explaning concepts of physics and mathematics

This work is addressed to senior high school graduates, for whom we will add some university-level concepts of natural functions which will be encountered throughout the book and which are necessary for its understanding.

1. Powers. $[\alpha^x]^y = (a)^{xy}$.
2. Derivative. It is the limit of the variation of a function by the variation of time $\Delta f/\Delta t$ για $\Delta t \to 0$.
3. The integral $\int_0^t f(x)dx$ is the area enclosed between the x-axis, the lines $x = 0, x = t$ and the function $f(x)$.
4. Lagrangean $L$ is a function whose integral $\int_0^t Ldt$, for real motion becomes minimal and from this property the equations of motion are derived. In classical mechanics Lagrangian $L$ is a function of vector space and velocity which are time-dependent. In quantum field theory the Lagrangian density is a function of the field $\varphi$ and its partial derivatives $\varphi$, $\partial^\mu\varphi = \partial\varphi/\partial x^\mu$, which – just like $\varphi$ – are functions of spacetime $x^\mu = (x^0, x^1, x^2, x^3)$, where $x^0$ represents time t and $(x^1, x^2, x^3)$ the space vector. In general, $\partial^\mu\varphi$ represents a four-column vector of partial derivatives of $\varphi$ and $\partial_\mu\varphi^+$ a series of four partial derivatives of the complex conjugate of φ; Represented as: $\partial_\mu\varphi^+\partial^\mu\varphi = \partial_0\varphi^+\partial^0\varphi + \partial_1\varphi^+\partial^1\varphi + \partial_2\varphi^+\partial^2\varphi + \partial_3\varphi^+\partial^3\varphi$.

   Latin indices, e.g. $i, j, k$, generally characterize the three spatial coordinates, usually as 1, 2, 3.

   Greek indices take the values 0, 1, 2, 3.

5. According to Einstein, space and time are not independent quantities, but form a single spacetime. For **light** the squares of the differential components of this spacetime are related by Eq. 7.1.1.
6. $g_{\mu\nu}$ tensor is a $4 \times 4$ matrix containing the properties of spacetime, whether it is expanded, flat, curved or concave. In spherical coordinates it will have the form (7.1.2). In an unexpanded flat empty space the matrix $g_{\mu\nu}$ takes the form $\eta_{\mu\nu} = \delta\iota\alpha\gamma.(-1, 1, 1, 1)$ and is called Minkowski.
7. $T_{\mu\nu}$ tensor is a type of table describing the content of space (matter, pressure).
8. The Ricci tensor $R_{\mu\nu}$ describes the shape of spacetime.
9. Gauge $R$ is derived from a contraction of the Ricci tensor.
10. The Christoffel tensor $\Gamma^{\mu}_{\nu\kappa}$ is a type of three-dimensional matrix, as defined in Eq. 8.1.5.
11. As the speed of light is independent of whether the reference system is stationary or moving at a finite speed less than the speed of light, we often prefer the system comoving with the body because the four-dimensional spacetime vector has the simple form $x^{\mu} = (t, 0, 0, 0)$.
12. The geodesic is the curve on a spherical, concave or flat surface that traces a photon as described by the tensor and by equation 8.1.4. In the case of a spherical surface, the photon returns to the point where it started.
13. Lorentz transformation is the transition, e.g. from a stationary reference frame to a moving or rotating one. Lorentz invariance represents the stability of the gauge magnitudes, and Lorentz covariance represents the preservation of the angles between two vectors, in the homonymous transformation.

14. A gauge, e.g. Lorentz *(Eq. 9.1)*, makes it possible for hitherto undefined physical quantities (temperature, pressure, mass, energy) to get a specific value.
15. Fourier synthesis. Fourier integral represents the analysis of a function into infinite plane waves. In other words, it shows to what extent the plane wave of wave number $q$ contributes to the function.
16. Clarifications. When using English tables, keep in mind that the dot (.) represents tenths and the comma (,)represents thousands.

# Introduction

In this work we have made a proposal, the so-called Mega-Bang, to explain how our $4{,}5 \times 10^9$ years old Sun – that will go out in about as many years – will light up again. We will then describe **three recurring events with an exclusive focus on the Mega Bang that take place in the Milky Way** and try to explain them using tools of physics, just as seismologists explain recurrence in **earthquakes**, volcanologists in **volcanoes** and meteorologists in **floods.**

In the first case, that of periodic elastic collisions, description is accurate to eight decimal places.

As for the cases of inelastic and plastic collisions, we tried to explain them qualitatively based on the laws of physics and observation. These facts are as follows:

- **Periodic Elastic Collisions** in the three-body problem (Sun, Jupiter and Saturn), where both energy and total momentum are conserved.
- **Plastic collision of two hot stars**. A more than rare **recurrence** that took place 13.5 billion years ago in our universe. Stars in the Milky Way with enormous mass densities collided head-on with slower stars, whose direction of motion, due to Newtonian attraction plus the Bernoulli force, was reversed raising their temperatures to $10^{28}$K. The two stars, whose masses dissipated, left a vacuum behind them. Into such vacuum the neighbouring stars rushed and collided with each other. In this way we will present in Chapter 14 the Mega Bang model. In this case, the mechanical energy of the two bodies is not conserved because it is converted into heat, while momentum (both locally and globally) is conserved.

The Mega Bang model describes the big bang not as an instantaneous continuous explosion, but as a series of several quite long successive explosions. The Milky Way was not created in one point but in numerous successive points, which, when put together, make up the current Milky Way.

From an electromagnetic and Higgs field we will both explain how mass is produced in elementary particles and the creation of our solar system, a part of which is the Earth. We will then explain how helium is produced by fusion of atoms and how medium atoms are produced from heavy ones by thermonuclear fission reactions.

# PART ONE:
## SIMPLIFIED DESCRIPTION

# 1. The Heavens

While a few years ago the vast space between the Sun and the stars was thought to be empty, it turned out that in the vacuum there was intergalactic gas and particles of the form of dust moving at non-negligible speeds.

The radiation that encounters these particles is reflected as **wavelength-dependent according to the law $\lambda^{-4}$.** This means that the longer wavelengths that are more easily absorbed by the above particles make the sky appear reddish in the morning, while at noon both sky and sea appear to be blue. Stars are formed by clustering of scattered matter and they are grouped into galaxies. The time a star is formed depends on special circumstances; moreover, they are not all formed at once. So our Sun has an age of $4{,}5 \times 10^9$ years.

For Earth's inhabitants, the Sun will be extinguished in as many years, due to the consumption of the hydrogen involved in fusion and radiation. In the vacuum (darkness) created we have the Higgs field $\varphi$ and the vector boson field $A^{\mu}$, as well as the creation of a new spherical galaxy, see Chap. 23, due to the collision of white dwarfs with AGN stars, see Chap. 2.1 and temperature $10^{28}$K, see Chap. 14.3, which will include the Sun and the Earth. The energy of the new spherical galaxy is conserved. Over time the temperature drops to 0°C bringing forth the Ice Age.

# 2. Formation and Evolution of Galaxies and Stars

## 2.1. Galaxies

The formation of galaxies is initiated by variations in mass density. Small regions of dense matter and under the dual property of mass and radiation attract matter from their immediate surroundings with the help of gravity and become increasingly dense, until stars are formed and then the first galaxies are formed by stars clustering.

Edwin Hubble classified galaxies in a shape known as Hubble's fork (Fig. 2.1).

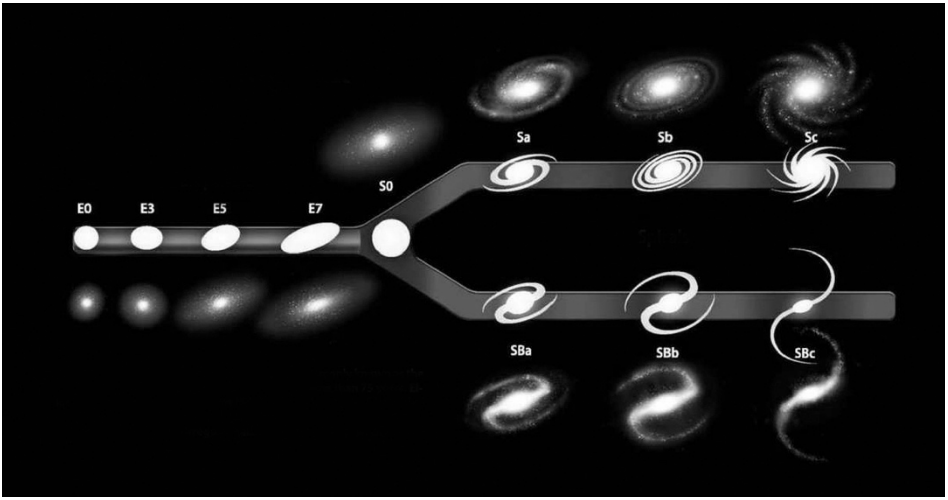



*Figure 2.1*

**Seyfert and Quasar** galaxies **are AGN (Active Galactic Nucleus) galaxies** with a black hole at the centre of the galaxy and much stronger luminosity than other galaxies. This luminosity does not come from stars but from the black hole at the centre. Ionized matter is attracted to the large mass at the center of the galaxy and causes such strong brightness. Galaxies contain billions of Sun-like stars. Their brightness depends on the time of their creation as well as their distance from Earth.

## 2.2. Stellar matter

This is a condition when there is fermionic matter of rather high density in which the Pauli Exclusion Principle exerts enormous pressure along with the thermal one. Fermions are the well-known electrons, neutrons and protons.

The term "stellar matter" is mainly used in astrophysics describing very dense stars, where gravitational pressure is so strong that quantum effects occur.

It is the matter found in stars in the last stage of their life, such as neutron stars, white dwarfs, where thermal pressure alone is unable to prevent gravitational collapse.

Quantum mechanics requires fermions to have an energy value each, so stars occupy a large energy spectrum.

Under high pressures the density increases; electrons remain in their positions in the inner and valence bands in atoms and at temperatures $T \approx 0$ they occupy all the lower positions in the inner, valence and conduction bands up to the upper energy value $E_F(0)$ (**Fermi,** C. Kittel). This means that the stellar pressure is non-zero. It is the one that exerts a force opposite to the gravitational one and keeps the star in equilibrium.

In common gases, thermal pressure dominates (zero at $T = 0$), while in stellar matter the pressure is non negligible.

## 2.3. Stellar electron matter

In a common electron gas most of the energy layers of the conductor are empty and the electrons are free to move. As density increases, the electrons gradually occupy the lower energy positions in the conductor band.

Additional electrons added due to high-energy-consuming entry of new atoms from the immediate environment occupy higher energy positions. Stellar matter resists further pressure increase because all the lower positions in the conduction band are occupied.

A typical example of this is the **white dwarfs**. The nuclei of the atoms in them form a sphere of high density and temperature at its centre. Its composition consists of carbon, oxygen and degenerate electrons in the conduction layer.

White dwarfs are bright because they emit radiation into the chaos.

## 2.4. Stellar neutron matter

The stellar matter of neutrons is similar to that of protons. Neutrons in stellar matter are more stacked than electrons because of their greater mass and the pressure is much higher. The ratio of the diameters of a white dwarf to a neutron star is

$$D_{\Lambda N}/D_{NE} \approx 10^{-8}.$$

## 2.5. The Hertzsprung-Russell diagram

The evolution of a star takes a very long time, so it is impossible to observe it.

However, we can interpret the order of their distance from the earth as a time series. Such an indicator is luminosity and another is the maximum wavelength, as shown in the diagram of Planck's radiation law or temperature $T$ of the blackbody temperature. We will describe the Hertzsprung-Russell diagram, Figure 2.2.

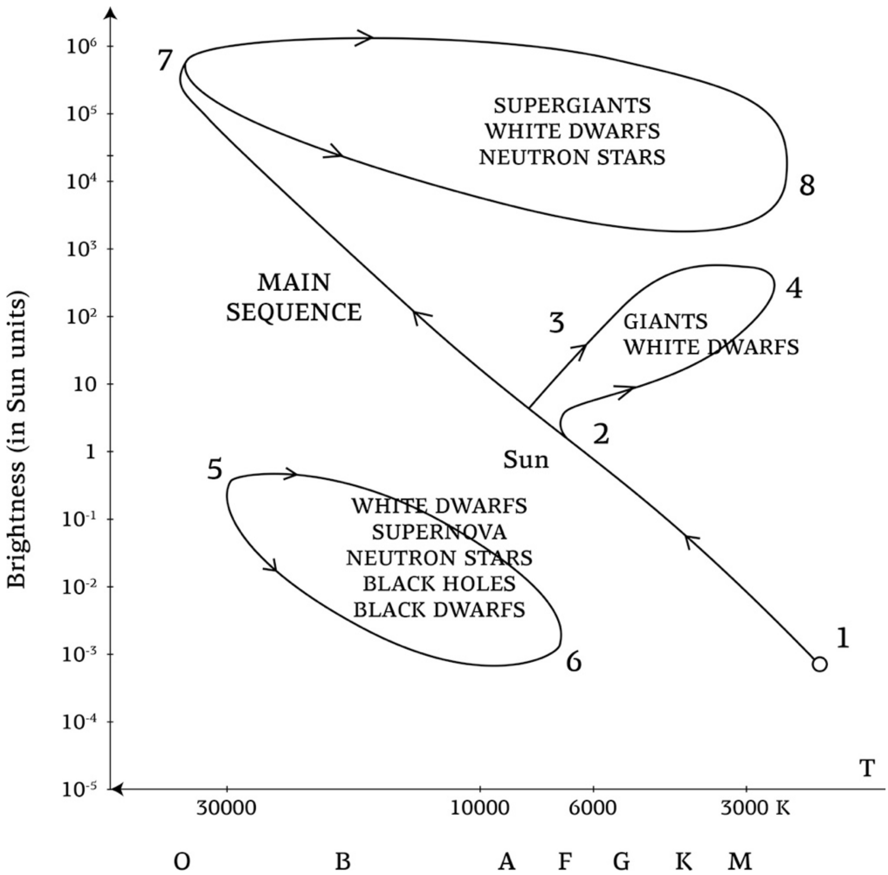



*Figure 2.2*

In this diagram we take the temperature from the higher to the lower values or from $O$ to $M$ as the intercept, and the luminosity as the intercept $y$ in units of the Sun's brightness.

We start (time $t = 0$) with the birth as a red star at point (1). The star grows by moving along a curve undergoing gravitational contraction at a point (2) on the Main Sequence (MS). On this curve there is our Sun, almost halfway through its life. The position of any star on the main sequence is a function of its mass; the greater its mass the higher it will be on the MS. When the internal temperature reaches $20 \times 10^6 K$, the proton-proton and carbon process begins, exactly as in the Sun, Chap. 27. Such processes are in balance with the radiation emitted. If the mass of the star is 0.3-8 times the mass of the Sun, it moves along the curve (3), (a motion accurately calculated by Schwarzschild) to land at point (4) as a Red Giant and then as a white dwarf.

Stars with a mass over 8-30 times the mass of the Sun moving along the main sequence end up at point 7 and from there to point 8 as **Red Supergiants** with an average lifetime of 25 million years and some of them as **white dwarfs** or **neutron stars.**

In region 5 there is an accumulation of white dwarfs, the precursors of Supernovae.

If the star mass is less than 8 times the mass of the Sun, it runs out of fuel, loses mass through explosions and shrinks until it becomes a white dwarf **with a mass of** $m \leq 1.44$ **(Chandrasekhar limit) times the mass of the Sun.**

The white dwarf with temperature $10^5 K$ radiates for up to eight billion years and so its temperature drops, turning it into a slightly radiating star **with a mass density of** $\frac{10^9 \mathrm{Kg}}{\mathrm{m}^3} = 4.3 \times 10^{-12} \mathrm{GeV}^4$ **(R. Pogge - 1GeV =** $1.44 \times 10^{-3}$ **kg** $= 1.16 \times 10^{13}$**K).** This star remains like that only to transform in **a trillion years into a black dwarf.** To date no black dwarf has been observed.

Accumulating mass beyond the Chandrasekhar limit, the stellar matter cannot contain gravity and the white dwarf begins to collapse. As density increases, the carbon cycle (Chap. 34.2) is triggered, thus increasing the temperature. The increase in temperature leads to fusion and the heavier ones to fission (Chap. 32), converting the lighter atoms into nickel and iron, leading after an explosion, to type Ia **supernovae**, stars with temperatures $T = 2 \times 10^8$K, which at some point explode, increasing their brightness 15 to 20 times, and after a short time disappear, leaving behind only iron scattered in space.

If the mass of the white dwarf is 20 to 300 times the mass of the Sun, what remains after the explosion is enough to start a new process. The gravitational force is enormous and gives rise to a continuous attraction of mass (Chap. 32). For each star there is a critical metallicity (atoms in the star with an atomic weight greater than that of the $He$) in relation to its mass, so that it becomes either a **neutron star** in case of smaller masses, $20 \leq m \leq 30$ times the mass of the sun (through the reaction $p^{+} + e^{-} \rightarrow n$, due to gravitational attraction), having the maximum density; or in case of larger masses $30 < m \leq 300$ times the mass of the sun, through collapse to gather all its mass within a sphere of radius $r = 2m$, **Schwarzschild radius**, spacetime becomes so distorted that it separates from its surroundings and acts as a **black hole.**

Because of the large gravitational force, a photon, with its double property as a mass $m = h\nu/c^2$cannot escape from the black hole. Only at the edge of the Schwarzschild radius, after a precise value of the photon's momentum, the $\Delta p$ is very small, and due to the Heisenberg relation $\Delta p \cdot \Delta x \approx \hbar$, can the $\Delta x$ be large enough to escape from the black hole, as S. Hawking concluded.

White dwarfs are the oldest stars. Time $t_Z$ is the life of the star. **Pulsars** are rapidly rotating magnetic neutron stars emitters of periodic gravitational waves discovered in 1967 by Joselyn Bell and Anthony Hewish.

The so-called AGN (Active Galactic Nucleus) galaxies, **Seyfert and Quasars**, radiate much more strongly from their centres, where there is a black hole and it strongly attracts ionised matter and white dwarfs around it and they collide. Their expansion velocity is greater than that of most galaxies.

The oldest Quasar discovered has a lifetime of 10 billion years, younger than many galaxies.

Their distance from the earth depends on the time of their creation.

# 3. The Evolution of the Universe

## 3.1. Various Models of Evolution

**Our universe is expanded by a factor $a(t)$, i.e. $V(t) = a(t) \cdot V(0)$. Einstein originally assumed that it was spherical and the coefficient $a(t) = a_E$ was fixed**. This universe turned out to be unstable *(Fig. 3.1)*.

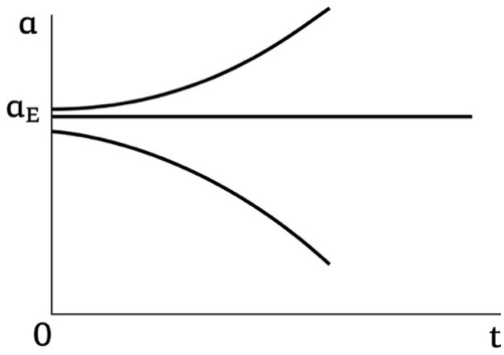



*Figure 3.1*

Later, the Lemaitre, Eddington-Lemaitre and de-Sitter models were proposed *(Fig. 3.2).* The latter was the most realistic.

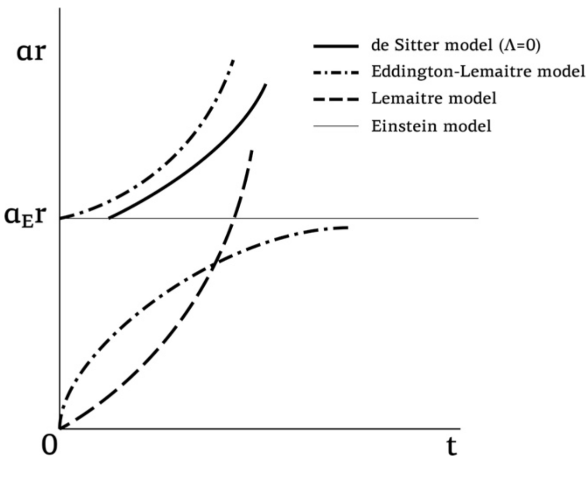



*Figure 3.2*

The collision of two white dwarfs (Chap. 20) creates a temperature of $T = 10^{28}$K. At this temperature all the masses dissipate, leaving behind a Higgs field $\varphi$ and an electromagnetic potential $A^{\mu}$. The density of the matter of the two colliding white dwarfs is converted to the density of the vacuum as the sum of the densities of the electromagnetic potential $\rho_R$ and the field $\varphi$, $V(\varphi) = \rho_{\Phi}$ over an unstable minimum of a Mexican hat (Figure 4.1).

## 3.2. The Higgs mechanism

In the Higgs mechanism, the field $\varphi$ and the electromagnetic potential cause the birth of mass that annihilated in the collision of white dwarfs, as predicted by the symmetry requirement between proton and neutron as well as between electron and neutrino (Chap. 9). During this period the curvature of space is infinite, $k = 1$.

## 3.3. The early vacuum era

Calculations in this period cannot be performed using Einstein's equations, because the momentum energy tensor $T^{\mu\nu}$ contains mass, which does not exist, since at Higgs temperature $T_H = 10^{28}K$ it has been converted into a potential of the field $\varphi$, thermal and electromagnetic radiation. This is the reason why the results of Chap. 22.1 are absurd. Such conversion of mass creates a vacuum and a positive pressure.

In position $\varphi = 0$ of the Higgs field, the potential $V(\varphi)$ is in an unstable and symmetric with respect to the $\varphi$ minimum of a Mexican hat (Figure 4.1).

When the potential $V(\varphi)$ drops from position $\varphi = 0$ to a constant minimum a symmetry breaking occurs.

## 3.4. The radiation era (hot mass)

**This era is characterized by density $\rho_R = 3p$ and universe expansion coefficient $a(t) \sim \sqrt{t}$. R index stands for radiation.**

In this era we have the synthesis of baryons and mesons from quarks, the nucleosynthesis of other light nuclei besides hydrogen.

Binding of an electron by a proton results of the formation of hydrogen and the first light at a temperature of 4500K.

## 3.5. The current matter and radiation era

This era begins when the Milky Way has cooled to a temperature of 4500K and the forming stars of a galaxy have moved far away from each other. This era cannot be described by Einstein's equations describing a curved space with mass density p equal to the sum of the light mass density and the dark mass density, because it ends up with zero pressure p. **This is not consistent with observations. This era is described by the physics of fluids with mass density $\rho$, pressure $p > 0$ and internal energy density $\rho(-1 + 1/(1 - v^2)^{1/2})$ (Chap. 23.1, Part B). The universe is expanding by accelerating at a rate of $a(t) \sim t^{2/3}$.**

The verification in 1998 of Hubble's 1929 prediction by Hubble's law of ($v = Hd$) and by Lemaitre and Eddington that the expansion of the universe is accelerating, brought cosmology into an era, initially called the "dark energy era" (Nobel Prize 2011).

Nowadays, research on light from supernovae (SN) has established **a theory which explains in a different way the accelerated expansion of the universe.** The expansion of the universe takes place without the contribution of dark energy or dark mass. This is due to the fact that light emitted by, for example, a star follows the path, until the light reaches star A, of least time (Fermat's principle). This means that the emitted quanta from the energetically denser SN star to the energetically thinner vacuum have total momentum in the direction towards star A, due to the lenticular attraction, Chap. 27.2, greater than the refractive index in the vacuum, where it equals to 1, greater than in the opposite direction (Fig. 3.3).

Inside and outside the star **momentum *p*** undergoes a gradual decrease in time $\Delta t = t_2 - t_1$ from $p_1 = h/\lambda_1$, until it takes the value $p_2 = h/\lambda_2$ of the vacuum. $h$ is Planck's constant and $\lambda$ is the wavelength.

The expression $F = [(p_2 - p_1)/(\Delta t)]S$ is a force pushing SN outwards.

$S = 2R^2\pi(cos\varphi_1 - cos\varphi_2)$ represents the spherical surface of the $S$ around the axis $x$ and $R$ the radius of the SN, $d$ the distance SN and A the Earth. The above applies to any radiating star. From Planck's equation and the dual property of light as mass and radiation we get $E = h \cdot \nu = h/T = h \cdot \lambda = mc^2$. The expansion velocity of each star is different. At the end of a galaxy's life, white dwarfs survive.

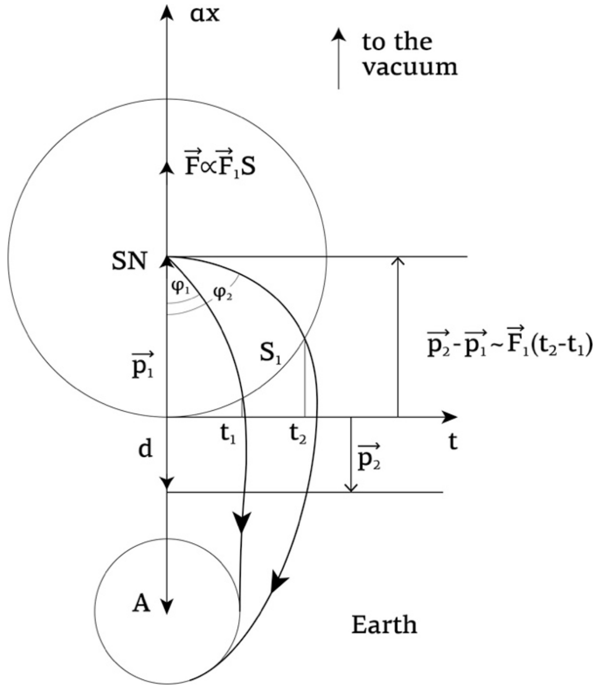



*Figure 3.3*

**Power $\vec{F}$ depends on the brightness and the distance $d$ of the SN. Thus, the expansion velocity of each star is different.**

At the end of a galaxy's life, white dwarfs survive.

## 3.6 Collision of white dwarfs in AGN galaxies

**The so-called AGN (Active Galactic Nucleus) galaxies, Seyfert and Quasars**, as mentioned in Chap. 2.4, radiate much more strongly from their centre, where there is a black hole and it strongly attracts matter around it, than most galaxies.

