MAN'S PLACE IN THE UNIVERSE

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Abstract

This presentation is concerned with cosmic evolution and the relation of mankind to the Universe. It starts by describing what the Universe looked like shortly after the Big Bang, the origin of time and matter, 15 to 20 billion years ago. From there on it traces the processes that gave rise to the formation of stars, galaxies, chemical elements and finally 4.5 billion years ago the formation of our Sun, its Solar System and the Earth, where biological evolution eventually gave rise to Mankind. An important element is, that most of the chemical elements that we are made of, were not present early on in the Universe, but required various generations of stars for their synthesis.

At the end a description is given of the European initiative to build the largest telescope in the world, the Very Large Telescope of the European Southern Observatory, which consists of four 8-meter telescopes and will be erected in Chile.

1 Introduction

In the following I will attempt to sketch in very broad terms the relation of us humans to the starry sky above us. My science, astronomy, may seem to some a very exact excercise in the human endeavor, that concerns itself mostly with very complicated mathematical formalisms, fundamental laws of physics and much "clever-chaps" reasoning, all much removed from the comprehension of ordinary human beings. To the contrary I hope to convince you that astronomy is much more than such black art, that it is really a voyage in time and space that touches the fundamentals of our existence. And that it is much more an expedition that searches for the origins of our being in a physical sense. I have contemplated as a matter of fact also "Origins" as the title of this talk. It is not meant to be an alternative to our religious beliefs, but rather an extension of man's quest for the meaning of his life on this world as far as it is open to perception by his senses and by reasoning.

Almost every one of us, who looks up on a dark night at the sky and sees it sprinkled with stars, has wondered what it is and what it means. Are we a part of that majestic display of distant lights? And what part then do we play in it? We all can only wonder at the splendor and be moved by the basic significance that we all feel it must in one way or the other be attempting to impress on us. I believe that in a basic sense we are "children of the Universe". What I mean by that is what I hope to convey to you in this presentation.

The way I will do this is the following. We will start our journey at the beginning of everything, the origin of space and time. From there we will trace the cosmic evolution up to the present. I will close this talk with a few words about the European project to build the largest telescope in the world in the Andes mountains in Chile.

2 The early Universe

The beginning of the Universe occured roughly 15 to 20 billion years ago (I use "billion" in the American sense, that is one billion is one thousand million). This sounds as an incomprehensibly large number. However, remember, that in a typical summer vacation journey to a destination of a thousand kilometers from your point of departure, you are covering a million meters or a billion millimeters. Also, national budget deficits are measured in billions of Marks, Guilders or ECU's, while power plants often have a capacity of the order of a billion Watts. There is good reason to replace the old saying of "astronomical numbers" by "economic numbers" or "technical numbers".

In any case, the Universe started of order fifteen billion years ago. The precise number is still unknown to us, but is not important for what follows. It is the beginning of both time and space in a very fundamental sense; there is no "before" in time that can be defined in physical terms and no "elsewhere" in space. Travelling back in time, it means that we are coming to a point where no continuation is possible, just like we cannot cool any substance below the absolute zero-point of temperature at minus 273 degrees Centigrade or like that Einstein has taught us that we cannot accelerate our motion beyond the speed of light.

We know that the Universe just after this Big Bang was very hot and very dense. That it must have been very dense, can even at present be seen from the fact that at a larger scale all parts of the Universe are moving away from each other and that consequently everything must have been closer to-

