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STARS AND PARTICLES: WORDS OF THE UNIVERSE.

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ABSTRACT

In this paper we review the long history of the relationship of humankind with the universe. From Stonehenge until the modern satellites, our race has always devoted huge resources and the best techniques to decipher messages coming from far away in the cosmos, trying to reach a better understanding of our place in the universe.

Keywords: *star, particles, cosmos, universe, physics, astrophysics*

ZVEZDE IN DELCI: BESEDI UNIVERZUMA

IZVLEČEK

V tem prispevku smo pregledali dolgo zgodovino odnosa, ki vlada med človeštvom in univerzumom. Od Stonehengea do modernih satelitov – naša rasa je vedno vlagala veliko denarja in najboljše tehnologije v dešifriranje sporočil, ki prihajajo iz oddaljenega kozmosa, da bi tako poskusila bolje razumeti svoje mesto v univerzumu.

Ključne besede: *zvezda, delci, kozmos, univerzum, fizika, astrofizika*

INTRODUCTION

We do not know when the first hominid raised his head and began to observe the sky. A sky full of stars dazzling on moonless nights without fires.

For millennia, stars have accompanied the events of history, pearls set in a mysterious and unchanging sky, sometimes interpreted as signs from a world above ours. A great scene, able to convey wonder and amazement. Deep feelings, intimately connected with a sense of awe towards nature, and its great creative and destructive power. A type of perception which left traces in the ways in which the various early civilizations have developed their vision of the cosmos and its origins.

Not surprisingly, the sky has long been the ultimate environment in relation with higher entities, the supernatural, the world of the gods, the religions. Those who watched the sky and interpreted the signs had a special status within ancient societies, such as priest, magician or astrologer. Structures such as the Neolithic site of Stonehenge or the Egyptian pyramids, whose designs are influenced by the study of celestial bodies and their alignments, undoubtedly had religious functions and meanings. The cosmogonies or creation narratives are based on concepts and ideas are inextricably linked to the philosophy, religion and science of the time.

A place of synthesis but also of comparison and often a clash of ideas, the study of the cosmos was, in the civilizations of the past, closely linked to the progress of scientific thinking in particular of mathematics and geometry (it is no coincidence that in Greek κόσμος means "order"). These studies were a major training ground for mathematics and geometry, the first attempts of what would become modern experimental science. The concepts of space, the role of time, the regularity and predictability of the motion of the stars are just some of the ideas that different civilizations grappled with. The evolution of these ideas was influenced and passed on via contact between different cultures, with deep insights which in some cases were forgotten and rediscovered more than once over the centuries, extending across the whole history of mankind.

We know how important the influence of Greek thinking was for the development of western astronomy. On the one hand, the Greeks developed astronomy using often quite sophisticated mathematical methods. Vastly more significant, however, was the influence of the thinking of two great philosophers of the fourth century BC, Plato and Aristotile, who became interested from the philosophical point of view, in the origin and the development of the cosmos. The description given by Plato in Timaeus, was of a cosmos shaped by a Demiurge as an imitation of ideas, and the model of the cosmos that Aristotle derived from Eudoxus, where the planets are carried around the earth on concentric spheres, had a profound influence on the vision of the cosmos in the western world until the time of Galileo. This profound influence lasted in spirit of other Greek thinkers who had developed in the subsequent centuries much more modern theories. Among them, Aristarchus of Samos, who introduced the first description of the heliocentric system in the second century BC, or Eratosthenes, who accurately determined the radius of the earth showing a mastery of methods for measuring distances and angles very accurately. It is also known that advanced techniques were available at that time, as evidenced by the sophisticated astronomical instrument found in a wreck in the seabed of Antikythera, able to calculate eclipses over a time interval of about 200 years. In spite of that, ideas like those of Aristarchus did not garner the attention of his contemporaries.