The oldest Quasar discovered has a lifetime of 10 billion years, younger than many galaxies.

The thrust force from the radiation of these galaxies is much stronger than the thrust of ordinary galaxies, and the expansion speed is much greater. Fig. 3.4 shows a white dwarf $G_1$ of a galaxy and an AGN star $G_2$ of the same galaxy, which formed after the $G_1$, moving, as indicated by their arrows, with $t$ being the time parameter.

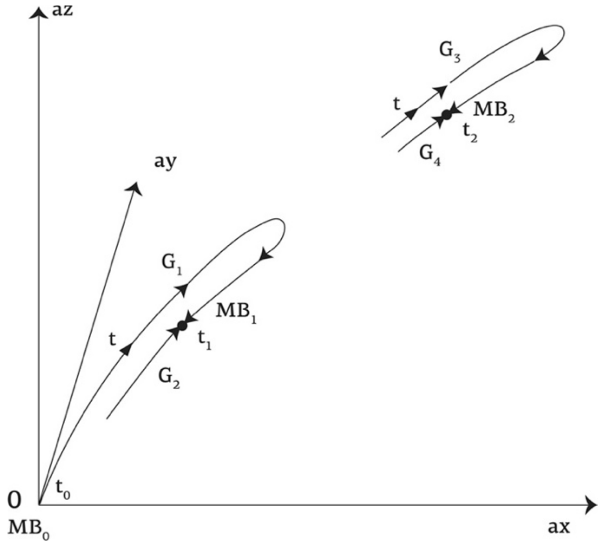



*Figure 3.4*

O $G_2$ approaching the $G_1$, which is gravitationally attracted by the first, faster and heavier, **changes direction and they collide head-on**.

In the vacuum created by the temperature increase in the $10^{28}$K and the burning of everything, the adjacent white dwarfs are attracted from different directions at enormous speeds and collide head-on. This continues until all the white dwarfs in the same galaxy collide with each other, ending in time $\Delta t$ a $MB_1$.

Because the MB is created by several successive collisions, the **duration of the $\boldsymbol{\Delta t}$** of the big bang seems to have been quite long.

The fact that light appeared 380,000 years after the Mega Bang at a temperature of 3000K means that this happened much later than the MB, when photons were not scattered on H atoms and could reach us as radiation. What the Mega Bang left behind was a Higgs field, a bosonic electromagnetic potential and a temperature $10^{28}K$ capable of destroying what was left of the galaxy.

The Galaxy is reborn from its ashes through the Higgs field and the electromagnetic potential. In time $t_2$ we have an MB in another galaxy.

## 3.7. Collisions between white dwarfs in the same galaxy

The collision of the two stars of Chap. 3.6 was an introductory example. The attractive force between stars (white dwarfs) of rest mass $m_0$ was the Newtonian $\sim m_0^2/r^2$.

After 13.5 billion years of radiation from the first galaxies, it makes sense that the remaining energy in the Milky Way is not enough to create new stars, and the only ones left are the oldest white dwarfs.

A galaxy contains about 100-400 billion stars, including **ten billion white dwarfs, which** are at the end of their lives (Young, K.).

Two white dwarfs from the same galaxy with different velocities and energy densities are strongly attracted $\sim m_0^2/r^2$.

If we also take into account the **Bernoulli** force (Fig. 3.5) generated by similarly rotating white dwarfs, which acts additively to Newton's, then stars can come into **plastic collision in a spherical galaxy** (Figure 23.1, Part B.).

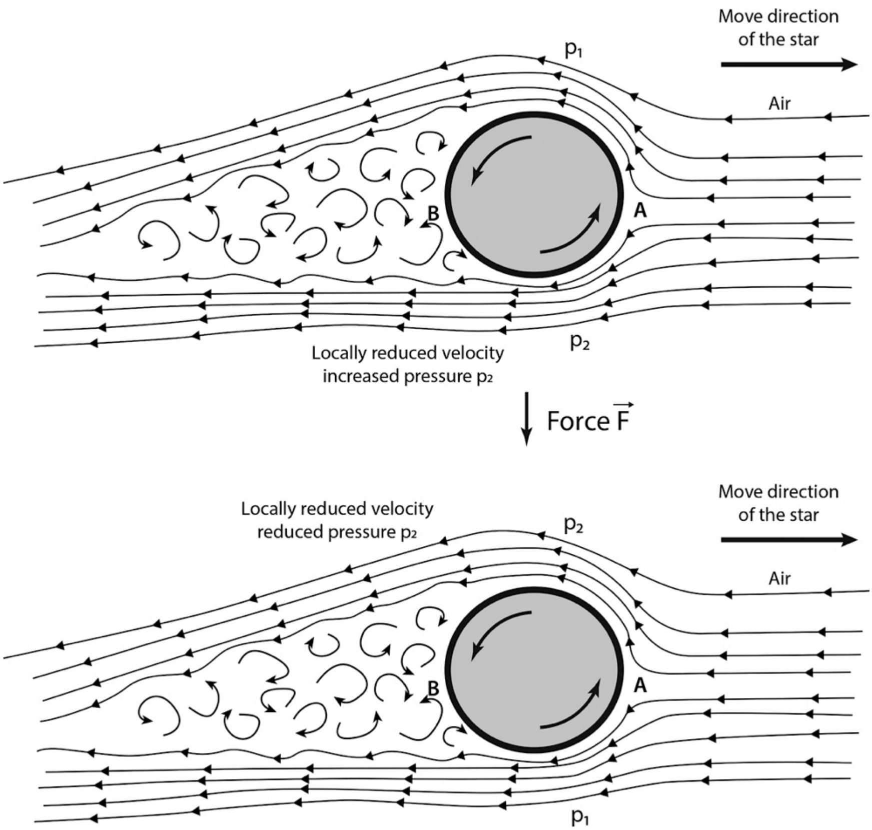



*Figure 3.5*

The radiation from the inner stars has no effect, because the radiation from one star is absorbed by other inner stars.

# 4. The Higgs mechanism

Fields respond to temperature just like ordinary matter. The higher the temperature, the more turbulent the field becomes. Compare the field to a pot lid bubbling up and down, over the stove eye. At moderate ambient temperatures the ripples in the fields are zero. However, at Mega Bang temperatures the Higgs field ripples were ferocious. As the universe cooled, the ripples got smaller and smaller. At temperature $10^{28}$K takes place for phase change, like water vapor changing into water at 100 degrees Celsius. At this temperature a latent energy, such as that of water vapor, is released. This happens in the case of the Higgs complex field $\varphi$ falling from a point of high potential $V(0)$ in the centre of a Mexican hat (Fig. 4.1) low in the hat cavity at the position $\varphi = (\mu/\lambda, 0)$, and by breaking symmetry it thereby acquires kinetic energy.

Higgs boson, combined with the bosonic potential $A^{\mu}$, acquire mass and then give mass to the massless particles in circulation. So we have the Higgs boson, the bosons $W^{\pm}, Z$ boson of the weak (distant) interaction, the quarks of the strong (near) interaction and the electrons with positive and negative signs as they are currently.

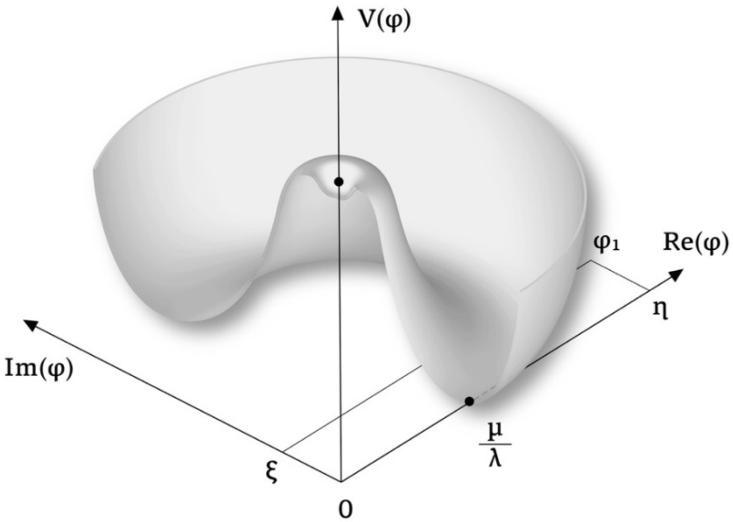



*Figure 4.1*

# 5. The Fate of the Universe

The arrow of time goes from $-\infty$ to $+\infty$.

If the Universe is flat, then some of the energy of the form of heat and radiation will be lost in chaos. The galaxies will freeze and the universe will disappear. **In this case, for believers the Shepherd is left without a flock. For non-believers they are left without any nature to develop and create the animal and plant kingdoms, according to Darwin's theory of evolution.**

However, in Chap. 23, we have proved that the universe is not flat, but curved, thus conserving energy and as a closed system the universe will never disappear and a new universe will be created after a Mega Bang and life repeats. **The components of the universe are recurring: (a) in the animal kingdom, (b) in the plant kingdom, (c) in the mountains through pressure and temperature, (d) in the sea through evaporation and liquefaction. Then, it should also be recurring as a whole.**

# 6. Periodic elastic collision trajectories in the three-body problem

**Four families of periodic collision trajectories in classical mechanics have been published in a previous scientific paper in "Celestial Mechanics" Journal (P. Delibaltas, 1982, see Literature). In a single-family trajectory the three bodies were the Sun, Jupiter and Saturn. The collision took place between the Sun and Saturn. The third body, Jupiter, was very far away, (I. Chadzidimitriou, G. Bozis). The initial momentum was very high, $p = mv$ and, because $m = \sigma\tau\alpha\theta.$, it follows that the velocities were infinite** and they were normalized to take finite values using the Waldvogel transformation. The Sun and Saturn collided again after a period T. These trajectories were calculated to eight decimal places.

In a system of units, where the gravitational constant $G = 1$ and the total mass $m_{H\Lambda} + m_{\Delta I} + m_{KP} = m_{TO} = 1$ the conserved total momentum and mechanical energy were $p = 6{,}456 \times 10^{-4}$ and $en = -6{,}58 \times 10^{-4}$ respectively, in the units defined above *(Figure 6.1.)*

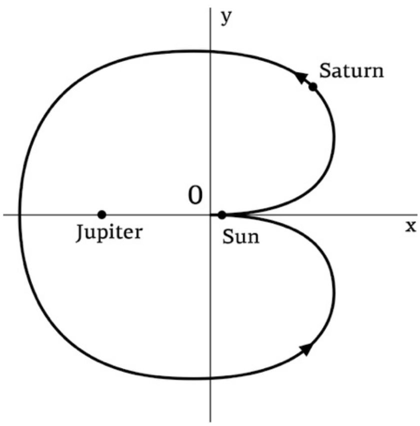



*Figure 6.1*

To the question asked by dozens of readers of the study from several countries, whether one could numerically continue such trajectory until reaching a Mega-Bang type collision, the answer is NO; and that's firstly because the mechanical energy in the case of a Mega-Bang, in the previously closed system, is not conserved and, secondly because only a local vacuum is created in the galaxy (see *Introduction*).

# 7. Perfect inelastic (plastic) collision between two stars

Two similar stars with mass $m_0$ are attracted and collide, developing enormous velocities, let's say $v = 1 - 10^{-x}$ with $x \gg 1 = c$ the speed of light, forming a cluster. The kinetic energy and mass of the two stars is converted into heat, as well as thermal and electromagnetic radiation. The energy of the pair of stars after the collision, in a natural units system of Chap. 17, would consist of the stationary mass $2m_0$ and the internal kinetic energy

$$Q = \sqrt{2} m_0 10^{x/2} \, GeV.$$

The energy density will be

$$\Pi E = Q^4 GeV^4 = 4\rho 10^{2x} GeV^4 \tag{7.1}$$

where $\rho$ is the energy density of a star.

# 8. The symmetry of the Grand Unification Theory (GUT) and the Gauge Theory

Maxwell's equations in electrodynamics are invariant (unchanging) if in the potential $A^{\mu}$ a derivative of a gauge function $a(x)$ is added. This implies a vagueness in the determination of the electric and magnetic fields. To remove this vagueness a **gauge** is introduced, e.g**. the Lorentz, the deviation of potential $A^{\mu}$ equals to 0** (Chap. 25, Part B).

One example is the casino roulette. During the spin of the roulette wheel every number is possible but none is definite. When the roulette stops (this corresponds e.g. to a Lorentz gauge) the pointer defines a single number (symmetry breaking, see Chap. 4) while the coordinates of the others are defined at the same time.

Modern physics has generalised the previous principle of symmetry in the vacuum and especially for the Higgs field $\varphi$ and the bosonic potential $A^{\mu}$. Symmetry should hold at the beginning of the Mega Bang at time $t = 0$. At this moment all fields $\psi$, describing the evolution of a pair of two particles, e.g. a proton and a neutron or an electron and a neutrino, in the context of the grand unification theory (GUT), must be locally invariant to rotations by an angle $\theta$ and by a symmetry in the position changes of the two particles, as the quanta of the fields $\varphi$ and $A^{\mu}$ are bosons. This in the case of the electron-neutrino pair, due to a large difference in their masses before the symmetry breaking made no sense and was the reason that forced Higgs, Englert, Brout, Guralnic, Hagen and Kibble (J. J. Sakurai Prize in 2010) to insist on symmetry in $t = 0$, requiring that the equality of the masses of electrons, neutrinos and all particles be satisfied by zero masses (2013 Nobel Prize to Higgs and Englert).

*Figure 8.1. From left to right: Kibble, Guralnik, Hagen, Englert, Brout. On the right P. Higgs.*

# 9. The radiation era

Before 1960, most of the information about the structure and evolution of the universe came from observations of redshift and distances of distant galaxies. In 1965, a nearly isotropic microwave radiation background rich in information about the evolution of the universe was discovered (Chap. 13).

**The birth of radiation implies the creation of protons and electrons as well as nuclei; first of all hydrogen, helium, then lithium, beryllium, carbon, nitrogen and oxygen.**

Because of the high temperatures and pressures in the cores of stars, the chemical potential of neutron as an electrically neutral element is greater than that of the proton. This is trapped in the nucleus of the atom and then decays into a proton, moving the atom up one place in the periodic table and releasing a b particle (rapid process). Thus we are led by fusion to the formation of the middle elements of the periodic table, to the creation of the heavier nuclei and then, by fission, to almost all the atoms in the periodic table (Chap. 15).

The core of stars is dominated by the most stable atom in the periodic table, iron (Κεφ. 33.3).

At a temperature of 3000K and 380,000 years after the Mega Bang, hydrogen began to radiate, sending the first light into the universe, long before the sun and the earth were created, see. Chap. 3.6.

# 10. The myth of inflationary theory

## 10.1. The first inflationary theory

This was proposed by Guth in 1979. The result was that the universe ended up being as inhomogeneous as Swiss cheese. Large regions of vacuum and large regions full of galaxies, **which is incompatible** with the current picture of the universe.

One droplet of $10^{-25}$ cm in diameter expands, in $10^{-32}$ sec time, into a sphere of $10^{4}$ cm in diameter. The expansion velocity is $(10^{4} - 10^{-25})/10^{-32} = 10^{36}\ cm/sec$, **which is absurd** since it exceeds the speed of light ($3 \times 10^{10}\ cm/sec$, G. Boerner).

## 10.2. The second inflationary theory

This was proposed by Linde, Albrecht and Steinhardt in 1982.

One droplet of $10^{-26}$ cm in diameter, in $10^{-32}$sec time**, expands into a sphere of** $10^{47}$ **cm in diameter.** The expansion velocity is $(10^{47} - 10^{-26})/10^{-32}\ cm/sec = 10^{79}\ cm/sec$, **which is absurd** because it exceeds the speed of light ($3 \times 10^{10}\ cm/sec$, G. Boerner).

## 10.3. Our proposal for an inflationary theory

The Higgs boson $H$ waited for its temperature to drop to $10^{28}K$.

Following the automatic symmetry breaking (Chap. 4) and the acquisition of mass, the Higgs boson and the vector boson [$(l(Z, W^{+}, W^{-})$ which is the linear combination of the three components of the vector boson] $(l(Z, W^{+}, W^{-}), W^{+}, W^{-}, Z)$, at a temperature of $10^{28}K$, have enormous kinetic energy and are scattered in every solid corner of the closed universe at sub-light speeds. The Higgs boson and the vector boson, coming into contact with the circulating massless fermions and their antiparticles, give mass to the escaped massless particles, forming the known electrons, quarks and their antiparticles (Chap. 4); and then they create atoms, molecules and galaxies, in every solid corner of the closed new universe, **thus solving the mass distribution problem of the inflationary theory. The Horizon problem** is solved, because in Chap. 3.7 we have proved that $k = \varepsilon \ll 1$. Our universe is slightly curved.

In the period between $10^9$K and 3000K, which is the time of the creation of hydrogen atoms, fluid physics can be applied, where the number of collisions between photons and plasma ions was so large that they were in thermal equilibrium. **If we assume that their velocities are also in equilibrium, then the mass of the plasma ions becomes infinite with a velocity of zero.** This contradiction leads us to the conclusion that **there is no cause and effect (expectation) problem** and that the velocity of the plasma ions and their small fluctuations (Chap. 33) are always much smaller than the velocity of the photons and within the timelike area (Fig. 33.1, Part B).

$r_H$ is the line of light of the horizon, $c = 1$.

As for the **problem of the magnetic monopole**, Faraday solved it in 1831, proving that Electricity appears as both a monopole and a dipole but Magnetism only as a dipole.

If we take the fossil of the 14mm microwave emission as the big bang time t of 13.5 billion years and the speed of light $3 \times 10^{10}$ cm/sec, then the radius of the universe will be

$$R = c \cdot t = 3 \times 10^{10} cmsec^{-1} \times 13.5 \times 10^9 \times 3.65 \times 10^2 \times 24 \times$$
$$3.6 \times 10^3 sec = 1.3 \times 10^4 \times 10^{24} cm = 1.3 \times 10^{28} cm,$$

a value almost equal to that of G. Boerner ($10^{28}$cm $= 10^{23}$km). The time for light to travel this distance is $t = 2{,}5 \times 10^{11}$ years. If we assume that the reactions that caused the Sun to radiate are reversible, then the end of the current universe for the Earth and the beginning of the next one will be after $4{,}5 \times 10^9$ (Chapter 34). This in practice corresponds to eternity, just as it is perceived by a large number of people.

# 11. Spectroscopy

Each chemical element has a unique emission spectrum indicating at which wavelengths it emits radiation if it is stimulated. At the same wavelengths is the absorption spectrum as well.

Wavelength, if visible, corresponds to different colours, red for a wavelength of 0,7$\mu m$, orange, yellow, green, light blue, blue and violet for wavelength 0,4$\mu m$.

The spectrum emitted by a star – and therefore its colour – depends on its temperature. The hottest stars are those of type $O$, whose colour ranges from blue to ultraviolet, while the coolest stars are those of type $M$, whose colour ranges from red to infrared.

The table below shows all spectroscopic types and their surface temperature τύπους και την επιφανειακή θερμοκρασία τους.

When **Annie Jab Cannon** between 1911 and 1915 was ranking on the

| Spectroscopic type | Surface temperature K |
|---|---|
| **O** | 30,000-60,000 |
| **B** | 9,700-30,000 |
| **A** | 7,200-9,700 |
| **F** | 5,700-7,200 |
| **G** | 4,900-5,700 |
| **K** | 3,500-4,900 |
| **M** | 2,100-3,500 |

above table about 5,000 stars a month, gaining among others a doctorate, the students, to make it easier to remember, turned it into a cute verse *"Oh, Be A Fine Girl, Kiss Me"*.

Light is an oscillation of electric and magnetic fields, in a vacuum perpendicular to each other, with a common wavelength $\lambda$. Each element emits a range of wavelengths, as shown in Figure 10.1 for the sodium atom.

The absorption spectrum of each element is at the same wavelengths. If the element hosting star is moving, the electromagnetic oscillation, in the case of zero expansion of the universe ($a = 1$) behaves just like acoustics, obeying Doppler's law

$$\lambda_0 = \lambda_E (1 - v_\Pi / c), \qquad (11.1)$$

where

$\lambda_0$ is the wavelength reaching us,

$\lambda_E$ is the wavelength emitted,

$v_\Pi$ is the velocity of the hosting star, and

$c$ is the speed of light (or sound).

In the case of electromagnetic radiation, we have red-shift when the emitting body is moving away and blue-shift when it is moving towards us, according to Equation 11.1, or our speed is greater than that of the emitting body.

*Figure 11.1. The spectrum of sodium (Kuhn's spectrum). From left red to right violet.*

## 12. The evolution of telescopes and distance measurement

Astronomy has two tools to evolve: theory and observation which confirms theory. The original observations of stars were made with the naked eye.

Telescope added a large number of new stars to the old list. For example, the Pleiades cluster appears to the naked eye to consist of seven stars. Galileo was able to detect 47 stars in this region with his telescope. The evolution that followed was rapid, building telescopes with increasingly larger objective lenses and longer lengths up to the eyepiece.

Photographing the stars added a huge advantage to telescope observation by allowing detailed observation afterwards. John Herschel was able to record an image on glass in 1839 after Louis Daguerre was able to capture an image on a metal plate.

Later, E. Hubble on Mount Wilson, with a telescope of initially 1.5 metres and then 2.5 metres in diameter, managed to prove that the observed nebulae belonged to other Galaxies, while other astronomers claimed that they belonged to our own Galaxy (Milky Way).

Hubble originally estimated the distance of Cepheid Andromeda at 900000 light years, while the Milky Way diameter is 100000 light years.

In 1990, the HST telescope with an objective lens diameter of 2.4 metres and a focal length of 58 metres was put into orbit around the Earth, with a rotation period of 95min.

Additional scientific instruments were, among others, the cosmic microwave spectrograph, the infrared camera and multi-object spectrometer, and the fine distance measuring sensor.

As the name of the scientific instruments suggests, their purpose, among others, was to examine the fossil 380 thousand years after the Big Bang.

*Figure 12.1. Edwin Hubble. He discovered the expansion of the universe, which was later found to be accelerating.*

The latest development of telescopes is the WEBB 2 telescope. With a 6.5m diameter eyepiece, consisting of 18 hexagonal lenses, a focal length of 131.4m and a concentration surface of 25.4m$^2$.

The telescope orbited the Earth at an altitude of 1.5 million km and sent the first images of the universe on 11.07.2022 (Fig. 12.2).

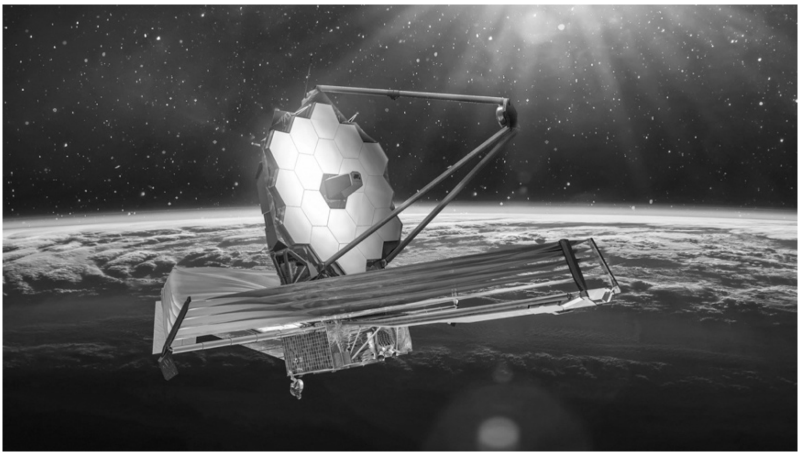


*Figure 12.2*

Its design is for close to mid-infrared reception for different reasons:

1. High infrared for very close and distant objects that shift visible emissions into the infrared.
2. Infrared passes through dust clouds more easily than the visible spectrum.
3. Frozen objects, such as fossil discs and planets, emit mainly in the infrared.

The images are 100 times clearer than those of the Hubble telescope. It was able to distinguish stars that were formed 100 and 180 million years ago, $z \approx 30$ and $z \approx 20$ galaxies that were created 270 million years ago, $z \approx 15$, after the Big Bang compared to the Hubble telescope, which can distinguish stars created 400 million years ago, ($z \approx 11{,}1$) after the Big Bang.

Let us emphasize here that the oldest fossil emits in the infrared and reaches us as a microwave with $z = 1100$.

# 13. Cosmic microwave radiation (CMR)

What preceded the first Big Bang still remains unknown. Shortly after the first Mega Bang and up to a temperature of three thousand degrees Kelvin the stars were of the form of opaque plasma. At this temperature the velocities of the proton, electron and neutron dropped so much that the proton and, with the addition of an electron, the hydrogen atom were formed. Plasma became transparent and light could pass through the star and escape.

The blackbody temperature of 3000K corresponds to the last scattering of photons by electrons and the star's age of about 3800000 years.

One can imagine the star as a blackbody emitting its maximum brightness at a wavelength of 14 μm. The wavelength that reached the Earth when it was created, due to the expansion of the universe and redshift, was 13 mm and falls within the microwave region.

Figure 13.1 shows the spectrum of the blackbody, where the maximum brightness at all wavelengths is proportional to the $T^4$**, Stefan Boltzmann's law.**

**Wien's law** applies to the blackbody. The product of the wavelength, at maximum brightness, $\lambda$ and its temperature $T$, $\lambda T$ is constant.

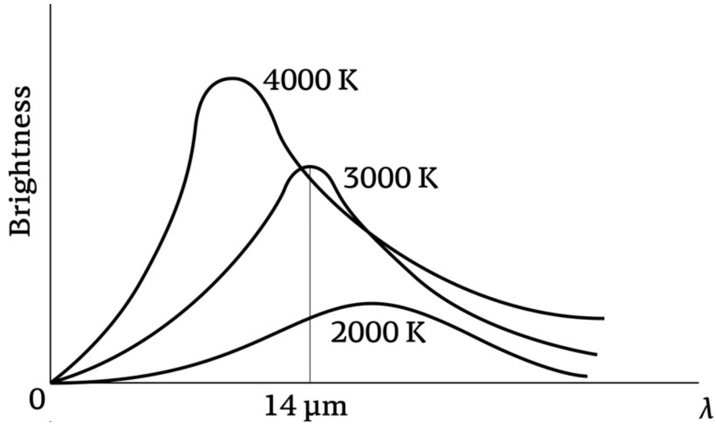



*Figure 13.1*

Arno Penzias was the only radio astronomer at Bell Laboratories. Later in 1963 Robert Wilson was also recruited. With a six metre long corneal radio antenna they began to explore the sky and study the various sources of radio waves.