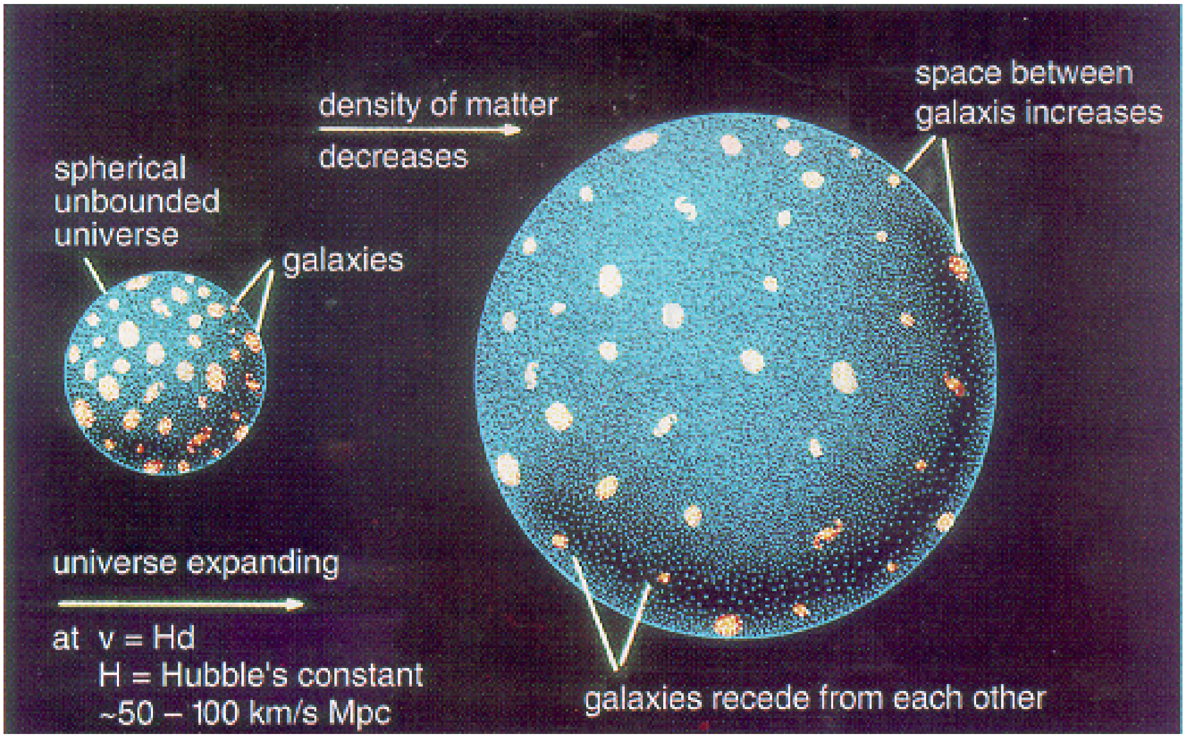

Figure 1: The expansion of the Universe. Just as spots on an expanding sphere each move away from all the others, galaxies in the Universe in three dimensional space move away from each other. The speed of recession increases with increasing distance according to Hubble's law ($V = Hd$ with H the so-called Hubble constant; it says that if the distance is d Megaparsec (Mpc; 1 Mpc is a little more than 3 million light years) the velocity of recession V is Hd km/s). Each location appears as the center of the expansion. (© Science Graphics)

gether in the past (see fig. 1). This was discovered by the American astronomer Edwin Hubble in the 1920's and is known as the expansion of the Universe. In fact, the Big Bang is the instant back in time, at which all matter was packed immensely close together. It lasted a few hundred thousand years before matter and radiation (heat) were sufficiently diluted to stop interacting. This means that from that time on radiation moved freely around in the Universe, meeting only occasionally a star, planet or dust particle.

That it was very hot is evidenced by a faint glow that we can still see and that comes to us from all directions, known as the cosmic background radiation. It cannot be seen by our eyes, but it can be observed by radiotelescopes sensitive to radiation with wavelengths of around 1 millimeter. It comes to us equally faintly from all directions and has been travelling from now distant parts of the cosmos for the whole age of the Universe. During this period it has cooled such that it is now at a temperature of only 2.7 degrees above the absolute zero-point, but going back in time we can calculate that it must have had a temperature of 3000 degrees when the Universe was a few hundred thousand years old.

There are two important points that I want to stress. In the first place we know from fundamental physics and from observations of the Universe at large distances (and thus earlier times) that matter in the Universe at that time must have been in the form of only two chemical elements, hydrogen and helium. Actually these were formed from the initial, extremely hot stages within the first three minutes after the Big Bang. Atoms that we know today (such as oxygen to breath, carbon so essential for life and the molecules of our genetic material, nitrogen, sulphur, sodium, but also metals as iron, tin, gold and silver and many others we now see all around and in us) did not yet exist. The essential ingredients for the formation of the Earth and eventually biological life were not even present. Matter in the Universe was for about three quarters hydrogen and one quarter helium.

The second point is, that the Universe contained very little structure. Everywhere it looked very much the same. The largest deviations from this uniformity were less than a hundredth of a percent in density or concentration of matter and radiation. The NASA satellite COBE (for Cosmic Background Explorer) has only about two years or so ago shown us for the first time these very minor seeds of structure in the background radiation. Where these minor deviations came from is an unsolved problem; the fact that they did exist was vital, as it made further developments possible. But for the moment, the Universe was not a very interesting place to be.