A summary of what was known in Greek astronomy was recorded at the time of the Romans in the Megale Syntaxis (Great Synthesis), better known by its Arabic name Almagest, in which Ptolemy of Alexandria provides the, classic description of the geocentric system around 150 AD. This Aristotelian text influenced, if not paralyzed, Western thought for the next thousand years. Geocentrism prevailed during this long period of time even if the mathematical models were becoming gradually more complex in order to reproduce the observed data.

To exit from this situation it was necessary that a radical gesture be made to begin the study of the cosmos with the methods of empirical science, wresting away the monopoly of deeply theoretical discussions. This was the gesture that Galileo made 400 years ago in January 1609, when he looked for the first time where no one else had. Using a new instrument, the telescope, which allowed one to zoom in on distant objects at about 20 times magnification, he saw what for thousands and thousands of years, men had not seen while watching the stars. To his eyes appeared the mountains of the moon, the stars of the Milky Way, the satellites of Jupiter: his mind formulated new hypotheses on the structure of the cosmos, hypotheses that forever revolutionized the way we think about the universe. The observations of Galileo gave a decisive confirmation of the Copernican model, paving the way for the fundamental contributions of Kepler and Newton. Modern science began with Galileo, based on the instrumental measurements, on the experimental verification of theoretical hypotheses, on the mathematical interpretation of the words written in the Book of Nature: this is the reason for the exponential scientific and technological development of the western world even today.

With the observations of 1609, astronomy started to dominate the scene of physics, a scene which did not leave during the following centuries, becoming the queen of sciences in the study of the cosmos. Thanks to the work of Galileo, Kepler and Newton, astronomers began not only to record events in the sky but to systematically ask questions on the physical causes of celestial phenomena.

Today's scientists are studying the Universe following the path opened by Galileo.

The stars are unreachable, but they send a large number of messages in the form of radiation, messages which, when detected and decoded, allow us to understand what happens in the heavenly bodies, how they develop, which is their role in the Universe.

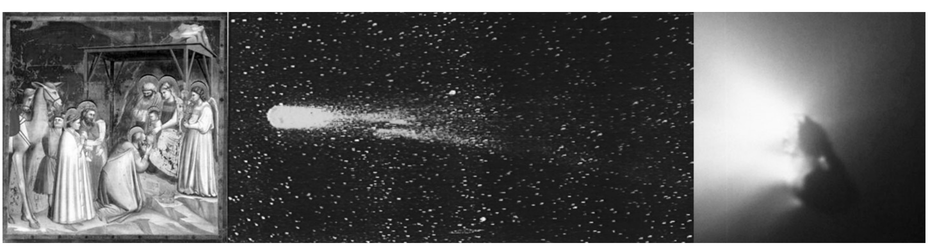
Much of this radiation is light, a small portion is matter. Of the light, only a small fraction is visible to our eyes. For three centuries after Galileo, astronomy has been able to progress by studying only this small fraction of the messages coming from the stars: telescopes have become increasingly complex over time, up to today's modern powerful telescopes, but we need to enter the century which just ended to witness the triumph of new kind of instruments, with the resulting exponential growth of our knowledge about the structure of the universe and its evolution.

The developments in physics in the second half of 1800s provided a huge boost to modern astrophysics and cosmology: the Universe became an extraordinary laboratory for testing the fundamental physical properties of force fields and of the particles, the building block of matter. Since then, a series of fundamental discoveries began which led to the current vision of the Universe.

At the end of the 19th century, the discovery of the laws of electromagnetism and the understanding of atomic structure brought an understanding of what causes the emission and absorption of light by the stars.

The advent of special relativity and general relativity have subsequently shown the deep links between space and time, mass and energy, relationships that have a decisive role in the various stages of development of the Universe.

At the beginning of the 19th Century the photographic recording start to change the astronomy, enhancing the ability to accurately and objectively record the astronomical phenomena which in the past were patiently recorded by hand by astronomers.