Signals from a distant galaxy are so weak that the issue of noise was of utmost importance. So they had to check that their radio telescope was receiving a minimum level of noise. They turned the radio telescope to a part of the sky where there were no radio galaxies (quasars). They expected the noise to be minimal but were rather impressed to discover an annoying noise, which of course did not bother them much for the measurements they wanted to make. However, they started studying how to avoid this noise. This noise could be coming from somewhere in their suroundings or could be caused by faulty components in the radio telescope. After ruling out both of these causes, they found that the noise was continuous and coming from every direction in space. What they didn't realize was that they had made a major discovery, which in 1978 was crowned with a Nobel Prize.

It was the 14 μm wave, which after a redshift $z = 1100$ (Chap. 13) reached the earth as a 13 mm microwave.

The prediction of the 13 mm microwave had been made as early as 1948 by Gamow, Hermann and Alpher **as the emission of the Big Bang fossil**.

Now they had been vindicated for their prediction.

# 14. The Mega-Bang model

## 14.1. A historical review

It was between 1940 and 1945 when Gamow, Alpher and Hermann formulated the idea of the creation of the universe by a **Big Bang).**

There was a dispute between Gamow and Alpher concerning who had fathered the idea. While presenting the paper on the creation of the universe Alpher, in an attempt to tease Gamow, secretly inserted between the slides one showing Gamow emerging as a – female – genie from a bottle of Quantro along with the primordial soup from Ylem – the primordial soup of the creation of the universe.

Shortly afterwards in 1946 the team of Gold, Bondy and Hoyle began to devise a radically new model for the universe. The **steady-state** model**.**

The idea was originally Gold's and two of his colleagues told him that it was crazy; yet during the discussion they found that it did not contradict any of the astronomical observations of the time. It described an **eternal and unchanging** expanding universe as well as the creation of new matter in place of the one destroyed. Until then, the concept of expansion had been associated with the big bang. The redshift observed by Hubble could also be explained by the new model.

Gold observed that withut a constant renewal, the universe would be constantly thinning, which contradicts the observation that the density of the universe (for short periods of time) remains constant. But the question had arisen as to where this matter comes from.

Hoyle wanted to express mathematically the idea of the steady state.

He wrote a separate paper in which he proposed a **C creation field** (currently we call it the Higgs field φ). However, he admitted that he had no idea about the nature of this field. Yet, it seemed to make more sense for the universe to be created in this way than for it to be created from a primordial Ylem soup through a bottle of Quantro.

For all these eccentric ideas for his time, the scientific establishment pushed Hoyle into obscurity, forcing him to put his ideas into popular books explaining in them the creation of atoms through nuclear fusion and fission.

The basis for his interpretations was the periodic table of the Russian chemist Dmitri Mendeleev, who a century ago in 1869, listed all the known elements from Hydrogen to Uranium.

UNESCO acknowledged Hoyle's contribution to science by awarding him the prestigious Kalinga Prize in 1967.

Higgs came to explain how this new matter is created by assuming a field $\varphi$, a vacuum of matter, the presence of a bosonic potential $A^{\mu}$ and a temperature of $10^{28}$K, which probably comes from a collision of stars.

## 14.2. Monoverse or Multiverse?

This question remains to be answered. In the case of Multiverse we should also detect blue-shift galaxies, which is not the case at present.

For this reason, we will deal only with the case of the Monoverse.

## 14.3. Collision of white dwarfs in the same galaxy

**So-called AGN (Active Galactic Nucleus) stars, Seyfert and Quasars, radiate much more strongly from their centre, where there is a black hole and it strongly pulls matter around it, than most galaxies.**

The oldest Quasar discovered has a lifetime of 10 billion years, younger than many galaxies.

The thrust force from the radiation of these galaxies is much greater than the one of ordinary galaxies, and the expansion speed is much greater. Fig. 14.1 shows a white dwarf $G_1$ of our galaxy $\Gamma A \Lambda_1$ and an AGN star $G_2$ of the same galaxy, which was formed after $G_1$, moving, as indicated by their arrows, where $t$ is the parameter of time.

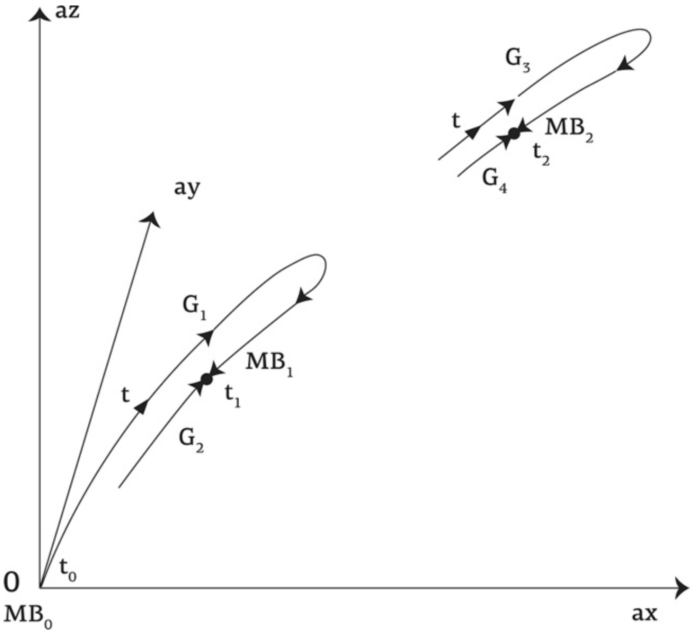



*Figure 14.1*

$G_2$ is approaching $G_1$, which is gravitationally attracted to the former, changes direction and they collide head-on.

In the vacuum created, the neighbouring white dwarfs are attracted to each other and collide. This continues until all white dwarfs collide with each other, ending in time $t_1$ a $MB_1$. At $t_2$ time an $MB_2$ of another galaxy will be completed.

Because the speed of white dwarfs is finite, **the duration of the big bang $\Delta t$ seems to have been quite long, consisting of several successive explosions.**

What Mega Bang left behind was a temperature $10^{28}$K, a massless Higgs field φ, a massless bosonic potential $A^{\mu}$, massless electrons $e^{\pm}$ and quarks, through which the galaxy is being reborn.

The collision of the two stars of Chap. 14.3 was an introductory example. The force of attraction between stars (white dwarfs) of rest mass $m_0$ was the Newtonian $\sim m_0^2/r^2$plus the Bernoulli force.

The velocities of the collision, let's assume that they were $v = 1 - 10^{-x}$ with $x = 35$, $(c = 1)$. These velocities are permissible because (Chap. 6), the velocities at the collision of the Sun with Saturn were infinite.

The collision increases the energy density of one pair of white dwarfs according to equation (23.2).

The energy density in the physical unit system of Chap. 17.2 will be increased to

$$\Pi E = [2m_0 x 10^{x/2}/\sqrt{2}]^4 GeV^4 = 4\rho 10^{2x} GeV^4.$$

**If we set the mass density $\boldsymbol{\rho}$ of the white dwarf equal to $\mathbf{4.3 \times 10^{-12} GeV^4}$ of R. Pogge of Chap. 2,** then the energy density after the collision will be

$$\Pi E = 4 \times 4.3 \times 10^{-12} \times 10^{70} GeV^4 \approx 10^{59{,}24} GeV^4.$$

The corresponding Higgs temperature is $T_H \approx 10^{14{,}81}$GeV, in natural units [G. Boerner, $T_H = (10^{14} - 10^{15})$GeV, S. Weinberg $T_H = 10^{15}$GeV].

Over a period of time $\Delta t$ all the remaining white dwarfs in the galaxy will collide.

These are $n = 10^7$ (Young, K.). This means that in $0{,}5 \times 10^7$ points in the galaxy we have, with a temperature $T_H = 10^{14{,}81} GeV \approx 10^{28} K$, **the conditions for the formation of a new star.**

What the stars left behind after the Mega Bang was a temperature $10^{28}$K capable of destroying what was left of the two stars and starting the phase of star mass and new galaxy formation. The dropping of the temperature to 0 degrees Celsius over time brought us the Ice Age and the death of the Dinosaurs. After the melting of the ice we have the great floods, the birth of the carnivores and the good hiding of the herbivores. **The periodicity of the phenomenon is $9 \times 10^9$ years, see. Chap. 1.**

[1] G. Boerner, The Early Universe, Facts and Fiction,Fourth Edition, p. 365.

[2] STEVEN WEINBERG COSMOLOGY, Appendix A, June 2007, p. 510, Planck energy = $1{,}22 \times 10^{19}$GeV ~ $1{,}4 \times 10^{32}$K

# 15. The era of matter

In the era when matter dominates we have

$$(p > 0), a(t) \sim t^{2/3}, \rho_M \sim a^{-3}, H = 2/3t$$

Where $a(t)$ is the expansion constant of the Universe and ***H* the Hubble constant (Chap. 22.3).**

The end of the radiation era is virtual, i.e. no other forms of energy should exist. However, current era is a mixture of light energy, dark energy, radiation and vacuum energy. Dark matter can only be estimated through gravitational lenses. The raw material was electrons, positrons, quarks and from these protons, neutrons, mesons and the visible atom $H$. The creation of atoms was the end of the dark era, in $t = 380000$ years the photons began to be emitted and reached the Earth.

The initial relative abundance of medium atoms is due to fusion, because of the high temperature and pressure in the core of the stars. However, the formation of medium and radioactive atoms is based on the well-founded hypothesis that they were formed in the early universe at high temperatures and pressures in the so-called r-process (from the word rapid), where the new neutrons were captured in the already formed nuclei and by expelling an electron (beta-radioactivity) mutated into a proton, thus raising the atom's position in the periodic table of elements by one position.

Because both the lower elements of the periodic table and the higher ones are unstable at high temperatures and pressures, we have fusion or fission, where hydrogen produces helium and heavy atoms produce fission (Chap. 34.3) and, as a function of temperature and pressure, all the atoms of medium atomic weight are produced.

The most stable element is iron, followed by manganese, chlorine, nickel and krypton, among others.

In 1940 Gamow, Alpher and Herman were the only nuclear physicists at George Washington University trying to link nuclear fusion to the Big Bang. The other Nuclear Physicists, Bethe, Oppenheimer, were engaged in the Atomic Bomb at Los Alamos.

However, around 1950 it was Hoyle who, by studying stars at different stages of their lives, was able to calculate at what temperature and pressure, through nuclear fusion and fission reactions, most of the elements in Periodic Table 15.1 are produced.

| Perioden | 0. Gruppe | 1. Gruppe Nebengruppe Hauptgruppe | 2. Gruppe Nebengruppe Hauptgruppe | 3. Gruppe Nebengruppe Hauptgruppe | 4. Gruppe Nebengruppe Hauptgruppe | 5. Gruppe Nebengruppe Hauptgruppe | 6. Gruppe Nebengruppe Hauptgruppe | 7. Gruppe Nebengruppe Hauptgruppe | 8. Gruppe | 0. Gruppe |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | **1 H** *1,00797* | — | — | — | — | — | — | | **2 He** *4,0026* |
| 2 | **2 He** *4,0026* | **3 Li** *6,939* | **4 Be** *9,0122* | **5 B** *10,811* | **6 C** *12,01115* | **7 N** *14,0067* | **8 O** *15,9994* | **9 F** *18,9984* | | **10 Ne** *20,183* |
| 3 | **10 Ne** *20,183* | **11 Na** *22,9898* | **12 Mg** *24,312* | **13 Al** *26,9815* | **14 Si** *28,086* | **15 P** *30,9738* | **16 S** *32,064* | **17 Cl** *35,453* | | **18 Ar** *39,948* |
| 4 | **18 Ar** *39,948* | **19 K** *39,102* | **20 Ca** *40,08* | 21 Sc *44,956* | 22 Ti *47,90* | 23 V *50,942* | 24 Cr *51,996* | 25 Mn *54,9381* | 26 Fe 27 Co 28 Ni *55,847 58,9332 58,71* | |
| | | 29 Cu *63,54* | 30 Zn *65,37* | **31 Ga** *69,72* | **32 Ge** *72,59* | **33 As** *74,9216* | **34 Se** *78,96* | **35 Br** *79,909* | | **36 Kr** *83,80* |
| 5 | **36 Kr** *83,80* | **37 Rb** *85,47* | **38 Sr** *87,62* | 39 Y *88,905* | 40 Zr *91,22* | 41 Nb *92,906* | 42 Mo *95,94* | 43 Tc [99] | 44 Ru 45 Rh 46 Pd 101,07 *102,905 106,4* | |
| | | 47 Ag *107,870* | 48 Cd *112,40* | **49 In** *114,82* | **50 Sn** *118,69* | **51 Sb** *121,75* | **52 Te** *127,60* | **53 J** *126,9044* | | **54 Xe** *131,30* |
| 6 | **54 Xe** *131,30* | **55 Cs** *132,905* | **56 Ba** *137,34* | 57 La *138,91* 58…71 Lanthaniden [1] | 72 Hf *178,49* | 73 Ta *180,948* | 74 W *183,85* | 75 Re *186,2* | 76 Os 77 Ir 78 Pt *190,2 192,2 195,09* | |
| | | 79 Au *196,967* | 80 Hg *200,59* | **81 Tl** *204,37* | **82 Pb** *207,19* | **83 Bi** *208,980* | **84 Po** *210* | **85 At** [210] | | **86 Rn** 222 |
| 7 | **86 Rn** 222 | **87 Fr** [223] | **88 Ra** *226,05* | 89 Ac *227* 90…103 Actiniden [2] | | | | | | |

[1]) Lanthaniden:

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **58 Ce** | **59 Pr** | **60 Nd** | **61 Pm** | **62 Sm** | **63 Eu** | **64 Gd** | **65 Tb** | **66 Dy** | **67 Ho** | **68 Er** | **69 Tm** | **70 Yb** | **71 Lu** |
| *140,12* | *140,907* | *144,24* | [147] | *150,35* | *151,96* | *157,25* | *158,924* | *162,50* | *164,930* | *167,26* | *168,934* | *173,04* | *174,97* |

[2]) Actiniden:

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **90 Th** | **91 Pa** | **92 U** | **93 Np** | **94 Pu** | **95 Am** | **96 Cm** | **97 Bk** | **98 Cf** | **99 Es** | **100 Fm** | **101 Md** | **102 No** | **103 Lw** |
| *232,038* | *231* | *238,03* | [237] | [239] | [241] | [242] | [247] | [249] | [252] | [253] | [256] | | |

*Table 15.1: Periodic Table of elements. The top number is the atomic number. The lower one is the mass number*

The current density of matter is

$$\rho = \rho_V + \rho_R + \rho_M,$$

where $\rho_V \approx 70\%$ is the residual thermal energy of the early vacuum and 30% that converted to mass (Chap. 18), $\rho_R \approx 0$ radiation and $\rho_M \approx 30\%$ the sum of the visible $\rho_B$ (atoms with baryons and electrons) and $\rho_D$ dark mass,

$\rho_M = \rho_B + \rho_D$. Further detailed measurements show that $\rho_B \approx 5\%$ and $\rho_D \approx 25\%$.

**These values are strongly supported by observations of anisotropies in the cosmic microwave background (CMB)**. If dark matter is so dominant, we should know its properties and components.

We know that this matter is dark, in the sense that it does not produce radiation and we cannot see it; but also because it has not lost its kinetic energy to the point where it loosens in the galactic disks, like baryonic matter. This means in particular that such particles should be electrically neutral. Detailed studies of the galaxy clusters dynamics indicate that dark matter particles should also be cold, in the sense that their velocities are extremely non-relativistic. According to S. Weinberg, the study of a double galaxy 1 E0657-558 (the "globular cluster") with $z = 0{,}296$ provided vivid direct evidence for the existence of dark matter, which has gravitational interactions with itself or with ordinary baryonic matter. The galaxies in this cluster are mostly grouped into two distinct subclusters, and the hot gas (observed because it emits X-rays) is concentrated between these subclusters. The interpretation is that two galaxy clusters have not collided. The galaxies, which have a low probability of close encounter, have come close to each other and, passing through each other without any interaction, have continued on their initial path, while the two clouds of hot gas that accompanied them previously collided and then surrounded and stabilised, due to the pressure of the hot gas, in the centre of the double cluster. The ratio of mass in the hot gas to mass in all matter is estimated to be about 1/6, according to $\Omega_B/\Omega_M = 11\%$ where the light component emits X-rays.

The pressure of the hot gas had cancelled out the attraction between the two dark matter subsets, keeping them apart. It turns out that most of the dark matter is not bound to the hot gas. Each component of dark matter is a degraded free gas, (stellar matter, Chap. 2.3) and degradation effects can convert the kinetic energy of baryonic matter into radiation. Radiative cooling then allows baryonic matter to sink into the centre of the condensed formation, while the initially well-mixed dark matter component separates and forms an extended halo around the central condensation.

If the diffusing collapse of baryonic matter is stopped by angular momentum, a disk is formed. If star formation is stopped, the diffusive collapse of baryons forms a spherical system.

The total density of matter, both light and dark, is mapped through its effect on the gravitational deflection of light from more distant galaxies along the same line of light (see Chap. 26).

Elementary particle theory reveals several candidates for cold dark matter particles. A major goal is to identify such particles.

In 1982 D. Nanopoulos, J. Ellis, J. Hegelin, K. Olive and M. Srednicki proposed **neutralino, the linear combination of bosons $W^+$, $W^-$ and $Z$ as a prime candidate for the texture of dark matter**. What remains is experimental confirmation by the Large Hadron Collider (LHC) at CERN, Chap. 24.4.

D. Nanopoulos with S. Weinberg (Nobel Prize in Physics 1979) are shown in the picture below).

# 16. Interaction of the photon with matter and measurement of dark matter

## 16.1. The attraction of the photon from the earth

For the amplitude $\Gamma$ of the energy emitted by a radioactive atom and its residence time $\tau$ in the excited state, Heisenberg's indeterminacy principle specifies that the product $\Gamma \cdot \tau = 1$ (for ħ=1). At a temperature of the radioactive atom $T = 0K$ the residence time $\tau$ becomes very long so the amplitude $\Gamma$ very small and the energy emitted becomes one line. This line was called the Moessbauer line (Professor of the Technical University of Munich, popular for his lectures) for the discovery of which the professor was awarded the Nobel Prize in 1961. Using the double property of the photon as a mass, it was possible to measure with the help of this line the reduction of mass at a height of $z$ from the earth's surface, due to its conversion into potential energy.

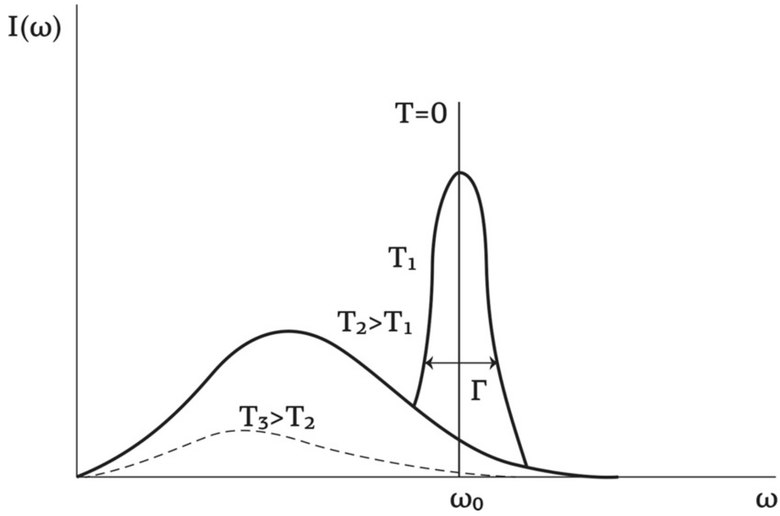



*Figure 16.1*

## 16.2. Measurement of dark mass

A dark mass of the form of a sphere with centre $L$ and radius $R$ attracts a photon whose mass is

$$m_{\gamma} = \hbar\omega_0/c^2$$

and therefore works like a lens. **The radius of the lens is the closest approximation to a beam of light and then the deflection of the photon's path is maximised. In the case where the dark mass is located between the line joining the source of the radiation *S* with the Observer *E*, we have a ring around the dark matter. From the angle of divergence *γ* of its trajectory, the dark mass is calculated (Fig. 16.2).**

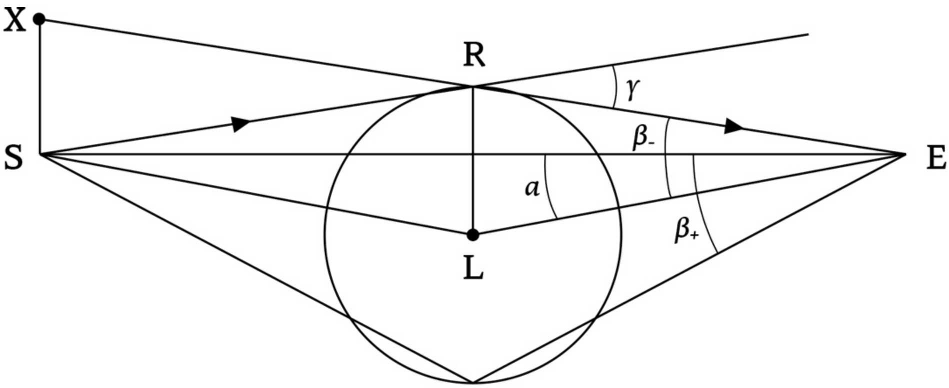



*Figure 16.2*

# 17. Unit systems

## 17.1. The international system (SI)

The International System of Units is based on the metre-kilogram-second (MKS) system of units. These are the fundamental units of Mechanics. All other units (energy, momentum, velocity, energy density, etc.) can be expressed as powers of the base units. The SI system is mostly used by engineers.

Physicists in special fields, where one or more constants are often used, such as the speed of light or the gravitational constant G, prefer to get rid of them, setting them equal to 1.

So we come to the special unit systems.

## 17.2. Natural units

Natural units are used almost exclusively in cosmology and general relativity (A. L. Myers). There, the constants of the following are often used:

| | |
|---|---|
| speed of light | $c = 2.9979 \times 10^{8} m/s$ |
| the reduced Planck constant | $\hbar = 1.0546 \times 10^{-34} Js$ |
| the Boltzmann constant | $k_B = 1.3806 \times 10^{-23} JK^{-1}$ |
| and the electric constant | $\varepsilon_0 = 8.8542 \times 10^{-12} A^2 s^4 Kg^{-1} m^{-3}$ |

**Therefore, all these are set equal to 1.**

Table 1 provides conversion factors for some of the variables ecountered in cosmology.

| Variable | SI Unit | Natural Unit | Factor | Natural unit → SI unit |
|---|---|---|---|---|
| mass | kg | E | $c^{-2}$ | 1 GeV → $1.7827 \times 10^{-27}$ kg |
| length | m | $E^{-1}$ | $\hbar c$ | 1 $GeV^{-1}$ → $1.9733 \times 10^{-16}$ m |
| time | s | $E^{-1}$ | $\hbar$ | 1 $GeV^{-1}$ → $6.5823 \times 10^{-25}$ s |
| energy | kg $m^2$ $s^{-2}$ | E | 1 | 1 GeV → $1.6022 \times 10^{-10}$ J |
| momentum | kg m $s^{-1}$ | E | $c^{-1}$ | 1 GeV → $5.3444 \times 10^{-19}$ kg m $s^{-1}$ |
| velocity | m $s^{-1}$ | dimensionless | $c$ | 1 → $2.9979 \times 10^{8}$ m $s^{-1}$ |
| angular momentum | kg $m^2$ $s^{-1}$ | dimensionless | $\hbar$ | 1 → $1.0546 \times 10^{-34}$ J s |
| area | $m^2$ | $E^{-2}$ | $(\hbar c)^2$ | 1 $GeV^{-2}$ → $3.8938 \times 10^{-32}$ $m^2$ |
| force | kg m $s^{-2}$ | $E^2$ | $(\hbar c)^{-1}$ | 1 $GeV^2$ → $8.1194 \times 10^{5}$ N |
| energy density | kg $m^{-1}$ $s^{-2}$ | $E^4$ | $(\hbar c)^{-3}$ | 1 $GeV^4$ → $2.0852 \times 10^{37}$ J $m^{-3}$ |
| charge | C = A·s | dimensionless | 1 | 1 → $5.2909 \times 10^{-19}$ C |

*Table 1. Natural units*

As an example, we discuss Einstein's equation

$$R^{\mu\nu} - g^{\mu\nu}R/2 - \Lambda g^{\mu\nu} = 8\pi G T^{\mu\nu}.$$

The Planck mass is

$$m_P = \sqrt{\hbar c/G} = 2.1764 \times 10^{-8} Kg.$$

In natural units $m_P = 1{,}2209 \times 10^{19} GeV$. Replacement of the gravitational constant $G = 0{,}667 \times 10^{38} GeV^{-2}$ in Einstein's equation ($\Lambda$ is the cosmic constant) with the Planck mass gives

$$R^{\mu\nu} - g^{\mu\nu}R/2 - \Lambda g^{\mu\nu} = 8\pi T^{\mu\nu}/m_P^2.$$

Continuing with the natural units, the energy momentum tensor $T^{\mu\nu} = \delta\iota\alpha\gamma\acute{\omega}\nu\iota o(\rho, p, p, p)$ has energy density units $GeV^4$ and Planck mass $GeV$ units. The right-hand side (RHS) of Einstein's equation therefore has $GeV^2$ units. On the left-hand side (LHS) of the equation, the metric tensor $g^{\mu\nu}$ is dimensionless, so the Ricci tensor $R^{\mu\nu}$, the Ricci scalar $R$ and the cosmological constant $\Lambda$ all have natural $GeV^2$ units, or mass and energy which are equivalent have $GeV$ units. Let us consider the cosmological constant $\Lambda$ which has the same units as the Ricci tensor $R^{\mu\nu}$ and is called the energy density of the vacuum $\rho_V$ ($E$ denotes Einstein):

$$\rho_{EV} \approx 3 \times 10^{-47} GeV^4.$$

The mass density of the vacuum is $\rho_{MV} \approx 0{,}92 \times 10^{-26} Kg/m^3$.

$$\Lambda = 8\pi\rho_{EV}/m_P^2 = 5{,}06 \times 10^{-84} GeV^2.$$

This physical unit converted to the SI unit gives

$$\Lambda = 1.3 \times 10^{-52} m^{-2}$$

Converting the vacuum energy density from natural units into SI units gives

$$\rho_{EV} = 6.3 \times 10^{-10} Jm^{-3}.$$

In some scientific fields, such as Plasma Physics, the Boltzmann constant appears $k_B = 8{,}6 \times 10^{-12} GeV$. Its conversion into natural units ($k_B = 1$) is given by the relation $1GeV = 1.16 \times 10^{13} K$.