3 Galaxies

After a billion years or so the Universe became a lot more interesting. The area's where there was a tiny amount more matter than on average, started to contract under the influence of the force of gravity that it exerted on itself. It eventually fragmented into smaller units or coalesced with similar, nearby contracting structures and formed swarms of stars that we today see as galaxies. To give you an idea of their dimensions: they consist of the order of a few hundred billion stars like our Sun and have a size such that light, which travels at 300,000 kilometers per second, takes a few ten thousand years to cross them. The speed of light is such that if it were to move in a curved line around the Earth (which in practise it does not do), it would circle the circumference of the Earth seven-and-a-half times every second. The galaxies are the fundamental building blocks of the Universe and it is these that move all away from each other; this is the expansion of the Universe that I mentioned above. Even for the nearest galaxy outside our own the light takes 2 million years to reach us. For those illustrated below a few tens of millions of years.

Galaxies come in a great variety of appearances. Some have more structure than others, some look more spherical (fig. 3), while others look flat, but seen at an angle (fig.'s 4, 5, 6 and 7). An important class that astronomers call for obvious reasons spiral galaxies consist for a large part of a very flat structure, the disk. Its thickness is less than a tenth of its diameter. There is a central concentration of light with very little structure in it, but the main part, as the eye sees it, is an apparantly rather flattened pancake-like disk, most of which seems to form elongated spiral arms. As detailed studies show, these spiral arms are the area's in the disks where stars are still being formed out of the gas in between the stars (the interstellar gas) at this moment.

Our own Galaxy, also called the Milky Way Galaxy, is also such a system and the Sun and Solar System, including the Earth, are right in the central layer of this disk at a moderate distance from the center. You may then also realise that, as we are in that flattened disk, it appears to us as a band of light from faint stars that circles the sky. This is the so-called Milky Way that we can see clearly during a dark night away from cities and other sources of light.

The Milky Way is most prominent when seen from the southern hemisphere. The reason for that is that in their winter (June is the most favorable time) the Galaxy is seen in the middle of the night spanning the whole sky with the center directly above our heads (fig. 8). Looking up, we see in all its splendor our home galaxy spanning from horizon to horizon, and in fact it extends beyond. This situation never occurs from our northern latitudes. From Europe we can also see the Galaxy as the Milky Way, but we are never looking at the center and always towards its outer regions. The remarkable thing is that from the southern hemisphere the Milky Way galaxy strikingly resembles pictures of other galaxies when seen edge-on, confirming that we are living in an ordinary spiral galaxy.

The Milky Way is really nothing more than the total light from a myriad of faint stars. Of course, we see brighter individual stars as well, scattered all over the sky. These are only the near ones within our Galaxy. But the fainter ones collectively show the structure on a larger scale, namely basically a