## 17.3. Geometrized units

In gravitational problems the constant often appears

Speed of light $c = 2.9979 \times 10^8 m/s$, και η

Newton's constant Newton $G = 6.6743 \times 10^{-11} m^3 kg^{-1} s^{-2}$.

Therefore, it is convenient to take them as

$$c = G = 1$$

and the result is Table 2.

| Variable | SI Unit | Geom. Unit | Factor | Geometrized unit → SI unit |
|---|---|---|---|---|
| mass | kg | m | $c^2G^{-1}$ | 1 m → $1.3466 \times 10^{27}$ kg |
| length | m | m | 1 | 1 m → 1 m |
| time | s | m | $c^{-1}$ | 1 m → $3.3356 \times 10^{-9}$ s |
| energy | kg $m^2$ $s^{-2}$ | m | $c^4G^{-1}$ | 1 m → $1.2102 \times 10^{44}$ kg $m^2$ $s^{-2}$ |
| momentum | kg m $s^{-1}$ | m | $c^3G^{-1}$ | 1 m → $4.0370 \times 10^{35}$ kg m $s^{-1}$ |
| velocity | m $s^{-1}$ | dimensionless | c | 1 → $2.9979 \times 10^{8}$ m $s^{-1}$ |
| angular momentum | kg $m^2$ $s^{-1}$ | $m^2$ | $c^3G^{-1}$ | 1 $m^2$ → $4.037 \times 10^{35}$ kg $m^2$ $s^{-1}$ |
| force | kg m $s^{-2}$ | dimensionless | $c^4G^{-1}$ | 1 → $1.2102 \times 10^{44}$ kg m $s^{-2}$ |
| acceleration | m $s^{-2}$ | $m^{-1}$ | $c^2$ | 1 $m^{-1}$ → $8.9875 \times 10^{16}$ m $s^{-2}$ |
| energy density | kg $m^{-1}$ $s^{-2}$ | $m^{-2}$ | $c^4G^{-1}$ | 1 $m^{-2}$ → $1.2102 \times 10^{44}$ kg $m^{-1}$ $s^{-2}$ |

*Table 2. Geometrized units*

## 17.4. Units of special relativity

In the Special Theory of Relativity, the constant speed of light is often used $c = 2.9979 \times 10^8 m/s$.

Setting c=1, we obtain Table 3.

| Variable | SI Unit | SR Unit | Factor | SR unit → SI unit |
|---|---|---|---|---|
| mass | kg | kg | 1 | 1 kg → 1 kg |
| length | m | m | 1 | 1 m → 1 m |
| time | s | m | $c^{-1}$ | 1 m → $3.3356 \times 10^{-9}$ s |
| energy | kg $m^2$ $s^{-2}$ | kg | $c^2$ | 1 kg → $8.9875 \times 10^{16}$ kg $m^2$ $s^{-2}$ |
| momentum | kg m $s^{-1}$ | kg | $c$ | 1 kg → $2.9979 \times 10^{8}$ kg m $s^{-1}$ |
| velocity | m $s^{-1}$ | dimensionless | c | 1 → $2.9979 \times 10^{8}$ m $s^{-1}$ |
| angular momentum | kg $m^2$ $s^{-1}$ | kg m | $c$ | 1 kg m → $2.9979 \times 10^{8}$ kg $m^2$ $s^{-1}$ |
| force | kg m $s^{-2}$ | kg $m^{-1}$ | $c^2$ | 1 kg $m^{-1}$ → $8.9875 \times 10^{16}$ kg m $s^{-2}$ |
| acceleration | m $s^{-2}$ | $m^{-1}$ | $c^2$ | 1 $m^{-1}$ → $8.9875 \times 10^{16}$ m $s^{-2}$ |
| energy density | kg $m^{-1}$ $s^{-2}$ | kg $m^{-3}$ | $c^2$ | 1 kg $m^{-3}$ → $8.9875 \times 10^{16}$ kg $m^{-1}$ $s^{-2}$ |

*Table 3. Units of Special Relativity*

# 18. Conclusions and suggestions for future research

## 18.1. Conclusions

The fact that the stars which make up galaxies have a limited life means that when each one of the last galaxies who die in a Mega Bang a billion new galaxies are born. Birth results from a Mega Bang of faster to slower stars colliding, dying and, through the Higgs mechanism, creating a new universe. The phenomenon is repeatable. Currently, we are in the era of our own Mega Bang. The arrow of time starts from the $-\infty$ and reaches $+\infty$. The **fact that the Mega Bang model together with Einstein's Equation predicts, according to the advancements of modern physics, all observations, such as the expansion of the Universe, the redshift of galaxies, the emission of microwaves from all directions of space, the large-scale structure in the distribution of galaxies, the observed concentrations of Hydrogen, Helium and Lithium allows us to call it the Big Bang model.**

On the theory of inflation we have made a proposal that does not contradict any natural law.

## 18.2. Suggestions for future research

- The question of the Monoverse or Multiverse remains unanswered.
- The distribution of dark energy needs to be investigated. Does it form a single whole or separate clusters?
- What makes up the dark energy?
- **How long is the time $\Delta t$** (Fig. 3.6) to complete a Mega Bang?

# 19. Processes during temperature drop

After time zero of the Big Bang the temperature started to drop.

We can distinguish 3 different phases in the evolution of the phenomenon described:

- The first phase is completed in an infinitesimal amount of time
- The second phase in about 100X the time of the previous one
- The third phase in about 200X the time of the previous

Each phase is also characterised by a process of sudden cooling, practically instantaneous by three orders of magnitude in about 168 sec, with a common characteristics between them, due to a decrease in velocity, the sudden decrease in radiation.

With the muons being overviewd and the electron mass negligible, it took 0.0098 sec for the temperature to drop from a value of $10^{12}K$ to $10^{11}K$, another 0.998 sec to drop to $10^{10}K$ and another 167 sec to drop to $10^{9}K$.

# 20. The time-varying dark energy of the vacuum

The natural way to introduce a varying vacuum energy density is to assume the existence of one or more gauge fields on which the vacuum energy density depends and whose expected values vary with time. Such fields are introduced in inflation theories. We are interested here in the case of the Robertson-Walker metric in a gauge field that depends only on time and not on position. A field $\varphi$ has an energy density $\rho_\varphi$ and correspondingly an electromagnetic potential $A^\mu$ energy density $\rho_R$. This field and electromagnetic potential were seen in Chapter 9 to be consumed through the mass acquisition mechanism.

So, the initial energy density $\rho_V = \rho_\Phi + \rho_R$ decreased with time (Figure 20.1).

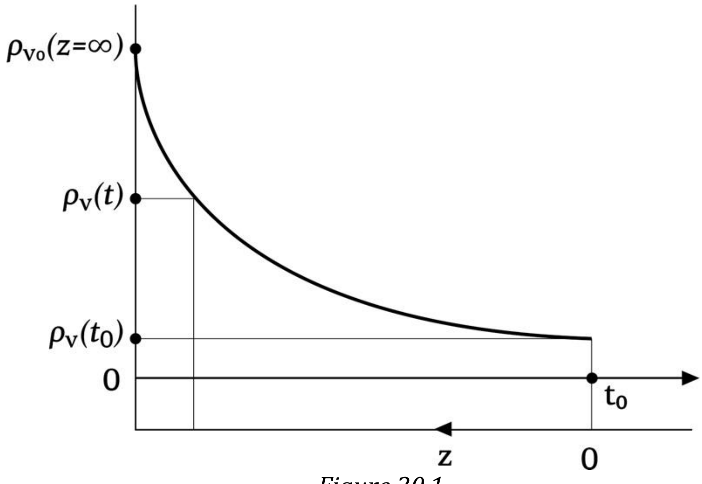


*Figure 20.1*

The initial and simple example is provided by an approach to a dynamic

$$V(\varphi) = M^{4+\alpha}\varphi^{-\alpha}, \tag{20.1}$$

near a constant minimum, where $\alpha$ is a constant $0 < \alpha < 1$ and $M$ also a constant, which gives the $V(\varphi)$ the energy density dimension.
Similar results are obtained if we take as possible the "linear" form

$$V(\varphi) = V_0 + V'_0(\varphi - \varphi_0).$$

At the end of inflation some values of z and $\rho_{V0}(z = \infty)/\rho_V$ are the following:

| z | Tracker $\rho_{V0}/\rho_V$ | linear $\rho_{V0}/\rho_V$ |
|---|---|---|
| 0 | 1 | 1 |
| 0,5 | 1.347 | 1.2 |
| 1 | 1.712 | 1.273 |
| 3 | 3.224 | 1.331 |
| ≥1 | ≥1 | 1.340 |

The linear approach best fits the observed values.

# 21. Theory of small fluctuations

Small variations in density are enough to affect the evolution of the universe. Small regions of dense matter $\rho$ attract matter $\delta\rho$ from their immediate surroundings with the help of gravity, causing them to become denser and denser until the first stars and then galaxies form. This is why during the formation of galaxies we have an unusually inhomogeneous universe, regions of density $\approx 1 g/cm^3$and vast empty regions. The average density currently is estimated at $\rho \approx 10^{-29} g/cm^3$.

In the period between $10^9 K$ and 3000K, which is the time of the creation of hydrogen atoms, we can take the hydrodynamic limit, where we apply the laws of fluid physics to the plasma where the number of collisions of photons with free electrons, scattered throughout the universe, was so large that the photons were in local thermal equilibrium with the ionized plasma, but not their velocities, which are always much lower than the speed of photons (Figure 33.1).

# PART TWO:

## DETAILED DESCRIPTION FOR READERS FAMILIAR WITH CONTEMPORARY PHYSICS

# 22. The equations of a spherical expandable space

## 22.1. Robertson-Walker metric and geodesy

### *(a) Curvature in general*

For the minimum distance between two nearby points A and B on the surface of a cosmic line curve, connecting two events in spacetime without mass, we use the metric for flat spacetime

$$ds^2 = -dt^2 + dx^2 + dy^2 + dz^2, (c = 1) \quad (22.1.1)$$

where we adopt the sign convention of the Minkowski tensor

$$\eta_{\mu\nu} = diag.(-1,1,1,1)$$

The distance between two events, A and B, in a frame of reference for which they occur simultaneously ($t_A = t_B$) the proper distance is

$$\Delta \mathrm{L} = \int_A^B \sqrt{(dx^2 + dy^2 + dz^2)}.$$

In a homogeneous and isotropic universe, although the curvature of space may vary with time, it can have the same value everywhere at a given time after Big-Bang.

On the surface of a sphere (Figure 22.1), **curvature is defined as $\boldsymbol{K} = \boldsymbol{1/R^2}$**. However, a more general expression for curvature in two-dimensional space is

$$K = \frac{3}{\pi} lim((2\pi D - C_{exact})/D^3)\ \gamma\iota\alpha\ D \to 0 \text{ (M. Pettini).}$$

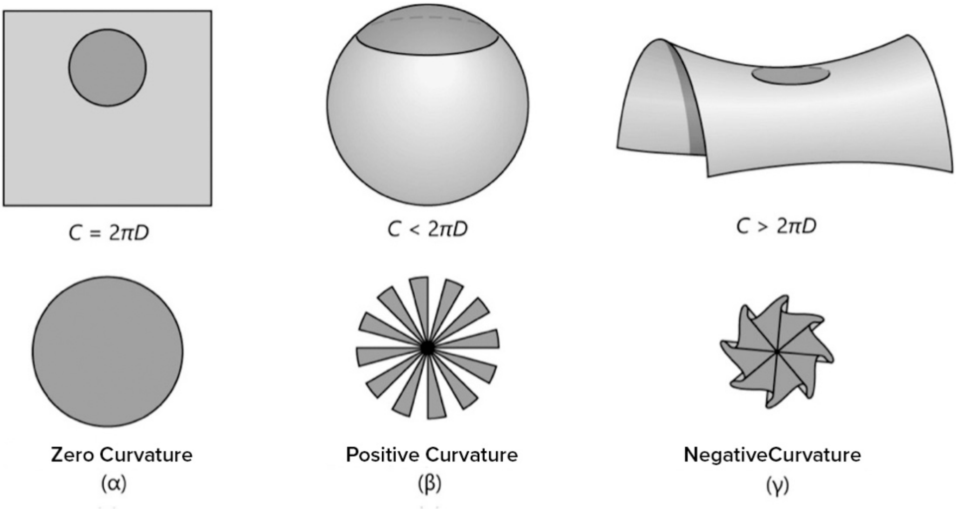



*Figure 22.1*

The distance between two points, $P_1$ and $P_2$ in a plane space in polar coordinates is the metric element

$$ds^2 = dr^2 + (rd\varphi)^2 \text{ (Σχ. 22.1.a)}$$

In spherical coordinates, the distance between two points, $P_1$ and $P_2$ in a sphere is given by Figure 21.2.b.

$$r = Rsin\theta, \text{ so } dr = Rcos\theta d\theta \text{ and}$$

$$Rd\theta = dr/cos\theta = Rdr/\sqrt{R^2 - r^2} = dr/\sqrt{1 - r^2/R^2}$$

so that

$$dl^2 = dr^2/(1 - kr^2) + (rd\theta)^2.$$

Adding the contribution of $d\varphi^2$ we have

$$dl^2 = dr^2/(1 - kr^2) + (rd\theta)^2 + r^2 sin^2\theta d\varphi^2.$$

In an expanding universe we do the transformation

$$l \rightarrow a(t)l.$$

So, the metric component takes the form

$$dl^2 = a^2(t)[dr^2/(1 - kr^2) + (rd\theta)^2 + r^2 sin^2\theta d\varphi^2]$$

Adding the contribution of time we have for the spherical space, $k = 1$, the Robertson-Walker metric

$$(ds)^2 = -(dt)^2 + a^2(t)[(dr^2/(1 - kr^2)) + r^2(d\theta^2 + sin^2\theta d\varphi^2)].$$

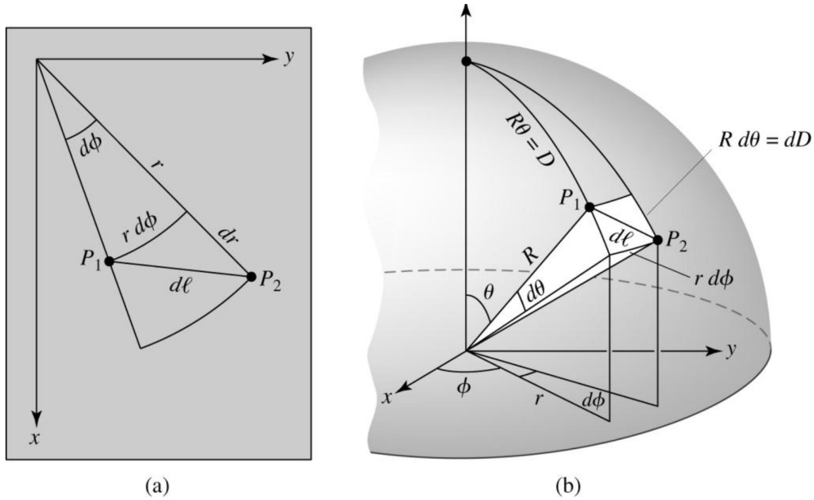



*Figure 22.2*

### *(b) The Robertson-Walker Metric, Steven Weinberg, Cosmology, p. 44*

In a homogeneous and isotropic two-dimensional space which is the plane, the linear component is

$$ds^2 = d\vec{x}^{\mathbf{2}},$$

where $\vec{x}$ represents a two-dimensional vector. Coordinate transformations that leave the linear component unchanged are parallel and ordinary rotations.

Another obvious option is a spherical surface in a three-dimensional space with radius $a$ and a linear component

$$ds^2 = d\vec{x}^2 + dz^2, \qquad z^2 + \vec{x}^2 = a^2.$$

It may turn out that the excessive surface area also leaves the $z$ unchanged in normal rotations. The linear component in such a pseudo-Euclidean space is

$$ds^2 = d\vec{x}^2 - dz^2, \qquad z^2 - \vec{x}^2 = a^2.$$

Due to the expansion of the universe, we change the scale of the coordinates

$$\vec{x}' = a\vec{x}, z' = az$$

and the linear component takes the form

$$ds^2 = a^2(d\vec{x}^2 \pm dz^2), \qquad z^2 \pm \vec{x}^2 = a^2.$$

The differential of the equation $z^2 \pm \vec{x}^2 = a^2$ gives $z \cdot dz = \mp\vec{x} \cdot d\vec{x}$ and thus

$$ds^2 = a^2[d\vec{x}^2 \pm (\vec{x} \cdot d\vec{x})^2)/(1 \mp \vec{x}^2)]$$

The above linear component can be extended to the case of the Euclidean three-dimensional space by writing it as

$$ds^2 = a^2[d\vec{x}^2 + k(\vec{x} \cdot d\vec{x})^2)/(1 - k\vec{x}^2)],$$

where

**$k = +1$ signifies global space**

**$k = -1$ signifies too much space**

**$k = 0$ signifies Euclidean space**

The above equation shows the effect of the curvature of the 3D universe on the spatial coordinates.

As a final step in the spacetime metrics, time is included. In an isotropic and homogeneous universe, there is no reason why time should pass at different rates in different locations. Therefore, the time term should simply be $cdt$. By $c = 1$ the metric component now becomes the Robertson-Walker metric

$$(ds)^2 = -(dt)^2 + a^2[d\vec{x}^2 + k(\vec{x} \cdot d\vec{x})^2)/(1 - k\vec{x}^2)],$$

which in spherical coordinates has the form

$$(ds)^2 = -(dt)^2 + a^2(t)[(dr^2/(1 - kr^2)) + r^2(d\theta^2 + sin^2\theta d\varphi^2)].$$

The Robertson-Walker metric is diagonal, with

$$g_{00} = -1, g_{rr} = a^2(t)/(1 - kr^2), g_{\theta\theta} = a^2(t)r^2, \quad g_{\varphi\varphi} = a^2(t)r^2(sin\theta)^2 \qquad (22.1.2)$$

In Cartesian coordinates

$$ds^2 = g_{\mu\nu}(x)dx^\mu dx^\nu,$$

where the curvature of space is contained in the metric tensor $g_{\mu\nu}$.

In an expanding universe with an expansion coefficient $a(t)$, curvature $k$ and Robertson-Walker metric, the squared distance is

$$ds^2 = dt^2 - a^2(t)[dx^2 + k(xdx)^2/(1 - kx^2)] = dt^2 - a^2(t)\widehat{g_{ij}}dx^i dx^j,$$

where metric $g_{\mu\nu}$ in Cartesian coordinates is

$$g_{\mu\nu} = \begin{pmatrix} -1 & 0 \\ 0 & \alpha^2(\delta_{ij} + (kx^i x^j)/(1 - kx^2\ )) \end{pmatrix} = \begin{pmatrix} -1 & \\ 0 & a^2\widehat{g_{ij}} \end{pmatrix}$$

με $g_{ij} = a^2(t)[\delta_{ij} + kx^i x^j/(1 - kx^2)]$, $g_{i0} = g_{0i} = 0$, $g_{00} = -1$, $\widehat{g_{ij}} = [\delta_{ij} + kx^i x^j/(1 - kx^2)]$, $\mu, \nu = 0, 1, 2, 3$, $i, j = 1, 2, 3$.

The concept of the Robertson-Walker metric with expansion coefficient a(t) can be clarified in spherical coordinates by calculating the real time $dt$ from the origin of a moving object in the radial coordinate $r$ in spherical coordinates.

If a particle falls in the opposite direction to

$$z = r\ (\theta = \varphi = 0)$$

$$ds^2 = dt^2 - a^2 dr^2/(1 - kr^2) = 0, dt = adr/\sqrt{1 - kr^2}$$

The actual distance is then the following Equation (22.1.3)

$$l(r, a) = a(t) \int_0^r dr\, /\sqrt{1 - kr^2} = a(t) \begin{cases} sin^{-1} r\ \gamma\iota\alpha\ k = 1 \\ r\ \gamma\iota\alpha\ k = 0 \\ sinh^{-1} r\ \gamma\iota\alpha\ k = -1 \end{cases} \qquad (22.1.3)$$

$k = 0$ for three-dimensional Euclidean (flat) space.

$k = 1$ for global space and

$k = -1$ for excessive space.

In a moving object, **the proper distance *r*** is independent of time, so the distance $l(t)$ increases or decreases with $a(t)$. The rate of change of any such distance $l(t)$ is

$$dl(t)/dt = \dot{a}(t) l(t)/a,$$

where $\dot{a}(t)$ signifies the time derivative of $a(t)$.

A particle at rest will be described in comoving coordinates. Because $g_{00} = -1$, the square of the proper time interval for a moving clock is

$$d\tau^2 = -g_{\mu\nu}(x) dx^\mu dx^\nu = dt^2 - a^2(t)[dr^2/(1 - kr^2) + r^2 d\Omega],$$

$$\text{where } d\Omega = d\theta^2 + \sin^2\theta d\varphi^2.$$

The same index above and below represents addition, according to Einstein's proposal. The equation of the motion of a particle (or photon) in free fall in a curved space is **geodesic**

$$\frac{d^2x^i}{du^2} + \Gamma^i_{kl}(dx^l/du)dx^k/du = 0 \qquad (22.1.4)$$

where $\Gamma^i_{kl}$ is the **Christoffel connection** and $u$ a parameter on the space-time curve, proportional to the proper time $\tau$ or the length of the curve $l$ on a curved surface, e.g. on a sphere, $x^i$ a Cartesian component. The geodesic equation means that the integral $\int dt$ has a minimum value after any infinite change in the path that leaves the endpoints constant. The Christoffel connection has the form

$$\Gamma^i_{kl} = \frac{1}{2}g^{i\lambda}\left[\partial g_{\lambda k}/\partial x^l + \partial g_{\lambda l}/\partial x^k - \partial g^{kl}/\partial x^\lambda\right] \qquad (22.1.5)$$

These components of the Christoffel tensor can be used to find the motion of a particle.

The quantity with non-zero mass $m_0$

$$P = m_0\sqrt{g_{ij}dx^i dx^j/d\tau d\tau} \qquad (22.1.6)$$

is its momentum, $d\tau$ **its proper time** $\boldsymbol{d\tau = dt\sqrt{1 - v^2}}$ **in a locally inertial simultaneously moving Cartesian coordinate system,** for which $g_{ij} = \delta_{ij}$. $P$ is the univariate magnitude of the momentum and thus in Lorentz transformations remains invariant. For the photon we either take its particle form, where $m_0 = h\nu/c^2$, or its wave form, where $m_0 = 0$, equation 22.1.4 holds, as will be seen from the comments on equation 22.1.7.

Therefore, we can calculate it both in the comoving Robertson-Walker coordinate system and in a spatial coordinate system in which the particle is close to the origin, where $g_{ij} = \delta_{ij} + O(x^2)$ and we can therefore overview the spatial components of the tensor $\Gamma^i_{kl}$.

First let's calculate the square of the rate of change of $(dx^i/d\tau)^2$,

$$\frac{d}{d\tau}(dx^i/d\tau)^2 = 2(dx^i/d\tau)d^2x^i/d\tau^2$$

The geodesic (21.1.4) gives

$$d^2x^i/d\tau^2 = -(2/a)(da/dt)(dx^i/d\tau)(dt/d\tau).$$

Multiplying by dτ/dt we get

$$d/dt(dx^i/d\tau) = -(2/a)(da/dt)(dx^i/d\tau),$$

whose solution is

$$dx^i/d\tau \sim a^{-2}(t).$$

Setting in Equation 22.1.6 a Robertson-Walker metric $g_{ij} = a^2(t)\delta_{ij}$ we have

$$P(t) \sim 1/a(t). \qquad (22.1.7)$$

The above equation also applies to photons in their wave form, where their momentum is $P(t) = h/\lambda$ με $\lambda \sim a(t)$.

Isotropy means that the average value of the galaxy matter stream $\boldsymbol{J}$ vanishes and homogeneity means that the average value of any scalar quantity is a function of time only, so the galaxies, baryons, etc. stream $J^\mu = (J^0, \boldsymbol{J})$ has the components

$$J^0 = n(t),\ J^i = 0,$$

where $n(t)$ is the number of galaxies, baryons, etc. per volume in a moving reference frame.

If $J^\mu$ is conserved, then the convolution, then the covariant derivative is zero

$$\partial J^\mu/\partial x^\mu + \Gamma^\mu_{\mu\nu}J^\nu = dn/dt + \Gamma^i_{i0}n = dn/dt + 3(da/dt)n/a = 0.$$

Thus, $n(t)a^3(t) = \sigma\tau\alpha\theta.$

Similarly, isotropy requires that the average value of any three-dimensional tensor $t^{ij}$ near to $\boldsymbol{x} = \mathbf{0}$ is proportional to $\delta^{ij}$ and therefore to $g^{ij}$, which is equal to $a^{-2}\delta^{ij}$ ($\delta^{ij} = 1$, if $i = j$ and 0, if $i \neq j$).

Thus, the **energy-momentum tensor** takes the form

$$\boldsymbol{T^{00} = \rho(t), T^{0i} = 0, T^{ij} = \delta^{ij} a^{-2}(t) p(t)} \qquad (22.1.8)$$

where $p(t)$ is the pressure in space.

The law of conservation of momentum requires the zeroing of the coinvariant derivative of the energy-momentum tensor

$$T^{i\mu}_{;\mu} = T^{i\mu}_{,\mu} + \Gamma^{i}_{\nu\mu} T^{\nu\mu} + \Gamma^{\mu}_{\nu\mu} T^{i\nu} = 0 \qquad (22.1.9)$$

In the comoving coordinate system ($\Gamma^{i}_{lk} \sim x^{i} = 0$) and for the Robertson-Walker metric tensor the above equation is automatically satisfied, yet the law of conservation of energy

$$0 = T^{0\mu}_{;\mu} = \partial T^{00}/\partial t + \Gamma^{0}_{ij} T^{ij} + \Gamma^{i}_{i0} T^{00} = d\rho/dt + 3\dot{a}(p+\rho)/a,$$

Gives the **continuity equation**

$$d\rho/dt + 3\dot{a}(p+\rho)/a = 0. \qquad (22.1.10)$$

Setting $w = p/\rho$, the solution of the continuity equation gives

$$\rho(t) = \rho_0 a(t)^{-3(1+w)}. \qquad (22.1.11)$$

where $w = p/\rho$ is time independent, corresponding to different eras.

- $\boldsymbol{w = -1}$, corresponds to the vacuum period ($p = -\rho_V$). In this era the density $\rho_V$ was constant.
- $\boldsymbol{w = 1/3}$ corresponds to the radiation era. This era ($p = \rho/3$) followed the inflation period. The particles (photons and neutrinos) created through electron-positron annihilation to heat the universe were relativistic and the density

$$\rho_R \sim a^{-4}. \tag{22.1.12}$$

The temperature at this era was starting from the $10^{10}$K and reached 4500K, equalizing the $\rho_R$ with $\rho_M$.

- $\boldsymbol{w = 0}$ corresponds to the matter era. This implies $p = 0$. In this era, however, the results do not agree with the observations. This is because not only gravity but also the internal energy density (Chap. 3.5) of the hydrodynamic intergalactic fluid takes part in the motion of bodies and its pressure is $p > 0$ (K. Kleidis, N. Spyrou 1999, N. Spyrou, C. Tsagas 2004).

## 22.2. Einstein's equation

Einstein, a brilliant and undisciplined student, managed to have bad relations with all his teachers. In fact, the famous Professor Minkowski once expelled him from class, calling him a lazy dog. Not having good grades in his degree he resorted to working as a clerk in the patent office in Bern, Switzerland. There he worked for seven years and with plenty of time at his disposal he busied himself with his concerns in Physics and in a letter to a friend he described his office as a secular monastery where his most beautiful ideas were incubated.

The universe, which contains matter and pressure differences and has a metric $g_{\mu\nu}$ , evolves according to Einstein's equation

$$G_{\mu\nu} = -8\pi G T_{\mu\nu}. \tag{22.2.1}$$

where

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R,$$

$R_{\mu\nu}$ are the Ricci tensor and scalar $R$ respectively.

$$R_{\mu\nu} = \partial\Gamma^{\lambda}_{\lambda\mu}/\,\partial x^{\nu} - \partial\Gamma^{\lambda}_{\mu\nu}/\,\partial x^{\lambda} + \Gamma^{\lambda}_{\mu\sigma}\Gamma^{\sigma}_{\nu\lambda} - \Gamma^{\lambda}_{\mu\nu}\Gamma^{\sigma}_{\lambda\sigma}.$$

$$\Gamma^{\mu}_{\nu\kappa} = \frac{1}{2} g^{\mu\lambda}[\partial g_{\lambda\nu}/\,\partial x^{\kappa} + \partial g_{\lambda\kappa}/\,\partial x^{\nu} - \partial g_{\nu\kappa}/\,\partial x^{\lambda}] \quad (22.2.2)$$

$\Gamma^{\mu}_{\nu\kappa}$ is the affine **Christoffel connection and $T_{\mu\nu}$ the energy-momentum tensor.**

The components of the Robertson-Walker metric are given by Equation 8.1.2.

For a co-moving observer, in the direction $x$ the tensor components $T_{00}$ and $T_{11}$ of Equation 22.2.1 are

$$T_{00} = -\rho \text{ και } T_{11} = pa^2/(1 - kr^2) \quad (22.2.3)$$

where $\rho$ and $p$ are the mass density and pressure respectively.

The corresponding tensor components of Einstein's equation after a rather lengthy calculation are

$$G_{00} = 3a^{-2}(\dot{a}^2 + k) \text{ and } G_{11} = -[2a\ddot{a} + \dot{a}^2 + k]/(1 - kr^2). \quad (22.2.4)$$

Substituting (22.2.3) and (22.2.4) into (22.2.1) we get the **Friedmann equation**

$$\dot{a}^2/a^2 + k/a^2 = 8\pi G\rho/3. \quad (22.2.5)$$

## 22.3. The different energy form ratios and the calculation of k

During the Big Bang, a collision of stars took place and a large amount of heat was released of the form of radiation in all directions, leaving a vacuum at the centre of the collision.

The division into different eras is a mathematical consequence of the definition of the $w$ as time-independent. In fact all eras give a distribution to subsequent eras.

We set a **critical matter density (the current one), with $\boldsymbol{H_0 = \dot{a}/a}$ current Hubble constant,** derived from the Friedmann equation (22.2.5) for a nearly flat galaxy

$$\boldsymbol{\rho_C = 3H_0^2/8\pi G},$$

the average matter density of the present universe $\rho_C \approx \rho_M + \rho_R + \rho_K + \rho_V$, where $\rho_M$ is the sum of the light and dark matter densities **and we define the curved density $\boldsymbol{\rho_K = -3k/8\pi G a^2(t)}$.**

By $\Omega_\nu = \rho_\nu/\rho_C, \nu = M, R, K, V$ we obviously have $\Omega_M + \Omega_R + \Omega_K + \Omega_V = 1$

From Equation (21.1.9) it follows that

$$\rho_M = \rho_{M0}a^{-3}, \rho_R = \rho_{R0}a^{-4}, \rho_V = \rho_{V0}\rho^{-3(1+w)} = \rho_{V0} = \sigma\tau\alpha\theta.$$

$\rho_K = \rho_{K0}a^{-2}, t$ is current time and $t = 0$ the time of Mega Bang, where $a = 1$. The current density is $\rho_{R0}$. $\rho_{R0}$ is not equal to 0.

$$\rho(t) = \rho_{M0}a^{-3} + \rho_{R0}a^{-4} + \rho_{K0}a^{-2} + \rho_V$$

This configuration has the advantage of allowing only one parameter $a$ to the densities and the Hubble constant $H$. All other quantities can be given as dimensionless ratios. The term $\rho_C$ is the critical current density of matter

$$\rho_C = 3H_0^2(8\pi G)^{-1} = 0{,}92 \times 10^{-26} Kg/m^3 = 4 \times 10^{-45} GeV^4.$$

Setting $x = a(t)/a_0 = 1/(1+z)$, with $a_0$ the expansion coefficient of the universe during the emission of radiation, $a$ the current expansion factor and $z$ the redshift factor with $z = 0$ the Mega Bang moment gives the age of the universe

$$t_z = H_0^{-1}\int_0^{1/(1+Z)} dx/x\sqrt{\Omega_V + \Omega_K x^{-2} + \Omega_M x^{-3} + \Omega_R x^{-4}}, \qquad (22.3.1)$$

We can rewrite the Hubble parameter as follows:

$$H(a)^2 = H_0^2(\Omega_K a^{-2} + \Omega_M a^{-3} + \Omega_R a^{-4} + \Omega_V) \qquad (22.3.2)$$

where the four currently assumed coefficients of the energy density of the universe are curvature, matter, radiation and dark energy. Each of the components decreases with the expansion of the universe (the expansion factor $a$ increases).

However, it should be noted that this does not mean that the Hubble parameter increases with time. Since the Hubble parameter is defined as $H(t) = \dot{a}(t)/a(t)$, it follows that the derivative of the Hubble parameter is given by

$$dH/dt = -H^2(1 + q_0).$$

Therefore, the Hubble parameter decreases with time (very slowly) unless the deceleration parameter $q_0 < -1$. Observations give us $q_0 \approx -0{,}55$, which implies a decrease in the Hubble parameter.

The **Einstein model,** $a_E = \sqrt{8\pi G \rho_V}$ turned out to be an unstable universe because for an infinite positive increase in $a$, $a_E$ increases. For a decrease of $a$ the $a_E$ decreases, so $a_E$ does not remain constant (Figure 22.3).

Observation established that the universe is expanding and therefore the $\rho_V$ is decreasing.

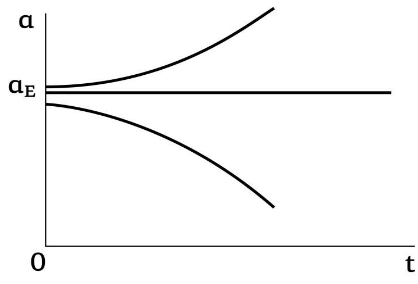



*Figure 22.3*

To make the universe stable, a cosmological constant $\Lambda$ was required in Einstein's equations, which Einstein did at first, but later removed it, admitting that this was his biggest mistake. Eventually he added it.

Starting from the proper distance $l = ar$, (22.1.3) for $k = 0$, and approaching $l_E = a_E r$, or starting from $l = l_E$ and tending to infinity, we have the Eddington-Lemaitre model.

Starting from $l = 0$ and diverging to infinity as $t$ →infinity we have the Lemaitre model and finally starting from $l = l_E$, spending a long time in $l_E$ and then tending to infinity, we have the de Sitter model *(Figure 22.3).*

Lemaitre, a Belgian clergyman (1894-1966) studied physics as well, and his sympathetic delivery made him one of the most important figures in the cosmological world.

His theological background, following his knowledge of nuclear fission and the release of great energy, led him to believe instinctively that a primordial atom could cause a temperature rise of $10^{35}$K (not a bad approach according to our $10^{28}$K of Chap. 14.4) to create by the Higgs mechanism a universe consisting of billions of galaxies where each galaxy contained billions of stars.

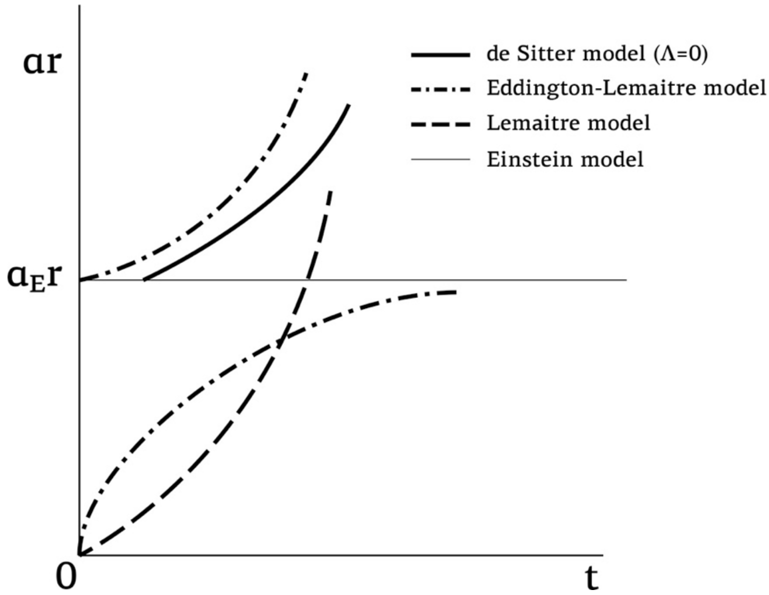
Of course, he tried to blunt his theological approach by saying that science is one thing and theology is another.I will try to serve both objectively and neutrally.

His mentor astronomer Eddington tried to give a more realistic solution by replacing the primordial atom of matter closed in a sphere of finite radius.

Hoyle, agreeing with our proposal, argued for a changing eternal universe, where stars are constantly being annihilated and created.

The de Sitter model was a little late in the radius proposed by Eddington.

*Figure 22.4*



# 23. Perfect plastic collision between two stars

Suppose that two stars B1 and B2 of a galaxy with nearly equal rest masses $m_{10}, m_{20}$=$m_0$ and radii $R_{i0} = R_0$ (without limiting the generality) and **zero initial velocities** are attracted and collide. Let us assume the stars as spheres and divide them into infinite sections $dm_i (i = 1, 2)$ perpendicular to the axis $B1 - B2$. Following the collision, one intersection is next to the other. We are interested in the motion of the bodies and the momentum along the axis $B1 - B2$ and we overview the intrinsic linear velocities in other directions or rotations. In a reference frame centered on the comoving reference frame of the two bodies, the bodies having an initial total momentum $p = 0$, will maintain it after the collision. The first collision takes place between the first infinite intersections $dm_{1,}$ $dm_2$ and the sum of the momenta of these intersections $dp_1 + dp_2$ along the axis $B_1$– $B_2$ will be zero, due to the conservation of momentum (Figure 23.1). During the collision, the velocities of the intersections are zero and the masses $dm_i$ become rest masses $dm_{i0}$ $(i = 1, 2)$. Because of the infinite thickness of the intersections and the infinite collision time between $dm_1$ and $dm_2$, the velocities of the components of the bodies in the other directions $B_1$– $B_2$ remain unchanged.

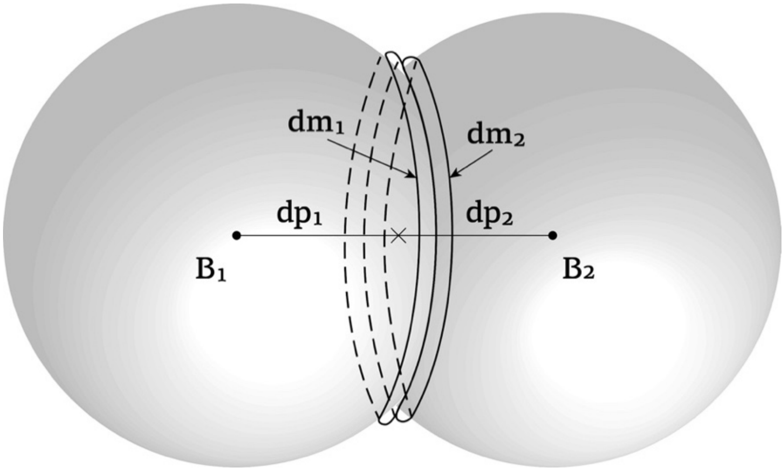



*Figure 23.1*

The mass differences will be converted into heat $dQ_i = dm_{i0}(-1 + 1/\sqrt{1 - v^2{}_i})GeV$, as a fixed reference system, where $v_i = 1 - 10^{-x}$ ($x = x_i \gg 1$, speed of light $c = 1$) the velocity of the mass $dm_i$, during the collision, increasing the temperature of the bodies B1, B2. The next spherical section will do the same, assuming that:

- At first approximation, the deceleration of bodies, due to the zeroing of the velocities of the masses $dm_1$ and $dm_2$, is cancelled out by the increase in their temperature. Then we can assume that $x$ is a constant from the beginning to the end of the collision.
- Overlooking terms of the order $10^{-2x}$, the energy (heat) for the two bodies after the final collision will be

$$Q_1 = \int (1/\sqrt{1 - v_1^2})\, dm_1 \approx m_{10} 10^{x/2}/\sqrt{2}\, GeV,$$

$$Q_2 = \int (1/\sqrt{1 - v_2^2})\, dm_2 \approx \frac{m_{20} 10^{\frac{x}{2}}}{\sqrt{2}} GeV.$$

The energy density of the star pair in a system of natural units of Chap. 17 will consist of the stationary $\rho = m_0^4$ and the internal energy density $\Pi_\rho$ of each star, where $m_0$ is the mass of the 2 stars

$$\Pi E = (2\mathrm{x}m_0 10^{x/2}/\sqrt{2})^4 \text{ GeV}^4 = 4\rho 10^{2x} \text{ GeV}^4 \tag{23.1}$$

That is

$$\Pi E = \rho + \Pi\rho, \text{where } \Pi\rho = 4\rho 10^{2x} - \rho.$$

Before the collision, energy density mass $\rho$ moving at a velocity $v$ has an internal energy density

$$\Pi\rho = \rho(-1 + 1/(1 - v^2)^{1/2}) \tag{23.2}$$

a. The volume of the two white dwarfs before the collision is $2V_0 = 2 \times 4\pi R_0^3/3$. After the collision the spherical aggregate, $k = 1$occupies a volume $V = 4\pi R^3/3$, with $R = 1.26R_0$ and containing a Higgs field $\varphi$a vector boson $A^\mu$ and the massless fermions, which like gas escaped to create a vacuum.
b. In the created vacuum run nearby white dwarfs. At the same time, the cluster with a radius $R$ acquires mass, through the Higgs mechanism, and collides with the nearest white dwarf to create the state described in paragraph (a), with a larger radius and smaller $k$. A small sphere has curvature $k = 1$. A much larger sphere will locally look like a Euclidean space and will have $k = \varepsilon < 1$. The above continue until all the white dwarfs collide, creating the Mega Bang. Because of the continuation of every physical event, the curvature of the curvature of the universe is not a matter of time. $k$ is preserved and currently $k = \varepsilon \ll 1$.

# 24. The Higgs mechanism

## 24.1. The spontaneous symmetry breaking of a real field

In the Standard Model the Lagrangian for a real field $\varphi$ is symmetric in $\pm\varphi$

$$L = \frac{1}{2}[(\partial_\mu \varphi \partial^\mu \varphi - V(\varphi, T)]$$

$$V(\varphi) = -\frac{1}{2}\varphi^2\mu^2 + \lambda^2\varphi^4/4 + V(0, T)$$

The dynamic energy density is a function of the Higgs field $\varphi$, (Higgs boson) and temperature. Its first term is the mass $m = \mu^2 = 125{,}1\text{GeV}$ and the second term is the interaction. The third term is the value of the potential $V(0, T)$. There is a critical temperature $T_H \approx 10^{28}$K, Higgs temperature, of transition from phase I to phase II. For $T > T_H$the potential $V(\varphi, T)$ in phase I is constant. For $T = T_H = 10^{28}K$ the potential $V(\varphi, T)$ is unstable, symmetric with respect to $\varphi$ and the slightest perturbation leads it to phase II, where a break in symmetry occurs with respect to $\varphi$. We usually start from an unstable minimum of the potential energy for $T = T_H$, i.e. from a zero derivative of the potential, so that the smallest perturbation in $\varphi = 0$ breaks the symmetry and leads the potential to a stable minimum, e.g. at $\varphi = +\mu/\lambda$. This symmetry breaking corresponds to the Lorentz gauge of Chap. 25, for the electromagnetic potential $A^\mu$ and makes it possible to calculate the observable physical quantities. The dynamic energy at the peak $V(0)$ falling to a constant minimum at the base of figure 24.1 is converted into kinetic energy $E$ in the system of natural units 17.2.

## 24.2. The spontaneous symmetry breaking of a complex field that gives the physical observable quantities a specific value

Lagrangean $L$ of a complex field is the difference between the kinetic and dynamic energy

$$V(\varphi) = -\frac{1}{2}\varphi^{+}\varphi\mu^{2} + \lambda^{2}(\varphi^{+}\varphi)^{2}/4 + V(0,T).$$

$$L = \frac{1}{2}[(\partial_{\mu}\varphi^{+}\partial^{\mu}\varphi \ - V(\varphi,T)].$$

We usually start from an unstable minimum of the potential energy, i.e. from a zero derivative of the potential,

$$\frac{dV(\varphi)}{dt} = \varphi(\mu^{2} - \lambda^{2}\varphi^{2}) = 0$$

This equation has the solutions $\varphi = 0$ and $\varphi = \pm\mu/\lambda$. We interpret the solution of the Higgs boson $\varphi = 0$ as sitting on an unstable minimum at the top of a Mexican hat with angular symmetry and the solution (without limiting the generality) $\varphi = \mu/\lambda$ on the real axis as a stable minimum, after a spontaneous symmetry breaking, at the bottom of the Mexican hat (Figure 24.1). This corresponds to adopting a gauge e.g. Lorentz for the electromagnetic potential and then every physical observable quantity is defined (see Chap. 25).

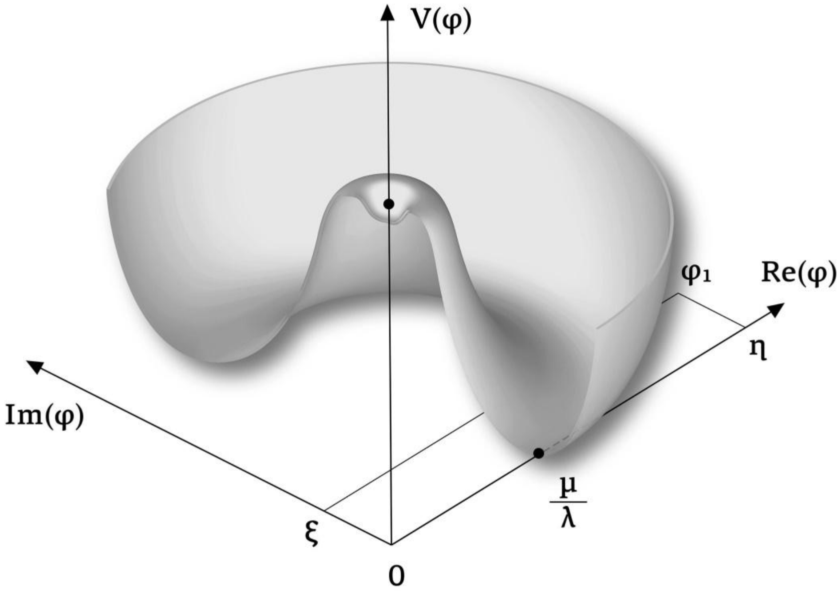



*Figure 24.1*

Figure 24.1 is double. At $t = 0$ the Higgs boson is at the top and in $t = \Delta t'$ is at the bottom of the hat in $\varphi = \mu/\lambda$.

## 24.3. Local gauge invariance

The local gauge invariance is necessary if the gauge fields are encountered with electromagnetic fields, with a potential $A_\mu$. Then the Lagrangian has the form

$$L = \frac{1}{2}(\partial_\mu \varphi^+ \partial^\mu \varphi) + \frac{1}{2}\mu^2 \varphi^+ \varphi - \lambda^2 (\varphi^+ \varphi)^2/4 - F^{\mu\nu} F_{\mu\nu}/4$$

where $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$.

This gauge invariance means that you should be able to do local gauge transformations on the fields involved in the theory without changing the laws of physics. One such gauge transformation is the rotation of the field

$\varphi(x) \rightarrow e^{i\vartheta(x)}\varphi(x)$. If $\theta$ depends on $x$ we call it local, otherwise we call it general.

In quantum field theory there are two ways in which gauge or complex fields $\varphi$ can occur: either directly or as derivatives. They always occur in pairs or larger groups, usually of a conjugate and a normal field, such as $\varphi^+\varphi$. $\varphi^+$ is the Hermitian conjugate). Such terms involving only the fields themselves are always measure invariant, because when you do the gauge transformation, the phase factor is cancelled. However, if you have a term involving factors, such as $(\partial\varphi^+)\partial\varphi$, you also have the derivative of the phase factor $\vartheta = \mu/\lambda$. In order to keep the physical laws unchanged we have to add to the derivatives the coupling of the electromagnetic potential $A_\mu$ with the field $q$, $iqA_\mu$. In addition, we have to do the transformation $A_\mu(x) \rightarrow A_\mu(x) + q^{-1}\partial\mu\vartheta$. Therefore, we end up with the integral derivative $D_\mu = \partial_\mu + iqA_\mu(x)$, where the phase factor $\vartheta$ is eliminated.

## 24.4. The mass gain mechanism

In time $t = 0$ the Higgs field $\varphi$ is a complex field. The electromagnetic potential, after adopting the Lorentz gauge, has two electrically charged transverse $A_1 = W^+$, $A_2 = W^-$ components, one electrically neutral $A_3 = Z = V(\varphi)$ and one zero $A_0$ component which, after adoption of the Lorentz gauge, becomes a linear function of the three previous ones.

The Lagrangian of a mixed field $\varphi$ together with an electromagnetic field with a potential $A_\mu$ is

$$L = \frac{1}{2}\left(\partial\mu - iqA_\mu\right)\varphi^+(\partial^\mu + iqA^\mu)\varphi + \frac{1}{2}\mu^2\varphi^+\varphi - \lambda^2(\varphi^+\varphi)^2/4 - F^{\mu\nu}F_{\mu\nu}/4.$$

Exact solutions in quantum field theory are possible only in special forms of the potential (e.g. $V(r)\sim r^{-1}$) and mostly impossible. Therefore, going from a known solution, e.g. after symmetry breaking $\varphi = \mu/\lambda$ we use

**perturbation theory** and try to continue it to a neighbouring $\varphi_1$. Defining the perturbations $\eta = \varphi_1 - \mu/\lambda$ and $\xi = \varphi_2$ the Goldstone boson (which is zeroed), the Lagrangian becomes

$$L = \left[\frac{1}{2}(\partial_\mu \eta)(\partial^\mu \eta) - \mu^2 \eta^+ \eta\right] + \left[-\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}\left(\frac{q\mu}{\lambda}\right)^2 A_\mu A^\mu\right] +$$

$$\left\{\frac{\mu}{\lambda} q^2 \eta (A_\mu A^\mu) + \frac{1}{2} q^2 \eta^2 (A_\mu A^\mu) + \xi^2 q^2 A_\mu A^\mu - \lambda \mu \eta^3 - \frac{1}{4}\lambda^2 \eta^4\right\} + \mu^4/4\lambda^2.$$

Now we need to explain the meaning of certain terms in the Lagrangian. There are:

1. Kinetic energy terms involving two derivatives of the fields e.g. $\partial_\mu \eta^+ \partial^\mu \eta$.
2. Mass terms including products of the form $m_\eta \eta^+ \eta$, or $m_A A_\mu A^\mu$.
3. Interaction terms involving products of three or more fields of the form $\sim A^2\eta, A^2\eta^2$ and terms $O(\eta^3, \eta^4)$ negligible as well as a constant term that are overviewed.