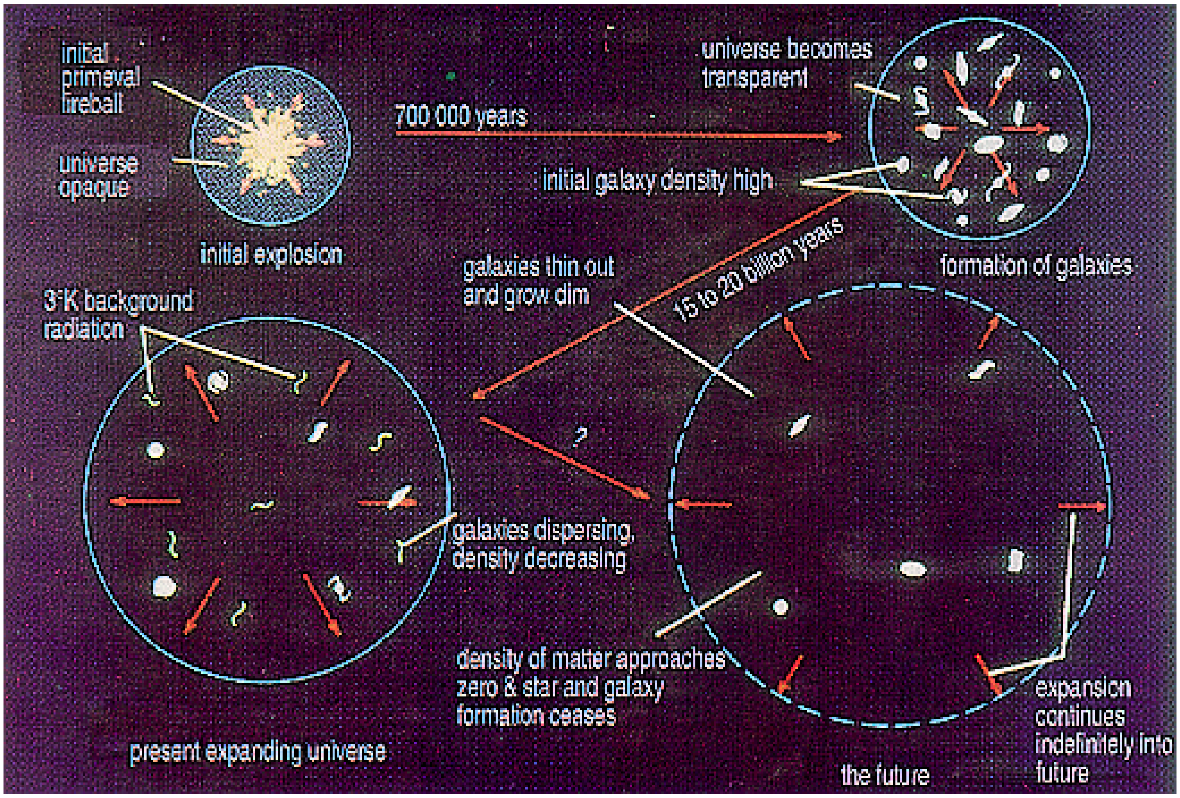

Figure 2: The standard Big Bang model of the Universe. Initially the Universe was very hot and opaque to radiation (also known as the primeval fireball). After about a billion years the Universe cooled down, became transparent due to the lower density and the first stars and galaxies formed. The expansion of the Universe continues to make galaxies move apart. The initial radiation field still permeates the Universe, but has cooled down to about 3 Kelvin temperature. The expansion is likely to continue indefinitely. The density continues to go down and eventually no new galaxies will form. In the galaxies, stars will die and no new ones will form and consequently galaxies will grow dimmer and dimmer. (©Science Graphics)

flat, disk-like (or, if you wish, pancake-like) structure. It is sobering to realise that the stars we see at night are only, so to speak, our immediate neighborhood in the Galaxy and that the faint band we can see as the Milky Way is the total of all stars that make up our Galaxy (fig. 9). Our Sun is only one in a hundred billion stars and what we see with our naked eyes at night is only a very localised region within the whole of the Galaxy. It is even more sobering to realise that not only is our Sun one in a hundred billion stars in the Galaxy, but that outside our Galaxy there are billions and billions of galaxies, consisting each of as many stars (or suns) as ours.

Our and the other spiral galaxies seem to have formed in a similar way. When it condensed out of the early Universe, the first stars formed. This is what we now see in our and other nearby galaxies as the central, more or less spherical concentration of light. The gas that remained from this initial phase formed the disk and in the disk the formation of stars is continuing up to this day. The Galaxy formed a few billion years after the beginning of the Universe and so probably did the disk, but only 4.5 billion years ago our Sun formed and with it the Earth and the other planets.

Figure 3: Picture of a so-called elliptical galaxy (M87; this means number 87 on the list drawn up by the French astronomer Messier about two centuries ago). Note the absence of much structure and the relatively red color. This indicates that there is little gas in the system for formation of new stars and that all stars in this galaxy are relatively old. (© Anglo-Australian Observatory)

4 Stars and chemical elements

For the following I now need to tell you in a few words and in very simple terms about the life of a star. Let me take our Sun as a first example. It is important to realise that our Sun is a very average star; we know of much larger and of much smaller ones. In its center the temperature is very high to terrestrial standards, namely about ten million degrees. As a result nuclear reactions take place as in a hydrogen bomb, "burning" hydrogen into helium and releasing energy that we see in the form of the light from the Sun. Calculations show that the Sun has sufficient fuel to continue to sustain these reactions, and therefore to keep shining, for another five or so billion years. But then it will eventually contract, the temperature will temporarily increase through the release of gravitational energy, but after that it will cool down. So the total lifetime of the Sun is about ten billion years and it is about halfway through this at the present time.

But there are also stars that are, say, ten or more times more massive (consist of ten or more times more matter) than our Sun. These do the same thing (burning of hydrogen into helium during most of their lifetime), but the temperature in the center is higher and the burning of the hydrogen occurs at a much faster rate. It uses all its fuel in ten or even fewer million years, rather than the ten billion of the Sun. This thousand or more times faster evolution of the heaviest stars is important, but it is not

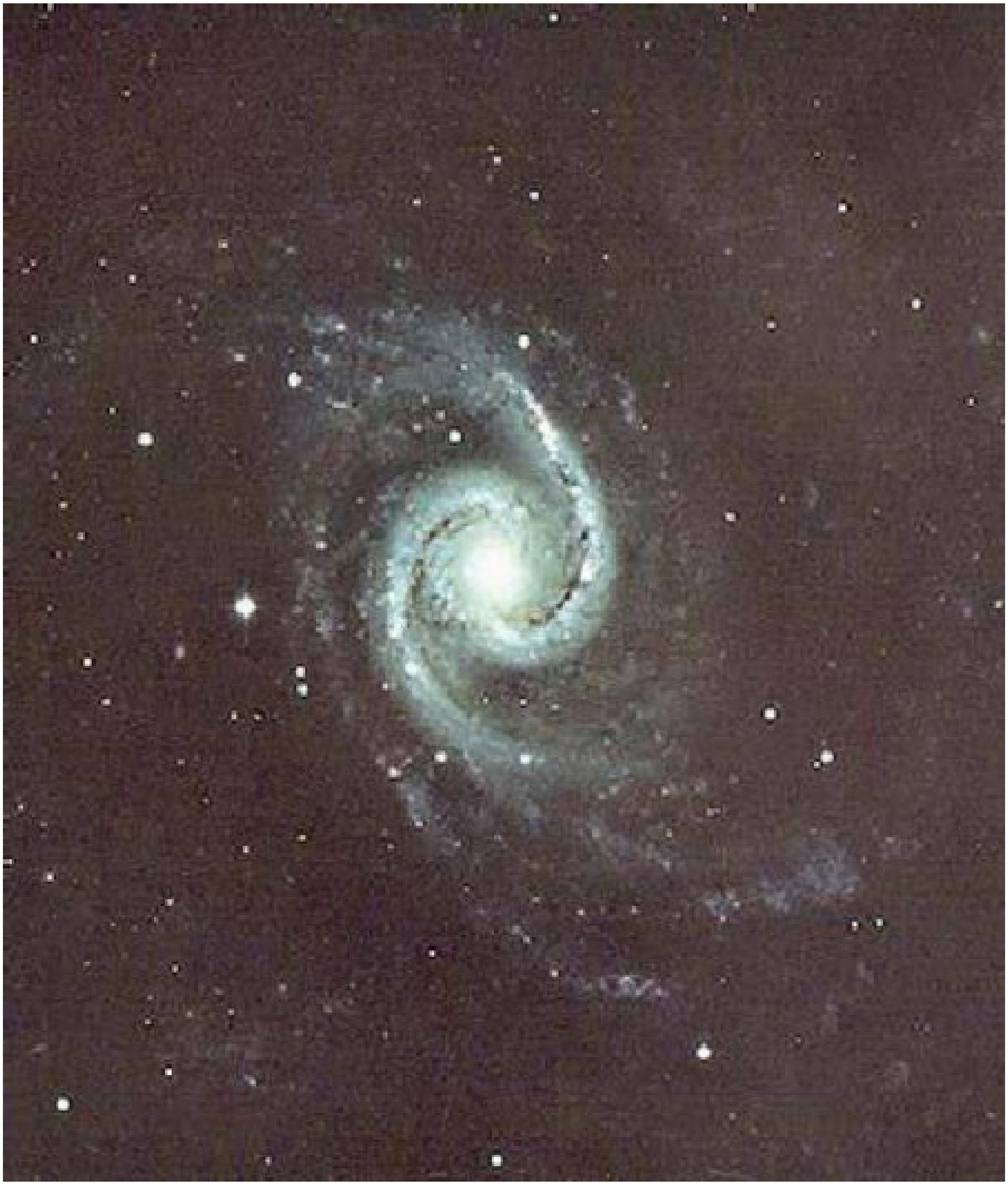

Figure 4: Picture of the spiral galaxy NGC 1566 (this means number 1566 in the New General Catalogue of nebulae and clusters, drawn up about a century ago). Note the blue spiral arms with much structure in them. This indicates that gas is present out of which even at this time stars are being formed. (©Anglo-Australian Observatory)

Figure 5: Picture of the spiral galaxy NGC 2997. Here the spiral arms are more tightly wound than in the previous picture. Note the inner smooth, red structure; this is the older part of the galaxy and consists almost entirely of old stars. (©Anglo-Australian Observatory)

the only difference. Their higher temperatures and masses result at the end of their relatively quiet lifetime of burning of hydrogen as in the Sun to the following. The contraction now leads to much higher temperatures than will ever occur in the Sun, up to hundreds of millions of degrees. This is so hot, that even more energetic nuclear reactions will take place. In fact, the helium "burns" into the whole range of chemical elements that we know today and the enormous release of energy that accompanies this, results eventually in a disruption of the star. It blows itself up by the prolific release of energy as a gigantic nuclear bomb. For a few days it shines as much light as a whole galaxy or hundreds of billion times as much as the Sun, after which the remaining central parts of the star cool down over a period of years. But most of its material is flying apart at large velocities (thousands of kilometers per second).