**We are left with one Higgs boson that gets mass first $m_H = \mu^2 = 125.1$GeV and then the electromagnetic force field $A^\mu$ with mass $\mu/\lambda q^2 + q^2\eta^2/2$, for the transverse components $W^+$, $W^-$. The component $Z$ becomes longitudinal with mass $m_Z = \xi^2 q^2$. We can say that he has devoured the Goldstone boson.**

Simply by breaking the symmetry, a smooth field $\varphi$ and an electromagnetic force field $A^\mu = (\mathrm{l}(W^+, W^-, \mathrm{Z}), W^+, W^-, \mathrm{Z})$ have acquired mass. This is in short the result of the Higgs mechanism.

The bosons were discovered chronologically first $W^+$, $W^-$ and $Z$ with masses $m_W = 80{,}399\ GeV$ and $m_Z = 91{,}2\ GeV$.

The discovery of the Higgs boson was announced by the ATLAS and CMS research teams in July 2012 at the Large Hadron Collider (LHC) in Geneva.

Evidence for a new particle with a mass of about 125.1 GeV and the properties of the Higgs boson is emerging in experiments where:

**(a)** The Higgs boson $H$ is produced by the collision of two gluons through a quantum loop process involving a pair of top-antitop quarks, $(t + \bar{t} \to H)$. This production process has the largest scatter cross section at the LHC (Large Hadron Collider), Figure 23.2.

**(b)** The second most important process is the radiation of bosons $W$ and $Z$ from incoming quarks, which fuse to produce a Higgs boson, $(W + q \to H$, or $Z + q \to H)$.

**(c, d)** There are two additional important contributions of Higgs boson production from the collision of a pair of vector bosons $W$ or $Z$ Figure 24.2(c) or a top-antipodal pair $(t - \bar{t})$ quarks Figure 24.2(d), $(W + W \to H$, or $Z + Z \to H$, or $t + \bar{t} \to H)$.

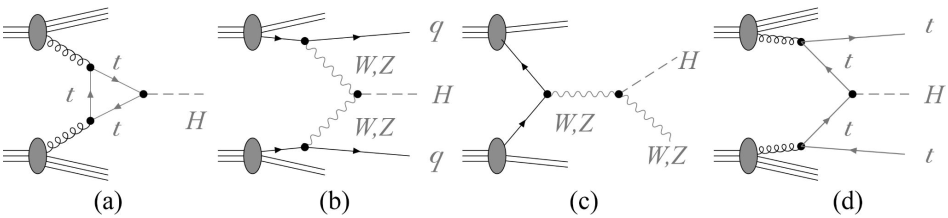



*Figure 24.2*

The boson $H$ naturally decomposes in various ways, mainly into $b, \overline{b}$ quarks with an average lifetime $10^{-22}$sec.

## 24.5. Obtaining mass of fermions

After obtaining mass of boson $H$ and the electromagnetic vector boson $A^{\mu} = (\mathrm{l}(Z, W^{+}, W^{-}), W^{+}, W^{-}, Z))$ the latter reacts with the quarks, electrons and their antiparticles through their currents and gives mass to the electrons $(\tau, \mu, e)$, the quarks $(u, d, s, c, b, t)$ and their antiparticles as well as creating the massless gluons $g_i, i = 1,2, \ldots ,8$ that bind the quarks to form baryons, e.g. $p, n$ and mesons $\pi^+, D^0$.

# 25. The symmetry of the Grand Unified Theory (GUT) and the Gauge Theories

## 25.1. The symmetry of the electromagnetic potential

The electromagnetic field can be expressed by the potential $A^{\mu} = (\Phi, \boldsymbol{A})$, where $\Phi$ is the Coulomb potential and $\boldsymbol{A}$ the vector magnetic field. The $A^{\mu}$ obeys the Maxwell equation in vacuum

$$\partial_{\mu} F^{\mu\nu} = 0,$$

$$\text{where } F^{\mu\nu} = \partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu}.$$

The Maxwell equation has gauge symmetry $\text{grad}a(x) = \partial^{\mu}(a(x))$ in time $t = 0$ of the Mega Bang, which means that the electromagnetic field does not change with transformation

$$A^{\mu}(0) \to A^{\mu}(0) + \partial^{\mu}\alpha(x) = A^{\mu}(0) + \text{grad}\alpha(x),$$

where $\partial^{\mu}\alpha(x)$ is a rotation of the Higgs boson, sitting on an unstable minimum at the top of a Mexican hat, Fig. 24.1.

The gauge should be defined for the calculation of observables and corresponds to a symmetry breaking.

The **Lorentz Gauge** is usually adopted

$$\partial_{\mu} A^{\mu} = 0. \tag{25.1}$$

Because $\text{rotgrad}\partial_{\mu}\partial^{\mu}\alpha(x) = 0$ the Maxwell equation takes the form

$$\partial_{\mu} F^{\mu\nu} = \partial_{\mu}\partial^{\mu} A^{\nu} - \partial_{\mu}\partial^{\nu} A^{\mu} = 0, \text{όπου } \partial_{\mu}\partial^{\nu} A^{\mu} = 0.$$

One example is the casino roulette. During the spin of the roulette wheel every number is possible but none is definite. When the roulette stops [this corresponds e.g. to a Lorentz gauge (25.1)] the pointer defines a single number (symmetry breaking, see Fig. 24.1) while at the same time defining the positions of the others.

Contemporary physics has generalized the above symmetry principle of the grand unified theory in vacuum, GUT. Symmetry should hold in the Mega Bang principle for the Higgs field $\varphi$, the bosonic potential $A^{\mu}$ and the non-Abelian group $SU(5)$. At this moment the Higgs field $\varphi$ should be locally invariant to the rotations $\varphi \to U(1)\varphi = e^{i\theta}\varphi$ and in general transformations $\psi \to SU(5)\psi$ of the symmetry group $SU(5)$which is valid at times $t = 0$. The group $SU(5) = SU(2) \otimes SU(3)$ at lower temperatures decomposes into the groups $SU(2)$ and $SU(3)$. The first factor represents the weak interaction, moving charge radiation or the electric field of a stationary charge. The second is the non-Abelian group $SU(2)$ and the third is the non-abelian group $SU(3)$.

The letter $U$ indicates that $U$ is a unitary matrix. A unitary matrix is one whose inverse equals its conjugate transpose ($U^{-1} = U^{T*} = U^{+}$). The letter $S$ denotes a special transformation, i.e. that the horizon $(U) = 1$. Finally, the number 5 defines the class $5 \times 5$ of the matrix. An Hermitian matrix $H$ is equal to its i conjugate transpose.

## 25.2. Non-Abelian Yang-Mills theory for the SU(2) group

As is well known, the bosons are an abelian group.

At $SU(2)$ non-abelian Yang-Mills group we have the pairs $(p, n)$ and $(e, \nu_e)$ or $(\mu, \nu_{\mu})$ or $(\tau, \nu_{\tau})$. Each time the combination $(p, n)$ is combined with one of the three generations (flavours) of the (electronic, neutrino)-pair[3]. Suppose now that we have two fields $\psi_1$ and $\psi_2$ with spin ½ (Dirac spinors)

[3] The masses of e, m and t are 0.511MeV, 105.7MeV and 1777MeV respectively. The τ–electrons were apparently created at higher temperatures in the universe.

of four components with masses $m_1$ and $m_2$. The Lagrangian function, in the absence of interactions, is the sum of their own Lagrangian functions

$$L = \sum_{i=1}^{2}[i\overline{\psi_i}\gamma^{\mu}\partial_{\mu}\psi_i - m_i\overline{\psi_i}\psi_i] \tag{25.2}$$

However, we can write Equation 24.2 in a more concise form by combining the $\psi_1$ and $\psi_2$ into a two component column vector

$$\psi = \begin{pmatrix}\psi_1 \\ \psi_2\end{pmatrix}$$

The conjugate spinorium is

$$\overline{\psi} = (\overline{\psi_1}, \overline{\psi_2})$$

And the Lagrangian function becomes $L = i\overline{\psi}\gamma^{\mu}\partial_{\mu}\psi - \overline{\psi}M\psi$ where

$$M = \begin{pmatrix}m_1 & 0 \\ 0 & m_2\end{pmatrix}$$

In particular, if the two masses happen to be equal to $m$, Equation (24.2) is reduced to

$$L = i\overline{\psi}\gamma^{\mu}\partial_{\mu}\psi - \overline{\psi}m\psi. \tag{25.3}$$

This looks exactly like Dirac Lagrangian for a particle. However, $\psi$ is now a two-element column vector and the $L$ takes a more general global invariant value in the transformation

$$\psi \to SU(2)\psi$$

where $S(U)2$ is one of the three unitary Pauli matrices $2 \times 2$, $SU^{+}(2) \times SU(2) = 1$.

In the case where the two Dirac fields are the proton and the neutron, the masses $m_1$ and $m_2$ are almost equal, so Equation 25.3 is justified, but if the two Dirac fields are the electron and the neutrino, Equation 25.3 with $m_1 = m_e$ and $m_2 = m_\nu \approx 0$ leads to destruction.

This was the reason that forced Higgs, Englert, Brout, Guralnic-Hagen and Kibble to insist on symmetry in $t = 0$, such as the Higgs boson $\varphi$as well as the field $A^\mu$ and the Lagrangians of a pair of fermions in the group $SU(2)$ and three quarks in the group $SU(3)$. This had the consequence of requiring the equality of the electron masses of the neutrino masses of the quarks and the vector boson $(l(Z, W^\pm), W^+, W^-, Z)$ to have masses in $t = 0$, equal to zero, as is the mass of the photon (Nobel Prize 2013 to Higgs and Englert). At temperature $T = 10^{10}$K we have the decoupling of the column $\psi = (e, \nu)$, the decoupling of the electron from the neutrino and at a temperature of 3000 K the formation of the hydrogen atom, from the reaction $p^+ + e^- \to H$ and the emission of the first light in 380,000 years after the Mega Bang. At this temperature we have radiation, because photons no longer collide with H atoms and reach us as radiation. The Mega-Bang happened at $10^7$ points and so we have so many stars (Young, K.).

## 25.3. The SU(3) chromodynamic group in the strong interaction

SU(3) group represents the **strong interaction** between the 3 quarks of baryons and can be expressed as follows:

$$SU(3) = e^{iH}, \text{where } H = exp(\boldsymbol{a\lambda}).$$

$\boldsymbol{a}$ is a vector of eight components and $\boldsymbol{\lambda}$ eight $3 \times 3$ non-Abelian matrices (Gell-Mann matrices); $\boldsymbol{a\lambda}$ is their inner product.

Because tables $\boldsymbol{\lambda}$ are not commutative, the transformation $SU(3)$ acting on three quarks

$$\begin{pmatrix} \psi_{f1}^{R} \\ \psi_{f2}^{B} \\ \psi_{f3}^{G} \end{pmatrix} \rightarrow SU(3) \times \begin{pmatrix} \psi_{f1}^{R} \\ \psi_{f2}^{B} \\ \psi_{f3}^{G} \end{pmatrix}$$

is also non-commutative (non-Abelian). Quarks have three generations (flavours $f = 1, 2, 3$), $(u, d)$, $(s, c)$, $(b, t)$ with different masses that do not allow the analogous Lagrangian to be written in the symmetric form of Eq. 24.3. The bond forming force between quarks is **eight massless gluons with three different colors, red, blue and green** ($\boldsymbol{R}, \boldsymbol{B}, \boldsymbol{G}$) and their symmetry was not challenged.

# 26. The cosmological red- and blue-shift

Imagine a beam of light emitted at a distance $r$ from the earth (index E) comes to us along axis $z$ $(\theta = \varphi = 0)$.

In spherical coordinates and a Robertson-Walker metric

$$ds^2 = 0, dt = -a(t)dr/\sqrt{(1 - kr^2)}.$$

Writing $\Delta t_0 = a(t_0)\,\Delta r/\sqrt{1 - kr^2}$ and $\Delta t_E = a(t_E)\,\Delta r/\sqrt{1 - kr^2}$ and dividing them we get

$$\Delta t_0/\Delta t_E = a(t_0)/a(t_E) = \lambda_0/\lambda_E.$$

Setting $\Delta t_0 = T_0, \Delta t_E = T_E$ the period of the light wave at the earth and the emission star, respectively, we obtain

$$T_0/T_E = a(t_0)/a(t_E) = \lambda_0/\lambda_E.$$

where $\lambda_0, \lambda_E$ are the wavelengths of the ray at the earth and the star respectively. The displacement is given by

$$\lambda_0/\lambda_E = 1 + z,$$

$z$ is positive, so $a(t_0)/a(t_E) > 1$ and because $t_E < t_0$ we conclude that the universe is expanding. The distance $r$ of the star was $a(t_E)r$ and now it is $a(t_0)r$.

During the previous period $t_E$, the density of matter was higher than currently because of the expansion

$$\rho(t_E) = \rho_V + \rho_R x^{-4} + \rho_M x^{-3}, \text{where}$$

$$x = a(t_E)/a(t_0) = 1/(1 + z) \tag{26.1}$$

In an ordinary unexpanded space the redshift from a source of radiation or sound with an emitted wave $\lambda_E$ moving away at a velocity $v_\Pi$ will reach us with a wavelength $\lambda_o$, as given by the Doppler equation 13.1. In an expanding space the ratio of the lengths of the transmitted wave and the wave measured on earth is $\lambda_o/\lambda_E = a(t_0)/a(t_E) = 1 + z$.

For the present time $t_0$ coefficient z is zero, while in Mega Bang time coefficient $z = 1/t \to \infty$.

While the majority of galaxies have redshifts, in our neighbourhood about 100 galaxies including two of the largest galaxies in the Andromeda and the Triangulum Galaxy have blueshifts, $z = -0.001$ for Andromeda and $z = -0.00061$ for the Triangulum Galaxy (Young K.). The reason is that for such nearby galaxies the Newtonian attraction, which is proportional to $1/r^2$, outweighs the pressure repulsion force. Furthermore, this means that the expansion velocity of our galaxy is greater than that of the Andromeda and the Triangulum Galaxy.

According to Chap. 3.7, different stars move at different speeds towards chaos. So, if the Sun is moving faster than the stars of Andromeda and the Triangulum galaxy, the former will eventually reach these galaxies. So we have an explanation why these galaxies exhibit a blueshift.

It is estimated that in about four billion years our galaxy will reach Andromeda, with which it will merge to form a new galaxy.

The distances between the stars in a galaxy are huge and most of it is empty space. So, the collision between the Milky Way and Andromeda looks more like a smooth flow star mix than a collision of massive bodies. The arrangement of current stars will be different from current arrangement.

Prior to such mergers, there shall be a merger of Andromeda with the "Small Magellanic Cloud", which is a redshifted satellite of the Milky Way Galaxy.

The blueshifted Triangulum Galaxy, which will reach the Milky Way sooner, is estimated to orbit as a satellite around the new Galaxy that will result from the integration of the Milky Way into the larger Andromeda.

A distant observer might see two bright galactic nuclei at first and then the two nuclei coalesce into a single bright nucleus. It is possible that this nucleus could eventually turn into a quasar, a source of radio waves ($\lambda = 10m - 1km$), where 30% of the mass of matter is involved in the energy-producing reaction, unlike our sun, where the proportion is about 0.7%.

**Thus, the quasar quickly runs out of fuel and ends up with a black hole in its centre.**

The oldest quasars that have been discovered are 10 billion years old, younger than many galaxies (Chap. 2.4).

# 27. Interaction of photon with matter and dark mass measurement

## 27.1. Photon attraction from the earth

A γ-quantum has energy $E = \omega_0$ and momentum ($\hbar = c = 1$). When emitted from an excited energy level $E_E$ of an atom with an average lifetime $\tau = T_{1/2}/ln2$ ($T_{1/2}$ = half-life) transitions to the stable ground state $E_K$. Its energy is $\omega_0 = E_E - E_K$ (R. Wegener, R. Mössbauer).

The corresponding average energy amplitude $\Gamma$ of the intensity centred on $\omega_0$ according to Heisenberg is

$$\Gamma\tau = \hbar = 1.$$

The nucleus that has a vector $\boldsymbol{p} = M\boldsymbol{v}$ before emission has energy

$$E_1 = E_E + p^2/(2M)$$

and after the γ-quantum emission with momentum $\boldsymbol{k}$ the energy is

$$E_2 = E_K + (\boldsymbol{q}^2)/(2M), \text{ where } \boldsymbol{q} = \boldsymbol{p} - \boldsymbol{k}.$$

The energy difference goes to the γ-quantum.

$$\omega = E_1 - E_2 = E_E - E_K - kvcos\varphi - k^2/(2M) = \omega_0 - kvcos\varphi - k^2/(2M).$$

$kvcos\varphi$ is the Doppler shift and $k^2/(2M)$ the backscatter energy.
For isotope $Fe_{26}^{57}$, $k^2(2M) \approx kv = 2 \times 10^{-2} eV$ (for average room temperature velocity, $v \approx 100\ m/s$, $\Gamma = 4{,}6 \times 10^{-9} eV$).

If $Fe_{26}^{57}$ is embedded in a crystal ($v \approx 0$ and $M \approx \infty$ is the mass of the crystal) then we should replace the $kvcos\varphi + k^2/(2M)$ with the oscillation energy $\Delta E_C$.

Therefore, $\omega = \omega_0 - \Delta E_C$.

Intensity $I(\omega)$ as a function of $\omega$ now takes the form of Figure 27.1.

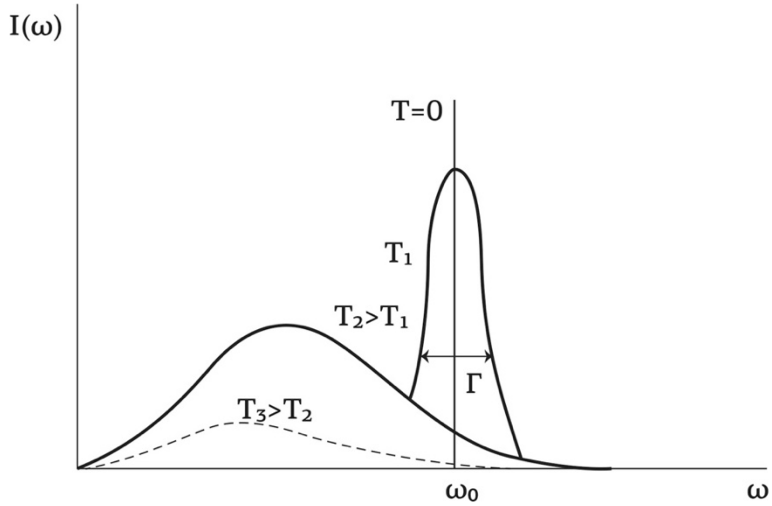



*Figure 27.1*

"line $\omega_0$" (after incorporation of Fe in crystal and cooling to $T \approx 0$) was named after **R. Mössbauer**, a Professor popular for his Lectures, for the discovery of which he was awarded the Nobel Prize in 1961. H. Wegener, BI, p. 14

Using the dual property of the photon as mass, a γ-quantum with energy $\hbar\omega_0$ has $m_\gamma = \hbar\omega_0/c^2$.

In the earth's gravitational field at a height $z$ from the ground, its dynamic energy is

$$Epot = m_\gamma gz = \hbar\omega_0 gz/c^2, (g = 981cm/s^2).$$

From the conservation of energy we have

$$\hbar\omega_0 = \hbar\omega + Epot \approx \hbar\omega(1 + gz/c^2),$$

where $\hbar\omega_0$ is the energy of the γ-quantum on the ground and $\hbar\omega$ its energy at altitude $z$.
This means redshift

$$\Delta\omega = \omega_0 - \omega = gz\omega/c^2.$$

For $z = 22{,}5m$, $\Delta\omega/\omega = 2{,}46 \times 10^{-15}$. For the isotope $Fe_{26}^{57}$ and the radius $\gamma$ ($\omega_0 = 14{,}4KeV$) it emits, this means a shift in the physical range $\Gamma/\omega_0 = 3 \times 10^{-13}$ by $\approx 1\%$. This may be small but, with the acute "Mössbauer line" it is measurable, because during cooling the average life $\tau$ increases and the range $\Gamma$ decreases making its distribution, $I(\omega)$, acute line.

## 27.2. Dark mass measurement, S. Weinberg, Cosmology, p. 437

Dark matter $M$ of the form of a sphere with a radius $R$ acts as a lens.
The beam $R$ of the lens is the closest approximation to a beam of light so the deflection is maximised. From general relativity we know that the deflection angle is

$$\gamma = 4MG/R.$$

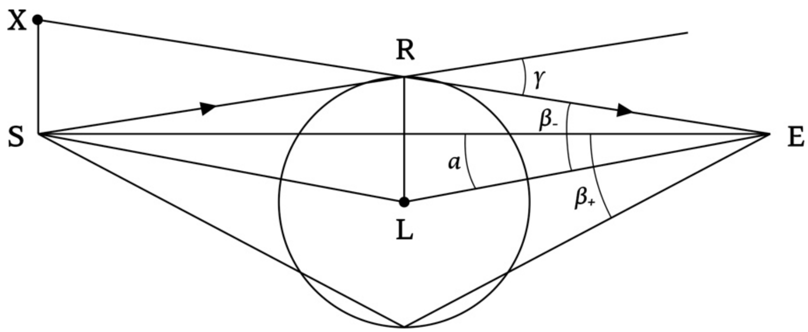



Figure 27.2

For the angles in Figure 26.2 we have

$$\beta_- = R/d(EL), \gamma = d(XS)/d(LS), \beta_- - \alpha = d(XS)/d(ES)$$

From the above equations it follows that

$(\beta - \alpha)\beta = \gamma d(LS).R/(d(ES).d(EL)) = 4MG.d(LS)/(d(ES)d(EL)) = \beta_E^2.$

The Equation $\beta^2 - \alpha\beta - \beta_E^2 = 0$ has the following solutions

$$\beta \pm = (\alpha/2) \pm \sqrt{\beta_\varepsilon^2 + \alpha^2/4}. \qquad (27.1)$$

Angle a is unknown because the $L$ is dark, but we can eventually measure the angle $\beta_+ - \beta_-$ between the two images in the opposite rays. Therefore, the absolute difference is

$$\delta = I\beta_+ - \beta_- I = 2\sqrt{\beta_\varepsilon^2 + \alpha^2/4} \geq 2\beta_E \qquad (27.2)$$

From this relationship we can calculate an upper limit

$$M \leq \beta_\varepsilon^2 d(ES)d(EL)/4Gd(LS) \qquad (27.3)$$

For example, if $d(EL) = d(LS) = 100Mpc$, $d(ES) = 200Mpc$ both images in the opposite rays of the lens are separated by $\beta_+ - \beta_- = 1''$ then $M \leq 6 \times 10^9$ Solar masses.

In the event that $L$ is on the line between the source and the earth, we have cylindrical symmetry. Therefore the two images form a ring around the lens. Then by defining in Equation 27.2 $\alpha = 0$ we have

$$\delta = I\beta_+ - \beta_- I = 2\beta E \qquad (27.4)$$

From the Equation

$$\beta_E^2 = 4MGd(LS)/d(ES)d(EL)$$

we can find the value M

$$M = \beta_E^2\, d(ES)d(EL)/\, 4Gd(LS).$$

# 28. The time-varying dark energy of the vacuum (significance)

The formulas for the energy density and pressure of the gauge field are

$$\rho_\varphi = \frac{1}{2}(d\varphi/dt)^2 + V(\varphi)$$

$$p_\varphi = \frac{1}{2}(d\varphi/dt)^2 - V(\varphi)$$

As a result $(1 + w)\rho_\varphi \geq 0$,where $w = p_\varphi/\rho_\varphi$.

Therefore, the case $w = -1$ represents the moment in time $t = 0$ of the Big Bang. We will now consider the time instant $t > 0$. Equation 7.1.10 of the continuum of energy here gives

$$d^2\varphi/dt^2 + 3Hd\varphi/dt + dV(\varphi)/dt = 0 \qquad (28.1)$$

This is the equation of motion of a unit mass particle with one-dimensional coordinates $\varphi$ moving at a potential $V(\varphi)$ with a frictional force – $3Hd\varphi/dt$. The values $V(\varphi)$ of the field will decrease until it finally reaches rest at a local minimum of $V(\varphi)$. We can adjust an additive constant to make it zero at the minimum.

- The initial and simple example is provided by a dynamic

  $$V(\varphi) = M^{4+\alpha}\varphi^{-\alpha}, \qquad (28.2)$$

  where $\alpha$ is a constant $0 < \alpha < 1$ and $M$ also a constant, which gives $V(\varphi)$ the energy density dimension. According to S. Weinberg, each potential is required at sufficiently early times $\rho_\varphi$ to be much smaller than the energy density $\rho_R$ of the radiation, because any significant increase in the energy density $\rho_\varphi$ at the moment of nucleosynthesis would lead to an abundance $He^4$ that would exceed the observed abundance. In these early times $\rho_R$ is also larger than $\rho_M$.

Chapter 10 gives $a_R \sim t^{1/2}$ and $H = 1/2t$. The field equation (28.1) with the potential (27.2) then gives

$$d^2\varphi/dt^2 + 3(d\varphi/dt)/(2t) - \alpha M^{4+\alpha}\varphi^{-\alpha-1} = 0, \qquad (28.3)$$

This has as a solution the field

$$\varphi = \{[\alpha(2+\alpha)^2 M^{4+\alpha} t^2]/(6+\alpha)\}^{1/(2+\alpha)}, \qquad (28.4)$$

Both the $(d\varphi/dt)^2$ and $V(\varphi)$ then give $t^{-2\alpha/(2+\alpha)}$ and therefore at very early times $\rho_\varphi = \rho_V$ must have been less than $\rho_R$ which is proportional to $t^{-2}$. The solution of Equation 28.4 is not unique, but it is an attractor in the sense that any other solution that approaches it (tracker) will approach it as time increases. To understand this, note that a small perturbation $\delta\varphi$ of the solution $\overline{\varphi}$ of (28.4) and the $\varphi = \overline{\varphi} + \delta\varphi$ equation 28.4 gives

$$d^2\delta\varphi/dt^2 + 3(d\delta\varphi/dt/dt)/(2t) + \alpha(1+\alpha)M^{4+\alpha}\varphi^{-\alpha-2}\delta\varphi = 0.$$

This has two independent solutions of the form

$$\delta\varphi \sim t^\gamma, \gamma = -\frac{1}{4} \pm \sqrt{1/16 - (6+\alpha)(1+\alpha)/(2+\alpha)^2}.$$

The square root is imaginary for $\alpha > 0$, so both solutions for $\delta\varphi$ diminish as $t^{-1/4}$ as $t$ Increases. For this reason, this particular solution $\varphi$ (28.4) is known as the “tracker solution” (Figure 28.1).

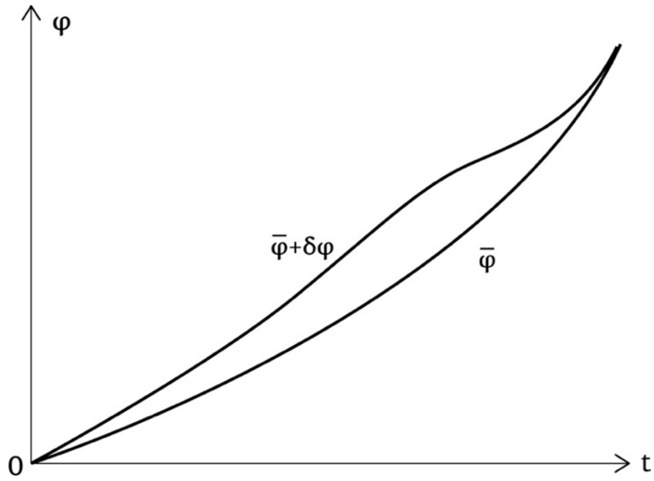



*Figure 28.1*

The energy densities are $\rho_V(t_0)$ of current, $\rho_V(t)$ at a previous time and $\rho_{V0}$ in time $t = 0, z{\sim}1/t$.

Nothing important changes when the energy density of the radiation falls below $\rho_M$. Tracker solution $\overline{\varphi}$ continues to increase as $t^{2/(2+\alpha)}$ and the $(d\varphi/dt)^2$ and $V(\varphi)$ as $t^{-2\alpha/(2+\alpha)}$. But $\rho_M$ and $\rho_R$ are decreasing faster, as $t^{-2}$, so eventually $\rho_V$ will fall below $\rho_{V0} = \rho_\Phi + \rho_R$, where $\rho_\Phi$ is the thermal density.

- Similar results are obtained if we take as possible the "linear" form

$$V(\varphi) = V_0 + V'_0(\varphi - \varphi_0).$$

We observe that current $w = p_\varphi/\rho_\varphi$ is $w > 0$.

The values of $\rho_V$, $\rho_{V0}$ and redshift $z{\sim}1/t$ (Chap. 15, Part B) are shown in Figure 28.2.

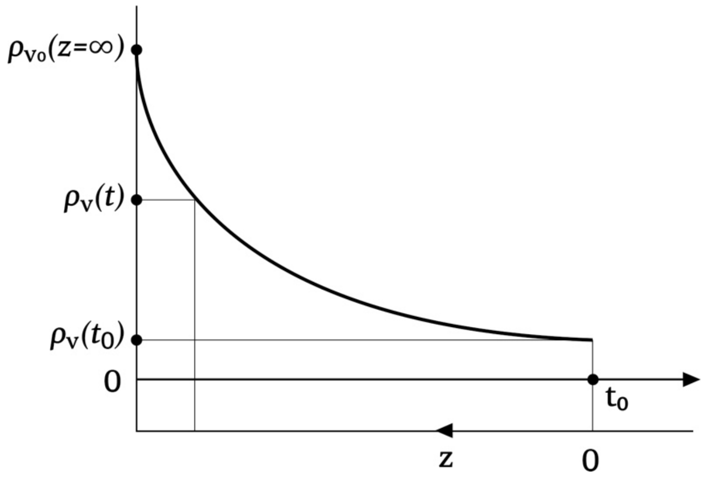



*Figure 28.2*

From this figure we conclude that the density of dark energy $\rho_V$ in earlier times was greater than it is currently. The result of the explanation is that part of the dark energy density was converted into mass $\rho_M = \rho_{BM} + \rho_{DM}$.

A field $\varphi$ has a thermal density $\rho_\Phi$ and correspondingly an electromagnetic potential $A^\mu$ with energy density $\rho_R$. This field and electromagnetic potential were seen in chapter 9 to be consumed by the mass acquisition mechanism. Thus the initial dark energy density $\rho_{V0} = \rho_\Phi + \rho_R$ decreased with time to $\rho_V(t_0)$ (Figure 27.2).

Certain values of z and $\rho_{V0}(z = \infty)/\rho_V$ are the following:

| z | tracker $\rho_{V0}/\rho_V$ | tracker $\rho_{V0}/\rho_V$ |
|---|---|---|
| 0 | 1 | 1 |
| 0.5 | 1.347 | 1.2 |
| 1 | 1.712 | 1.273 |
| 3 | 3.224 | 1.331 |
| ≥1 | ≥1 | 1.340 |

The linear approach comes closest to the observed values$\rho_V(t_0)/\rho_{V0}(t = 0) = 0.75 = 1/1.340$.

Thus, $\rho_V(t_0) = 0.75 \cdot \rho_{V0}$.

Accurate measurements give $\rho_V(t_0) = 0.7\rho_{V0}$ (Chap. 15). 30% of $\rho_{V0}$ was converted by 5% into luminous $\rho_{BM}$ and 25% into dark matter $\rho_{DM}$.

# 29. Procedures during temperature drop

The energy density ρ(T) is $\sim T^4$. If we add the coefficients this becomes

$$\rho(T) = N\alpha_B T^4/2,$$

where $N$ are the particle types that measure particles and antiparticles and each spin state separately for bosons and with an additional factor of 7/8 for fermions. $a_B$ is the radiation energy constant.

With these coefficients it took time $t = 0.0098$sec for the temperature to drop from a value $T^{12}$K to $10^{11}$K, another 0.998sec to drop to $10^{10}$K and another 167sec to drop to $10^9$K.

After the Big Bang's time zero, the temperature started to drop. When breaking symmetry the temperature is estimated to be $10^{28}$K. During the inflation period the universe cools down. At temperature $10^{12}$ with $10^{11}$ the fermions appeared $\tau$ with mass in equilibrium with the left neutrinos $\nu_\tau$ and $\overline{\nu_\tau}$ counterfermions with mass in equilibrium with the right antineutrinos $\overline{\nu_\mu}$. Later, fermions appeared $\mu$ and the antiferromions $\overline{\mu}$ with mass and in equilibrium with neutrinos $\nu_\mu$ and $\overline{\nu_\mu}$ with the same helicity (left or right) as generation $\tau$. At temperature $10^{10}$K the decoupling of the left neutrinos began $\nu_e$ of electrons. Later at $T \approx 10^9$K with $10^{10}$K the heating of the universe began through fermion-antiferromion annihilation. The radiation age began in $T \approx 10^8$K until the equilibrium of the energy density of radiation and matter at 4000K.

The structure of H atoms began at 4500 K. At 3000 K, the last scattering of photons took place to reach us as microwaves with a wavelength of 13 mm.

The numerical density of baryons is so much smaller than the numerical density of photons, $n_B/n_\gamma = 10^{-10}$, that we can overview the chemical potential associated with the number of baryons to form atoms. Also, because the electron/ photon number ratio was also very small, we can conclude that even at temperatures on the order of $10^{10}K$ the energy density of radiation ($\rho_R = T^4$), pressure and entropy density were functions of temperature only.

To get a picture of the thermal history it is necessary to consider the thermodynamics and statistical mechanics of this kind of matter in thermal equilibrium with negligible chemical potentials. All particles at temperature $10^{10}$K are relativistic and initially in thermal equilibrium, which means that the entropy product $s$ with $a^3$

$$s(T)a^3 = constant \tag{29.1}$$

Because $a \sim 1/T$ it follows that the entropy density

$$s(T) = 2Na_BT^3/3 \tag{29.2}$$

where $N$ are the particle types that measure particles and antiparticles and each spin state separately for bosons and with an additional factor of 7/8 for fermions. $a_B$ is the radiation energy constant.

From Friedman Equation, (22.2.5), for $k \approx 0$, we obtain

$$da = adt\sqrt{8\pi G\rho(T)/3}.$$

By differentiating (28.2) with respect to temperature T we obtain

$$da = -s'adT/3s.$$

Equating the above differentials, we get

$$dt = -s'dT/s(t)\sqrt{24\pi G\rho(T)} \text{ and integrating}$$

$$t = -\int s'dT/s(T)\sqrt{(24\pi G\rho(T))} + constant$$

Taking the specific entropy function $s(T) = 2Na_B T^3/3$, where $\alpha_B$ is the radiation constant and

$$\rho(T) = Na_B T^4/2, \text{arises}$$

$$t = \sqrt{3/16\pi GNa_B}T^{-2} + constant \qquad (29.3)$$

Let's start now at a time when the temperature was about $10^{11}$K, which is in the value range $m_\mu \gg k_{B\times T} \gg m_e$, where $k_B$ is the Bolzmann constant. Although it was too cold at that time for lepton reactions $\tau$ ή $\mu$ of the form $\nu_\mu + e \rightarrow \mu + \nu_e$ ή $\nu_\tau + e \rightarrow \tau + \nu_e$, $\mu$ and $\tau$ neutrinos and antineutrinos were maintained in thermal equilibrium by neutral current reactions, such as neutrino-electron scattering mediated by boson $Z$ (Section 23.4), or vaporizations $e^+ + e^- \leftrightarrow \nu + \overline{\nu}$. Therefore, **components *N* of the universe at that time** were photons with two spin states plus three kinds of neutrinos and antineutrinos, each with one (left for $\nu$, right for the $\overline{\nu}$) spin state, plus electrons and anti-electrons (positrons), each with two spin states, all in equilibrium and all very relativistic, giving

$$\boldsymbol{N = 2 + 7(6 + 4)/8 = 43/4},$$

**with an additional multiplier of 7/8 for fermions.**

Therefore, Equation 28.3 gives in cgs

$$t = 0.994sec(T/10^{10}K)^{-2} + constant$$

For example, with the muons overviewd and the electron mass negligible, it took 0.0098 sec for the temperature to drop from a value of $10^{12}$K to $10^{11}$K, another 0.998 sec to drop to $10^{10}$K and another 167 sec to drop to $10^9$K

# 30. Brightness and the measurement of the age of the Universe

The most common method of determining distances in astronomy was the determination of apparent brightness. **The absolute brightness of a light source $L$** is defined as the energy emitted per second and **the apparent luminosity $l$** at a distance $r$ is the energy incident per second on one square centimetre. That is

$$l = L/(4\pi r^2).$$

At long distances, this formula should be modified for three reasons.

- At time $t_0$ when the light reaches the earth, the self-distance from the star to the earth becomes $a(t_0)r$. Therefore, the surface of the sphere $4\pi r^2$ should be replaced by $4\pi[a(t_0)r]^2$.
- The frequency of the photon reaching the earth is reduced by the frequency emitted by the star by the redshift factor $1/(1+z)$.
- The energy of the photon reaching the earth is reduced by the energy emitted by the star by the redshift factor $1/(1+z)$.

Combining the above we have $l = L/(4\pi d_L^2)$, where

$$d_L = a(t_0)r(1+z) \tag{30.1}$$

In the second century AD, the astronomer Claudius Ptolemy published a list of 1022 stars with a luminosity of m falling into one of six categories (from 1 to 6). The stars with $m = 1$ were bright stars and stars with $m = 6$ were barely visible.

In 1856 Norman Pogson proceeded to the distinct classification of Ptolemy's catalogue, with the formula $l = L/(4\pi d^2) \sim 10^{-2m/5}$, with brightness $m$. Later distance $d$ is defined as equal to $= 10pc$ ($1pc = 3{,}1 \times 10^{18} cm$).

Therefore brightness $L_{10}$ is defined as the absolute for an apparent $l$ at a distance $10pc$, as a function of luminosity $M$.

$$L_{10} \sim 10^{-2M/5}$$

Distance $d_L$ can be expressed in terms of modulus $m - M$.

$$d_L = \sqrt{L/4\pi l} = 101 + (m - M)/5\ pc, \text{ or } m - M = 5(\log d_L - 1)$$

We can compare the photometrically measured distance $d_L$ as a function of modulus $m - M$ and the calculated distances from Chap. 21 as a function of $z$ and $\Omega$.

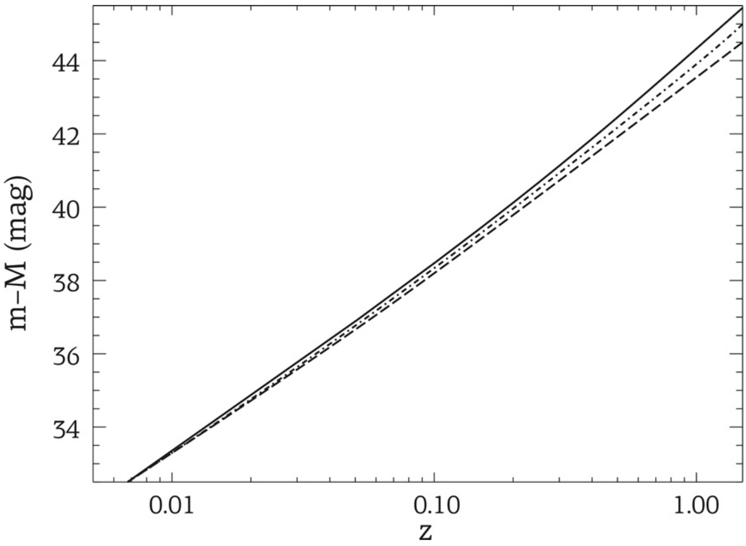



*Figure 30.1*

Figure 30.1 shows the calculated distances with the continuous and dashed curves. The photometrically measured distances of A. G. Riess et al., Astron. J 116, 1009 (1998) for some stars best fit the combination $\Omega_\Lambda = 0.76$ ($\Lambda$ is the cosmological constant $= 1.3 \times 10^{-52} m^{-2}$), $\Omega_M = 0.24$, $\Omega_R = 0$, $\Omega_K \approx \varepsilon \ll 1$ for the calculated distances of line —. The other lines represent:

------- $\Omega_M = 0.20, \Omega_{\square} = 0, \Omega_K = 0.80,$

$$\text{while} \cdots\cdots \Omega_M = .0, \Omega_\Lambda = 0, \Omega_K \approx 0.$$

Cepheids are stars of periodic brightness.

Henrietta Levitt in 1912 observed that in 25 Cepheids of the small Magellanic Cloud (a satellite of the Milky Way) brightness $L$ was a function of the period $P$ between a maximum and a minimum brightness. He even noticed that brighter stars have shorter periods.

The mathematical expression of this discovery was of the form

$$L = alogP + b$$

Later astronomers Shapley and Hertzsprung, using the parallax method, were able to measure distance $d$ of a Cepheid. By measuring both the apparent brightness $l$ they calculated absolute $L$. **Thus they were able to determine coefficients $a$ and $b$ of the Levitt function.**

For visible light, brightness $L$ is written as

$$L = -2.76 \times logP - 1.458 \tag{30.2}$$

So when the distance of a Cepheid was measured, the above Levitt Equation became a guide to measuring astronomical distances.

When Shapley and Hubble were working on Mount Wilson, around 1920, there was a dispute between the two astronomers as to whether Milky Way was the only one in the universe, as Shapley passionately argued.

Spotting a faint star, which had not been detected before, Hubble suspected that it was Cepheid and belonged to another distant galaxy. According to the Levitt equation, the distance of this Cepheid from Earth must have been 900,000 light years. But Milky Way was about 100,000 light years across. So, the new Cepheid belonged to another galaxy. That was the Andromeda Galaxy. So our universe expanded by one galaxy.

Later, using the photometric parallax method and the HIPPARCOS (High Precision Parallax Collection Satelite) satellite, the calibration of the distance as a function of the emitted colour **or temperature from the highest to the lowest values (O, B, A, F, G, M of Canon. Chap. 2.4)** of about 100,000 stars of the main sequence (KA) of the Hertzsprung-Russell diagram was achieved.

# 31. Calculating the age of the Universe

Distance $d(r,t)$ at time $t$ from the origin to a star moving in equidistance $r$ according to Chapter 7.1 is

$$d(r,t) = a(t)\int_0^r dr\,/\sqrt{1-kr^2} = a(t)\begin{cases} sin^{-1}r & for\ k=1 \\ r & for\ k=0 \\ sinh^{-1}r & for\ k=-1 \end{cases}$$

We set

$$x(t) = a(t)/a(t_0) = 1/(1+z), \qquad (31.1)$$

Then

$$dx/dt = da(t)/a(t_0)dt = (da(t)/dt)/a(t))(a(t)/a(t_0)) = H(t)x(t)$$

or because of (6.3.3)

$$dt = dx/x(t)H(t) = dx/a(t)H_0 =$$
$$dx/x(t)H_0\sqrt{\Omega_V + \Omega_K x^{-2} + \Omega_M x^{-3} + \Omega_R x^{-4}}$$

If we set zero time as corresponding to an infinite $z$, the current time $t_0 = t(z)$, the $x(t=0) = x(z \to \infty)$ and the present $x = 1/(1+z)$, then by integration we have

$$t(z) = H_0^{-1}\int_0^{\frac{1}{1+z}} dx/(x\sqrt{\Omega_V + \Omega_K x^{-2} + \Omega_M x^{-3} + \Omega_R x^{-4}})$$

For $\Omega_V = 0.72$, $\Omega_M = 0.28$, $\Omega_K = \Omega_R \approx 0$ and $H_0 = 2.26 \times 10^{-18} sec^{-1}$ the above integral gives $t_0 = 13.4 \times 10^9$ years.

# 32. Age calculated through nuclear decays

In addition to calculating the age of the universe according to Chap. 31, we can estimate it using physical isotope decay.

If the initial concentration of an isotope is $\varepsilon_0$ and the rate of decomposition $\lambda\tau = ln2$, $\tau$ the half-life, the present concentration is

$$\varepsilon = \varepsilon_0 \exp(-\lambda t). \tag{32.1}$$

We go further if we use two isotopes with the relevant current concentration $\varepsilon_1/\varepsilon_2$, which is

$$\varepsilon_1/\varepsilon_2 = \exp[(\lambda_2 - \lambda_1)t]\, \varepsilon_{10}/\varepsilon_{20}. \tag{32.2}$$

with $\varepsilon_{10}, \varepsilon_{20}$, the initial concentrations of the radioactive elements $E1$ and $E2$.

Inferences about the concentrations of certain long-lived radioactive isotopes can be used as chronometers to determine the age of older stars.

There have been several recent detections of the element thorium ($Th$), with a half-life $\tau = 14Gyr$in stars with an attenuated iron halo ($Fe$). This element, along with Uranium ($U$)with a half-life $\tau = 9{,}5Gyr$is synthesized exclusively in the rapid proton capture and even faster neutron capture process (r-process), shortly after the Mega Bang.

The comparison of the observed (currently) stellar concentration of this radioactive element with the initial (in time ≈ zero MB) at a period of the rapid neutron capture process, leads to a direct estimate of the radioactive age of the star. Figure 32.1 shows the logarithmic distribution of concentrations, including $Th$ and $U$ in the BD+ star$17^0$3248. While the heavy neutron-binding elements are consistent with the dashed continuum of the solar fast neutron capture process, the observed concentration of $Th$ and $U$

are below this line, meaning that these elements were created shortly after the BB, long before the Sun was formed.

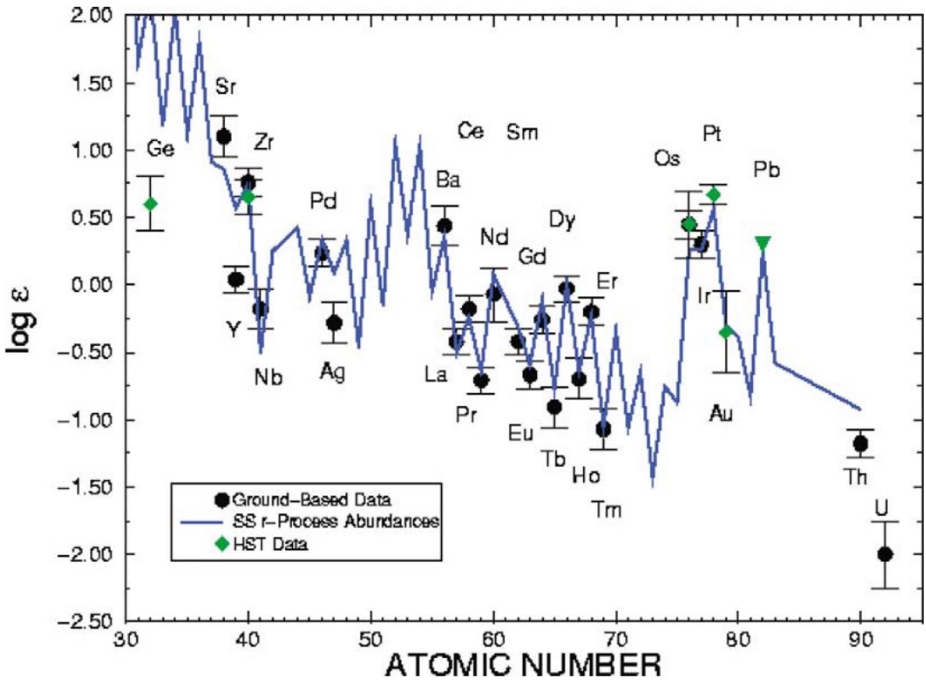



*Figure 32.1. Concentrations of the elements produced by the fast neutron capture process in the BD+ star$17^0$3248, obtained from ground-based and spectroscopic observations with the Hubble Space Telescope (HST). The continuous dashed line gives the theoretical initial concentrations, based on Solar System (SS) data. From J. J. Cowan et al., Astrophys. J 572, 861 (2002) [astro-ph/0202429].*

Such differences are clear evidence that these stars are older than the Sun. Determining how much older requires knowledge of the initial concentrations of $Th$ and $U$ which must be predicted by models of the fast neutron capture process. One such model calculation is illustrated in equation 32.3.

Similar predictions use the Thorius analogy ($Th$) to another element of the fast neutron capture process, usually the europium ($Eu$).

Returning to Equation 31.1 we have time

$$t = ln(\varepsilon_1 \varepsilon_{20} / \varepsilon_{10} \varepsilon_2)/(\lambda_2 - \lambda_1).$$

Setting $A = \varepsilon_1/\varepsilon_2$, $A_0 = \varepsilon_{10}/\varepsilon_{20}$, we have

$$t = (logA - log\varepsilon_{10} + log\varepsilon_{20})/(\lambda_2 - \lambda_1) \quad (32.3)$$

Current $A, \lambda_1, \lambda_2$ values can be measured and $log\varepsilon_{10}$, $log\varepsilon_{20}$ values can be read from Figure 31.1.

For the pair $U^{238}$, $Th^{232}$, Equation 31.3 gives $t_0 \approx 15.5Gyrs$, while for the pair $Th^{232}$ , $Eu^{152,}$ Equation 31.3 gives $t_0 \approx (11 - 15) \pm 4Gyrs$, where $Gyr = 10^9$ years.

# 33. Theory of small fluctuations

So far we have described the universe as isotropic and homogeneous with a Robertson-Walker metric.

For $k = 0$ we write the perturbation of the metric as follows

$$g_{\mu\nu} = \overline{g_{\mu\nu}} + h_{\mu\nu},$$

perturbed momentum-energy tensor as

$$T_{\mu\nu} = \overline{T_{\mu\nu}} + t_{\mu\nu},$$

where $t_{\mu\nu}$ means disorders e.g. $\delta\rho_m, \delta\rho_R, \delta u$

and Ricci tensor as

$$R_{\mu\nu} + \overline{R_{\mu\nu}} + r_{\mu\nu},$$

where $\overline{g_{\mu\nu}}$ is undisturbed Robertson-Walker metric

$$\overline{g_{00}} = -1, \overline{g_{0j}} = \overline{g_{j0}} = 0, \overline{g_{ij}} = a^2(t)\delta_{ij}, i.j = 1,2,3$$

and $h_{\mu\nu} = h_{\nu\mu}, t_{\mu\nu} = t_{\nu\mu}$ και $r_{\mu\nu} = r_{\nu\mu}$ a small disturbance.

(From now on, the line above a quantity indicates its undisturbed value.)

With these distinctions and using Equations (7.1.10) and (6.1.8) ($k = \Lambda = 0$), Einstein and the laws of conservation of energy and momentum, we obtain the perturbation equations. We divide them into gauge equations $\delta\rho, \delta p, du$ ..., vector and tensor perturbations $\pi^T_{\mu\nu}, D^T_{\mu\nu}, \ldots$, with inertial momentum and gravitational radiation tensors respectively.

However, the results are very complicated.

However, the results are very complicated.

We are working on the system of simultaneously moving coordinates. Only the initial normalized conditions $\alpha_n(\boldsymbol{q})$ depend on direction $\boldsymbol{q}$ rather than the Fourier components $\delta\rho_q, \delta p_q, \delta u_q$ ... (Eq. 13.1). These depend only on the $\boldsymbol{q}$.

$$\delta\rho(\boldsymbol{x}, t) = \sum_n \int d^3 q exp(i\boldsymbol{qx})\alpha_n(\boldsymbol{q})\delta\rho_{nq}\,(t) \tag{33.1}$$

The advantage of Fourier synthesis for example $\delta\rho(x, t)$ ($n$ is the number of independent solutions, $\alpha_n(\boldsymbol{q})$ the normalized initial conditions of each solution) is that partial derivatives $\partial/\partial^j$ are converted into coordinates $q^j$. $\boldsymbol{\nabla}$ (gauge) is converted into a momentum vector $\boldsymbol{q}$ and differential equations into linear equations. Considering the perturbations as infinite, we can be sure, because $\delta\rho_q\delta p_q \approx 0$, that no couplings occur between the Fourier components of different numbers of wave numbers.