This short-lasting phase is essential, because the products of the nuclear reactions are blown at great speed into the medium surrounding the massive stars and mix with the gas already present. This is called a supernova, such as the supernova 1987A (we saw the explosion in February 1987) in the Large Magellanic Cloud, which unfortunately could only be seen from the southern hemisphere. For a few months it was easily visible to the naked eye. The Large Magellanic Cloud (which can be seen in Fig.

Figure 6: Picture of the spiral galaxy NGC 253. The spiral structure is much less well-defined here than in the previous two. We can see that the galaxy consists mainly of a flat structure (the disk) that is seen here at a large angle. (©Anglo-Australian Observatory)

10 below) is a companion galaxy to our Galaxy and therefore very near and the supernova very bright. It was the first supernova visible to the naked eye since almost four centuries and only the fourth recorded in the last thousand years. Of course, we observe many supernovae in other galaxies, but these can only be seen using telescopes. Remember that a heavy star takes only of the order of a few tens of million years from its formation to the exhaustion of its central fuel and its eventual explosion as a supernova. This is extremely short compared to the roughly ten billion years that the Galaxy existed at the time our Sun and its planets formed.

What does this mean? It means that in a relatively short period of time the gas that formed the galaxies and that originally consisted only of hydrogen and helium, gets "enriched" by the other chemical elements, in particular, as it turns out, by carbon, oxygen and nitrogen. Calculations and observations have shown that it took no longer than a few billion years after the formation of the Galaxy to build up significant quantities of the chemical elements in the gas in between the stars. For at least ten billion years heavy stars have been producing the elements we consist of and have been adding these to the interstellar gas. At the time of formation of the Sun and the Solar System, 4.5 billion years ago, the process of formation of chemical elements (astronomers call this stellar nucleosynthesis) resulted in the conversion of only 2 percent of the original hydrogen and helium into heavier elements. This may not sound like much, but when the Earth had formed and the gaseous hydrogen (as

Figure 7: Picture of the spiral galaxy NGC 4565. We now see the disk completely edge-on and consequently we cannot study the spiral structure. The central, old part is seen to be less flattened than the disk. Also note the thin "dustlane"; this is the thin layer where dust and gas between stars resides and where star formation is still occuring. (©Polyvisie-Hilversum)

far as it was not kept in chemical compounds like water or in rocks) and helium evaporated away by the heating from the Sun, we had a planet, consisting of the great variety of chemical elements we see around us today and that now has made chemistry possible.

So, we have come to the conclusion that almost all matter that makes up our planet Earth and -most importantly- ourselves is the result of nuclear reactions in heavy stars in the Galaxy, that have long since died in gigantic supernova explosions and that have enriched the gas in the disk of the Galaxy in the course of time with the elements that are essential for the formation of a planet like the Earth and the origin of life on it. It took more than ten billion years to synthesize these chemical elements, and after the Sun and Earth formed it took again more than four billion years for life to originate and biological evolution to get to the present stage, when there are humans on this Earth. Our species now wonders when it looks up at the sky and realises that earlier generations of heavy stars have been necessary to make our fundamental building blocks. Most of what we are made up of is synthesized in the extremely hot centers of stars and we have come to understand this process at least in general terms.

Of course, this process is still continuing in the Universe. So, if again you look up at the sky one night and you see the many stars above, contemplate the fact that there are