Small variations in density are enough to affect the evolution of the universe. Small regions of dense matter $\rho$ attract matter $\delta\rho$ from their immediate surroundings with the help of gravity, causing them to become denser and denser until the first galaxies form. This is why during the formation of galaxies we have an unusually inhomogeneous universe, regions of density $\approx 1g/cm^3$and vast empty regions. The average density currently is estimated to be $\rho \approx 10^{-29}g/cm^3$.

In the period between $10^9$K and 3000K, which is the time of creation of hydrogen atoms, we can take the hydrodynamic limit, where we apply the laws of fluid physics to the plasma where the number of collisions of photons with free electrons, scattered throughout the universe, was so large that the photons were in local thermal equilibrium with the ionized plasma, but not their velocities, which are always much lower than the photon velocity and within the time region, Fig. 33.1, $r_H$ is the line of light of the horizon, $c = 1$.

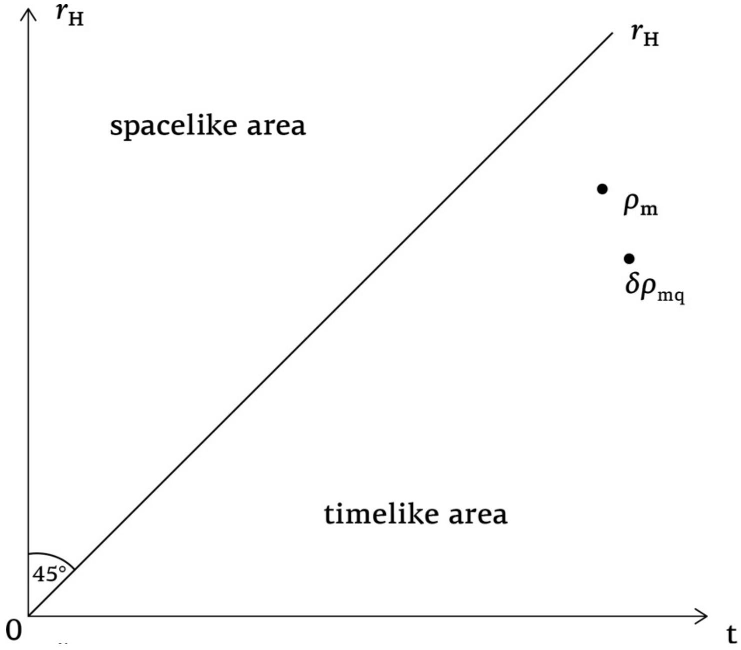



*Figure 33. 1*

# 34. Solar radiation processes

The sun as the centre of our system is the most important star for us. Its mass is $M \odot = 1{,}99 \times 10^{30} kg$, its radius $R_S = 1{,}4 \times 10^6 km$its its brightness $L = 2{,}4 \times 10^6 MeV \cdot sec^{-1}$ **and its age is $\mathbf{4,5 \times 10^9}$ years**. Its rotation period is 25.4 days and its temperature moves from the inner to the outer surface from 7000K to 4000K (K. Stumpff).

In addition to its valuable radiation, it is the place where we can do experiments on more distant stars.

## 34.1. The proton-proton process

This process is the most likely source of energy in stars with a mass similar to that of the Sun. The early stages are common:

Reaction $p - p$: $H_1^1 + H_1^1 \rightarrow H_1^2 + e^+ + n + 1.74\ MeV/Mol$.

Reaction $pep$: $H_1^1 + e^- \rightarrow n, H_1^1 + n \rightarrow D_1^2 + 1.44\ MeV/Mol$.

$$D_1^2 + H_1^1 \rightarrow He_2^3 + \gamma$$

The second reaction: $He_2^3 + He_2^3 \rightarrow He_2^4 + 2H_1^1$.

The third reaction: $He_2^3 + He_2^4 \rightarrow Be_4^7 + \gamma$

$Be_4^7 + e^- \rightarrow Li_3^7 + n + 0{,}86\ MeV/Mol$, (with 0.9 probability)

$Be_4^7 + e^- \rightarrow Li_3^{7*} + n + 0{,}38\ MeV/Mol$, (with 0.1 probability)

$$Li_3^7 + H_1^1 \rightarrow 2He_2^4 \rightarrow Be_4^7 + \gamma$$

$$Be_4^7 + H_1^1 \rightarrow B_5^8 + \gamma$$

$B_5^8 + e^- \rightarrow Be_4^{8*} + e^+ + n + 14{,}06\ MeV/Mol$,

$Be_4^{8*} \rightarrow 2He_2^4$

As a sum

$$4H_1^1 \rightarrow He_2^4 + 2e^+ + 2\nu + \text{in the form of radiation } 28.3 MeV/Mol \text{ (W. Finkelnburg)} \quad (34.1)$$

## 34.2. The carbon cycle

The second way is the carbon cycle, where a carbon atom reacts with a hydrogen nucleus to create a nitrogen atom. Nitrogen then reacts with a hydrogen nucleus to produce a carbon atom, and similarly a nitrogen, oxygen and helium atom, always with the addition of an H nucleus, which as a primitive is abundant.

The end result is $He_2^4$ Carbon took part in the reaction as a catalyst.

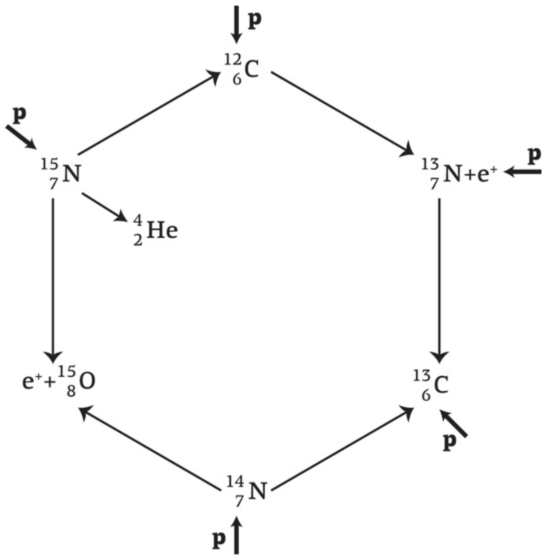



*Figure 34.1. The carbon cycle*

## 34.3. Energy through nuclear fusion and fission

Accurate measurement of the baryons mass of different atoms shows that it depends on the atom in which they participate. As an example, consider the nuclei $He_2^4$ with an atomic mass of 4.0015g≙3725MeV, consisting of 2 protons with an atomic mass of 1.0073g≙1875.2MeV and 2 neutrons with an atomic mass of 1.0086g≙1878.1MeV in the sum 4.0318g≙3753.3MeV. $He_2^4$ is 28.3MeV lighter than the sum of its components. This mass difference after the fusion of four H atoms to create a $He_2^4$ is converted into energy E according to Einstein's equation

$$E = mc^2.$$

The 4 Mol conversion $H_1^1$to 1 mole $He_2^4$ releases an energy of 28.3 MeV.

Our sun produces $1{,}8 \times 10^{16}$ tons of helium every year. Its current content is $5 \times 10^{26}$ tons. At the current rate of production, it would take the sun about 27 billion years to produce this amount of helium. But the sun is only 4.5 billion years old. So helium existed as a primordial molecule before the Sun was created and was obviously formed by fusion under the high temperatures and pressures of the Big Bang. **Note: Helium without the hydrogen nucleus does not radiate**.

In nuclear power plants, where e.g. the $U_{92}^{235}$ decomposes into $Ba_{56}^{137}$ and $Kr_{36}^{84}$ we get a release of 162 MeV/Mol of energy that is converted into heat and then into electricity. 1kg of U235 gives the same energy as 30000kg of coal. The binding energy per nucleon in mega-electronvolts (MeV) as a function of mass number is shown in Figure 34.2. Here we see that the most stable chemical element is iron, Fe.

A simplified fission reaction, with thermal neutron bombardment, is the decay of $U_{92}^{235}$

$$U_{92}^{235} \rightarrow Ba_{56}^{137} + Kr_{36}^{84} + 14n + 162\ MeV/Mol$$ (Finkelburg, W. Σχ. 34.2)

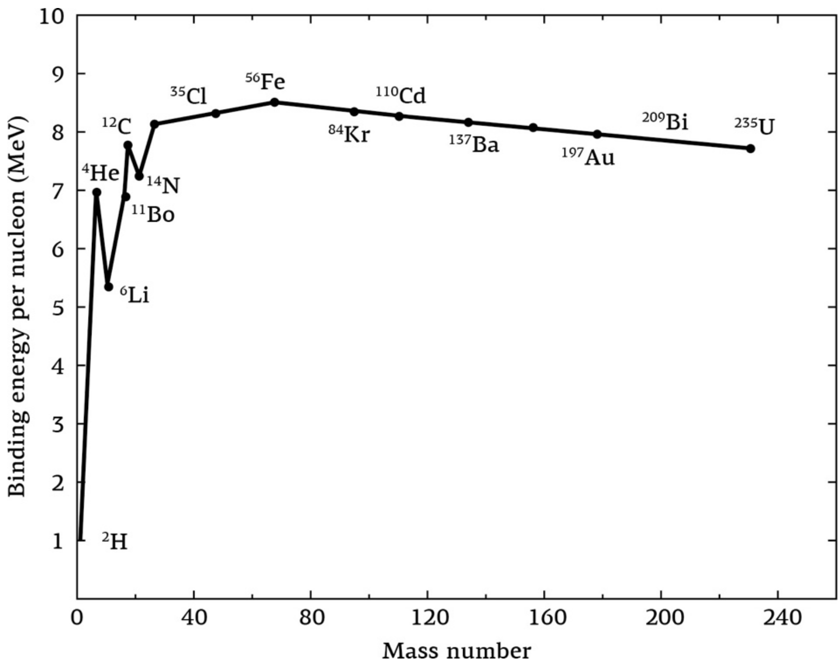



*Figure 34.2*

The emissions of particles $(\gamma, e^-, e^+, \nu, \alpha)$ from the nucleus represent the **weak long-range interaction**, while the Yukawa potential

$$V(r) = -g^2 e^{-mr}/4\pi$$

of the nucleus components (quarks connected by gluons) represent the **strong short-range interaction**.

## 34.4. Solar activity

The Sun's magnetic field changes polarity about every 11 years. This occurs at the peak of each solar cycle, as the Sun's internal magnetic state is reorganized. The coming reversal is upon us. The poles are the harbinger of the change. Just as geologists watch the polar regions of our planet for signs of climate change, solar physicists do the same for the Sun.

The sun's polar magnetic field fades, goes to zero and then reappears with the opposite polarity. This is a regular part of the solar cycle.

According to T. Phillips, a reversal of the sun's magnetic field is literally a big event. The sun's magnetic influence field (i.e. "heliosphere") extends billions of kilometers beyond Pluto. Changes in the field's polarity range up to the Voyager spacecraft at the threshold of interstellar space.

When solar physicists talk about solar field reversals, they often focus on the "current sheet". Current sheet is a vast surface that protrudes from the sun's equator, where the sun's slowly rotating magnetic field causes an electric current. The current itself is small, but its quantity is large. The current flows over an area 10,000 kilometres thick and billions of kilometres wide. In terms of electricity, the entire heliosphere is organized around this huge sheet.

During field reversals, the current sheet becomes very undulating, its ripples resembling the seams on a baseball. As the Earth rotates around the sun, we sink in and out of the current sheet.

The transitions from one side to the other can cause stormy space weather around our planet.

Cosmic rays are also affected. These are high-energy particles accelerated to near-light speed by supernova explosions and other violent phenomena in the galaxy. Cosmic rays pose a risk to astronauts and telecommunications satellites. The current sheet acts as a barrier to cosmic rays, deflecting them as they try to penetrate the interior of the solar system. A wavy, crimped sheet acts as a better shield against these energetic particles from outer space.

As the field reversal approaches, the data show that the two hemispheres of the sun are not synchronized.

The sun’s north pole has already changed its sign, while the south pole is racing to catch up.

# 35. Anisotropies of cosmic microwave radiation

Anisotropies can occur in the cosmic microwave background if dark matter galaxies, invisible from Earth, interfere in the line of light, but still reflect light due to gravitational interaction with photons (see Chap. 30, fig. 35.1).

Big Bang proponents faced the problem of how the universe could evolve from a uniform soup of matter into a heterogeneous whole populated by galaxies of enormous mass separated by vast distances. The cosmological proponents of the Big Bang devised the theory of fluctuations due to which the homogeneity of the early universe was disturbed.

They believed that these small variations in density would be enough to affect the evolution of the universe. Small regions of dense matter would attract matter from their immediate surroundings with the help of gravity, causing them to become denser and denser until the first galaxies formed. If this was the reason for the formation of galaxies then we would have an unusually inhomogeneous universe, regions of dense $\approx 1g/cm^3$ and vast empty regions. The average density currently is estimated at $\approx 10^{-29}g/cm^3$.

The same inhomogeneity should characterize the Milky Way $z = 1100$ the first fossil of the early universe. Its surface should consist of irregular mountains and gorges.

When the light of the $13\mu m$ emitted from the tops of the mountains will have a wavelength $13\mu m$, while if it is emitted from the bottom of a ravine, under its dual mass property, it will expend energy until it reaches the top and will have a wavelength of $> 13\mu m$.

To see the fossil of $13\mu m$ from many sides, it was necessary to place the radio wave detector in space.

Professor George Smoot of UC Berkeley was the first to try to investigate the topography of this fossil by placing his probe first in a balloon and then in a U2 reconnaissance plane, without any results.

NASA, in an attempt to support this research, funded the construction of a satellite called COBE (Cosmic Background Explorer) in 1976.

Anisotropies can occur in the cosmic microwave background if dark matter galaxies, invisible from Earth but still reflecting light due to gravitational interaction with photons, interfere with the line of light (see Chap. 27).

A cloud of hot electrons in the line of light creates Thomson scattering in the photons, causing redshift. Another reason is the range of density variations at the birth of stars (see Chap. 2).

The average temperature variations of the Microwave Background Radiation (CMB) are proportional to $\lambda^{-4}$ (Chap. 1) and $\lambda$ reaching the Earth depends on whether it is emitted from the top of a mountain or a ravine (Chap. 27, Fig. 35.1). It is also expected to depend on the angle between the direction of the microwave star and the velocity of the Earth, presenting a sequence of peaks at different angles, due to deflection of the light into clusters of dark matter, (Fig. 35.1).

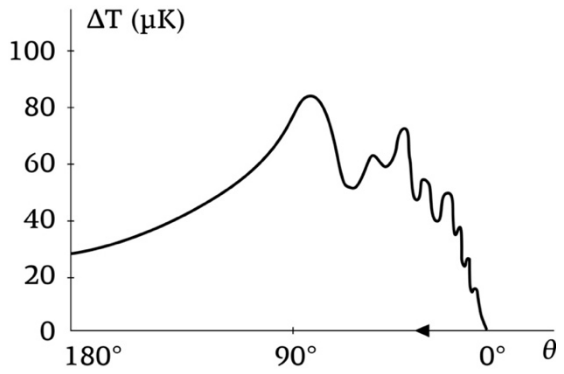



*Figure 35.1*

After repeated difficulties in building the COBE and launching the rocket that would orbit the COBE, it arrived in 1989, 13 years after the approval to build the COBE. It was the year that the Delta rocket, left over from Star Wars, put COBE with its DMR radio detector into orbit at an altitude of 900 kilometers and orbiting the Earth 14 times a day.

The DMR detector, applying Wien's law instead of the wavelength, measured the temperature at different points in the fossil.

Analyses with an accuracy of 1/3,000 and 1/10,000 showed no relief in the first fossil of the universe. At 1/100,000 resolution the first results were seen. Having collected 70 million measurements and confident, Smoot announced the results of the measurements in 1992 to the American Physical Society in Washington, DC.

It was 25 years after Penzias and Wilson had discovered cosmic microwave radiation before Smoot presented the maps of the universe, which accurately depicted the relief surface of the first fossil of the universe, in Figure 35.2 below (after S. Singh).

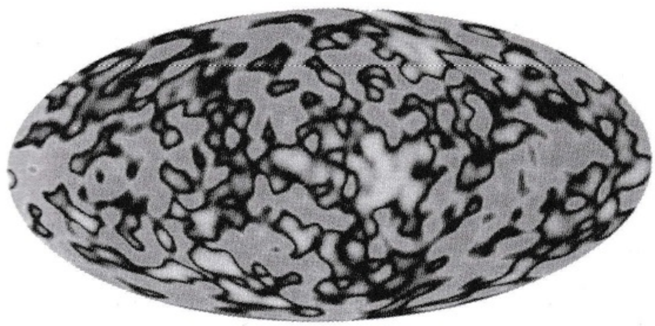


*Figure 35.2*

# Annex 1

| Quantity | Symbol | Value unit |
|---|---|---|
| Speed of light in vacuum | $c$ | $2.997925 \times 10^{8}$ m s$^{-1}$ |
| Planck constant | $h$ | $6.626069 \times 10^{-34}$ J s |
| Planck constant, reduced | $\hbar$ | $1.054572 \times 10^{-34}$ J s<br>$= 6.582119 \times 10^{-22}$ MeV s |
| Conversion constant | $\hbar c$ | 197.326963 MeV fm [a] |
| Electron charge magnitude | e | $1.602176 \times 10^{-19}$ C |
| Electron mass | $m_e$ | 0.510999 MeV/$c^2$ |
| Proton mass | $m_p$ | 938.272013 MeV/$c^2$<br>$= 1.672622 \times 10^{-27}$ kg |
| Neutron mass | $m_n$ | 939.56536 MeV/$c^2$ |
| Avogadro constant | $N_A$ | $6.022142 \times 10^{23}$ mol$^{-1}$ |
| Boltzmann constant | $k$ | $1.380650 \times 10^{-23}$ J K$^{-1}$<br>$= 8.617343 \times 10^{-5}$ eV K$^{-1}$ |
| Fine structure constant | $\alpha = e^2/4\pi\epsilon_0\hbar c$ | $7.297353 \times 10^{-3}$<br>$= 1/137.036000$ [b] |
| Classical electron radius | $r_e = \alpha\hbar/m_e c$ | $2.817940 \times 10^{-15}$ m |
| Bohr radius | $a_\infty = (1/\alpha)\hbar/m_e c$ | $0.529177 \times 10^{-10}$ m |
| Thomson cross section | $\sigma_T = 8\pi r_e^2/3$ | 0.665245 barn [c] |
| Gravitational constant | $G_N$ | $6.67428 \times 10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$<br>$= 6.70881 \times 10^{-39}\hbar c\,(\text{GeV}/c^2)^{-2}$ |
| Planck mass | $\sqrt{\hbar c/G_N}$ | $1.22089 \times 10^{19}$ GeV/$c^2$ |
| Planck length | $\sqrt{\hbar G_N/c^3}$ | $1.61624 \times 10^{-35}$ m |
| Planck time | $\sqrt{\hbar G_N/c^5}$ | $5.39124 \times 10^{-44}$ s |
| Fermi coupling constant | $G_F/(\hbar c)^3$ | $1.16637 \times 10^{-5}$ GeV$^{-2}$ |
| $W^{\pm}$ boson mass | $m_W$ | 80.398 GeV/$c^2$ |
| $Z^0$ boson mass | $m_Z$ | 91.1876 GeV/$c^2$ |
| Weak mixing angle | $\sin^2\theta_W$ [d] | 0.2231 |
| Strong coupling constant | $\alpha_s(m_Z)$ | 0.1176 |

**a** fm $= 10^{-15}$ m.
**b** At $Q^2 = 0$. $\sim 1/128$ at $Q^2 = m_W^2$.
**c** barn $= 10^{-28}$ m$^2$.
**d** defined by $1 - m_W^2/m_Z^2$.

# Annex 2

## Numerical Constants

| | |
|---|---|
| $\pi = 3.1415927$ | $1'' = 4.84814 \times 10^{-6}$ radians |
| $e = 2.7182818$ | $\ln 10 = 2.3025851$ |
| $\gamma = 0.5772157$ | $\zeta(3) = 1.2020569$ |

## Physical Constants[1]

| | |
|---|---|
| Speed of light in vacuum | $c \equiv 2.99792458 \times 10^{10}$ cm sec$^{-1}$ |
| Planck constant | $h = 6.6260693(11) \times 10^{-27}$ erg-sec |
| Reduced Planck constant | $\hbar \equiv h/2\pi = 1.05457168(18) \times 10^{-27}$ erg sec |
| | $= 6.58211915(56) \times 10^{-22}$ MeV sec |
| Electronic charge (unrat.) | $e = 4.80320441(41) \times 10^{-10}$ esu |
| Electron volt | 1 eV$= 1.60217653(14) \times 10^{-12}$ erg |
| | $\hbar c = 197.326968(17) \times 10^{-13}$ MeV cm |
| Fine structure constant | $\alpha \equiv e^2/\hbar c = 1/137.03599911(46)$ |
| Electron mass | $m_e = 9.1093826(16) \times 10^{-28}$ g |
| | $m_e c^2 = 0.510998918(44)$ MeV |
| Rydberg energy | $hcR \equiv m_e e^4/2\hbar^2 = 13.6056923(12)$ eV |
| Thomson cross section | $\sigma_{\mathcal{T}} = 8\pi e^4/3m_e^2c^4 = 0.665245873(13)\times 10^{-24}$ cm$^2$ |
| Proton mass | $m_p = 1.67262171(29) \times 10^{-24}$ g |
| | $m_p c^2 = 938.272029(80)$ MeV |
| Neutron mass | $m_n c^2 = 939.565360(81)$ MeV |
| Deuteron mass | $m_d c^2 = 1875.61282(16)$ MeV |
| Atomic mass unit | $m(C^{12})/12 = 1.66053886(28) \times 10^{-24}$ g |
| | $m(C^{12})c^2/12 = 931.494043(80)$ MeV |
| Avogadro's number | $N_A = 6.0221415(10) \times 10^{23}$/mole |
| Boltzmann constant | $k_{\mathcal{B}} = 1.3806505(24) \times 10^{-16}$ erg/K |
| | $= 8.617343(15) \times 10^{-5}$ eV/K |
| Radiation energy constant | $a_{\mathcal{B}} = \frac{8\pi^5 k_{\mathcal{B}}^4}{15h^3c^3} = 7.56577(5) \times 10^{-15}$ erg cm$^{-3}$ $K^{-4}$ |

[1] From *Review of Particle Physics*, S. Eidelman *et al.* (Particle Data Group), *Phys. Lett. B* **592**, 1 (2004).

# Annex 3

**Astronomical Constants**[2]

| | |
|---|---|
| Julian year | 1 year $\equiv$ 365.25 days $= 3.1557600 \times 10^7$ sec |
| Light year | 1 light (Julian) year $= 9.460730472 \times 10^{17}$ cm |
| Mean earth-sun distance | 1 A.U. $= 1.4959787066 \times 10^{13}$ cm |
| Parsec | 1 pc $\equiv 648000/\pi$ A.U. $= 3.0856776 \times 10^{18}$ cm $= 3.2615638$ light (Julian) year |
| Solar mass | $M_\odot = 1.9891 \times 10^{33}$ g |
| Solar luminosity | $L_\odot = 3.845(8) \times 10^{33}$ erg sec$^{-1}$ |

Apparent luminosity for apparent magnitude $m$

$$\ell = 2.52 \times 10^{-5} \text{ erg cm}^{-2} \text{ sec}^{-1} \times 10^{-2m/5}$$

Absolute luminosity for absolute magnitude $M$

$$\mathcal{L} = 3.02 \times 10^{35} \text{ erg sec}^{-1} \times 10^{-2M/5}$$

For a Hubble constant $H_0 = h \times 100$ km sec$^{-1}$ Mpc$^{-1}$:

| | |
|---|---|
| Hubble time | $H_0^{-1} = 3.0857\, h^{-1} \times 10^{17}$ sec $= 9.778\, h^{-1} \times 10^9$ years |
| Hubble distance | $c/H_0 = 2997.92458\, h^{-1}$ Mpc |
| Critical density | $\rho_{\text{crit}} \equiv \frac{3H_0^2}{8\pi G} = 1.878\, h^2 \times 10^{-29}$ g cm$^{-3}$ $= [0.00300 \text{ eV}]^4\, h^2$ |

[2]From *Allen's Astrophysical Quantities*, ed. A. N. Cox (AIP Press, New York, 2000).

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# Index of terms

## N



## P



## R



## S



## T



## U



## W

All cosmologists agree that our Universe originated from a great Explosion. However, no one describes how exactly this Explosion occurred. Was it a large continuous one, or did it consist of many successive explosions, the duration of which was quite long? In this book, we describe a Model of this Explosion. Galaxies in an acceleratingly expanding Universe enter the void, and the only way for an Explosion to occur is a head-on collision of faster stars with slower ones, whose direction of motion had previously, for a reason we describe, been reversed. In the vacuum created, at a Higgs temperature of about 10^28K, we had the conditions for the acquisition of mass by elementary particles, and from them, the formation of atoms, molecules, and eventually the Galaxies of a new Universe. The Mega Bang phenomenon is locally repeatable. We also describe a model of inflationary theory that does not violate any law of Physics, as we consider the previous two models to be incorrect, because the expansion velocities were greater than the speed of light by 30 and 70 orders of magnitude.

The book is divided into two parts. The first offers a simplified description for high school graduates, and the second is for readers familiar with modern Physics.

**From the contents**

- The Ice Age and the extinction of the Dinosaurs
- The glow of the extinguished sun
- The Mega-Bang model of the Big Bang
- The Higgs mechanism of mass acquisition and the formation of the Universe
- Energy through nuclear fusion and fission

Pantelis Delibaltas studied Physics at the University of Munich and obtained his diploma in the Technical University of Munich. He obtained his Ph.D. degree for periodic orbits in the three-body problem at the Aristotle University of Thessaloniki. In a short time, he published a study for collisions in the same problem. He has been a Professor at the Alexander Technological Educational Institute of Thessaloniki.