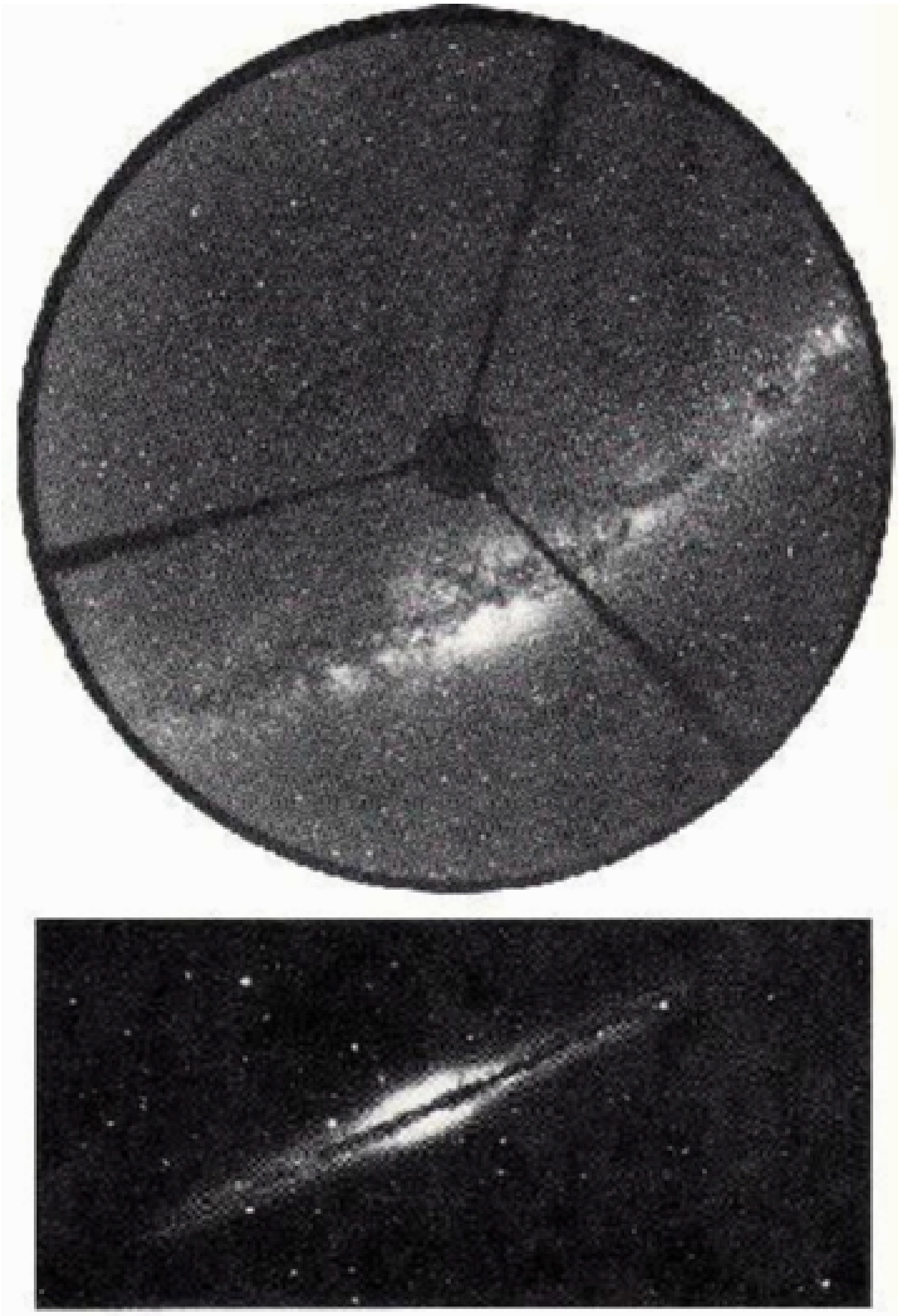

Figure 8: The upper part of the figure is a fullsky photograph, taken from Australia. This done by a special technique, where a photographic camera looks down at a half-sphere with a mirror-coated surface. In this way the whole sky can be seen by the camera. The circular edge is the horizon and the center the zenith (the point directly above our heads). The central black area and the spikes emerging from that are the camera and its supporting structure. The picture shows our Milky Way Galaxy seen from our vantage point. The lower picture is of the galaxy NGC 891, which in many respects closely resembles our own.

Figure 9: Photograph towards the central part of our Galaxy. It shows that it consists of many stars. Also note the dust in the disk of the Galaxy, which blocks our view of the very central regions

stars among these that will explode as supernova and will add more carbon, oxygen and other elements to the gas in between it, so that future stars and planetary systems may form. On such planets life may form as a result of this. And also realise that stars, now long disappeared, have formed the building blocks of life on Earth or maybe elsewhere in the Universe. Indeed, there is an intimate connection between us and the sky; we are children of the Universe.

5 Large telescopes

In order to see further into the Universe, astronomers need to study ever fainter galaxies. Earlier in this century, when we were dependent on photographic plates for our pictures and other observations, the quest was to build ever larger telescopes. After all, the surface area of the mirror in the telescope (in astronomical jargon the "collecting area") determines how much light (or how many photons) are collected from an astronomical object for activation of the photographic plate. The major steps were taken in the United States, first in 1918 with the completion of the 100-inch (2.5-meter) telescope on Mount Wilson near Los Angeles and in 1948 with the famous 200-inch (5-meter) telescope at Palomar Mountain in Southern California. These sizes refer to the diameter of the (primary) mirror in the telescope, that collects the light. Think of this: A glass mirror with an area of almost 20 m^2 ground into a parabolic form to a fraction of a millimeter, mounted in a structure that can point to any position on the sky with the mirror supported in such a way that it never distorts under its own weight of more than 14 tons! Certainly a major feat of engineering for the thirties and forties.

It is no surprise that it turned out impossible with then current technology to build even larger telescopes. The 6-meter telescope, built by the Soviet Union in the 1960's, never lived up to expectations. In spite of this a major revolution took place during the 1970's and 1980's. To understand this one must first realise that up till that time telescopes relied mostly on photographic plates for the recording of images, etc. Photographic plates are notoriously inefficient; only a few percent of the light (photons) is effectively used by the emulsions for the formation of a picture (in technical terms the quantum efficiency is a few percent). That is no problem for our every-day use of photography; there is plenty of light. But for astronomical purposes it is essential that as much of the light is used as possible. Heroic efforts in particular by the Kodak Company to develop special photographic emulsions for astronomy have only increased the quantum efficiency to as much as ten percent or so and then only after special treatment such as baking just before use in the telescope.

Nowadays photographic material is hardly used anymore at astronomical observatories. Rather, astronomers use so-called CCD's (charge coupled devices), which are the same detectors as used in television camera's and in fact in your private video-camera's. With special adaptions these now have reached quantum efficiencies close to 100%. This means that compared to photographic emulsions the sensitivity or ability to register faint light by telescopes has increased more than tenfold compared to the 1960's. Clearly, progress has been achieved through better detecting devices rather than the construction of ever larger telescopes. But now that effectively all the light is used to register the image, there is no further room for improvement and astronomers are looking again after almost half a century towards the building of giant telescopes.

A major initiative in this respect is taken by European astronomy. A consortium of West-European countries (all the major ones, except the United Kingdom) have build since the 1960's one of the leading observatories in the mountains of the Andes in Chile. This "European Southern Observatory" (ESO), for which in particular Netherlands astronomers such as Professor Oort, were the major initiators and which has his headquarters in Germany (near München), has now taken the world lead. Early in 1988 it decided to build the largest telescope in the world, named prosaicly the Very Large Telescope (VLT; fig. 10). It will consist of a set of four 8-meter diameter telescopes, to be erected by the turn of the century in the north of Chile (at a site called Paranal, not far from Antofagasta). When operated together, these will form the equivalent of a 16-meter telescope with a total collecting area of about 200 m^2 or an increase of about a factor ten over the Palomar 200-inch.

Figure 10: Artist drawing of the Very Large Telescope of the European Southern Observatory, which will consist of four 8-meter telescope and will be the largest in the world when it is completed at the end of this decade. The background shows a picture of the sky towards the Large Magellanic Cloud, a small companion galaxy to our own, that can be seen from the southern hemisphere. (©European Southern Observatory)

The construction of these giant telescopes is made possible by the technique of active control of the mirror shape through laser interferometry measurement and computer control of adjustable support systems. That means that lasers are used to monitor continuously the exact shape of the mirror and this information is fed into a computer. This computer then activates little devices at the back of the mirror that push or pull it back into the correct shape. As a result these mirrors can also be thinner and therefore less heavy.

The construction of the VLT is a major challenge to European industry. The mirrors are being cast in Germany and will be ground in France. The main structure of the telescopes and the enclosures are being designed and built in Italy and the critical optical parts in Germany and France. Other European countries are contributing as well on various other aspects of this enterprise. At this time the first mirrors have been cast and are being ground into the required shape. Design of the telescopes themselves is more or less complete and construction will start soon. The same holds for the domes, that is the buildings that will house the telescopes. The top of the mountain at Paranal has been flattened and the foundations are being laid at this moment.

With the completion of the Very Large Telescope (it is expected to come into full operation around 1999), Europe will remain at the forefront of astronomy.

6 Conclusion

I hope that I have been able to convey to you some of the excitement and significance of astronomy and that you will have more appreciaton for the relation of the human species to the stars in the sky. I would like to thank the Board of the VGB and the organisors of this meeting for the honor of being invited to explain some aspects of Man's place in the Universe.