Halley's comet through six centuries of observations: (a) Giotto di Bondone, Adoration of the Magi, the Scrovegni Chapel (1303–1305), the Halley comet was seen by Giotto in the year 1301. (B) One of the first photographs of the Halley comet taken during the passage of the 1910 (c) The nucleus of the Halley comet photographed from a satellite, Giotto, which reached the comet in 1986 (courtesy ESA)

In the second decade of The 20th Century, scientists identified a new form of radiation from the cosmos, invisible, penetrating: energetic Cosmic Rays were discovered by V. Hess in 1912, matter particles accelerated to relativistic energies, messengers of the Universe whose nature is still partly mysterious one century later.

The study of cosmic rays leads to a whole new discipline, that of elementary particles, also called sub-nuclear physics, which, together with nuclear physics, increasingly influences the understanding of the laws that govern the evolution of stars and the early universe. Until the mid-1950s, when sufficiently powerful particle accelerators became available, the Universe, providing the energetic cosmic rays as a natural accelerator, allowed the discovery of a dozen new sub-nuclear particles.

Reproduction of Wulf electrometer used by V. Hess to discover the existence of cosmic rays using a balloon (model built by INFN Padova)

During the 1930's nuclear physics and quantum mechanics made it possible to explain the structure of neutron stars, among the most extraordinary objects in the cosmos.

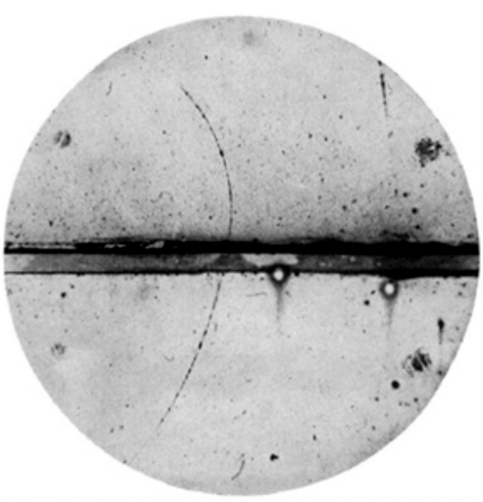
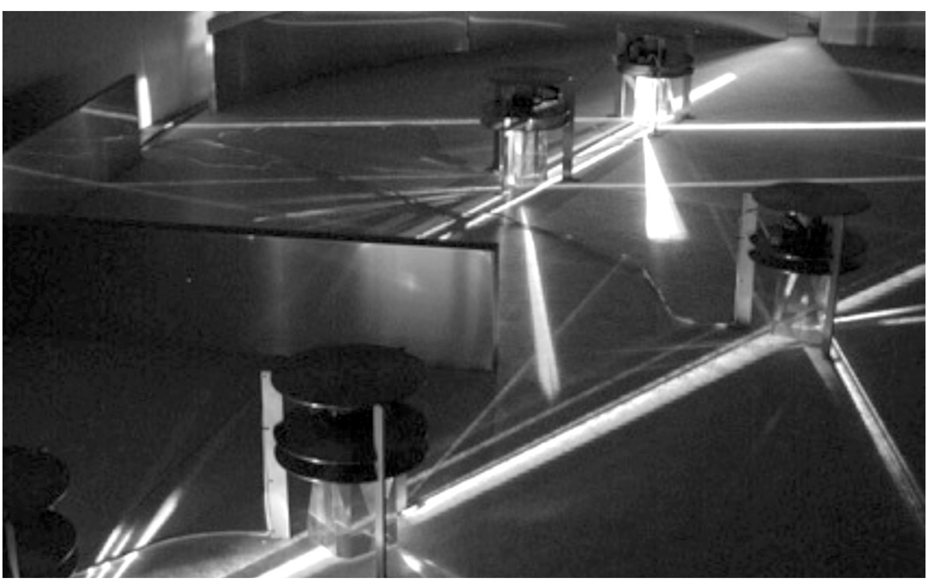


Photo of the first particle of antimatter (anti-electron or positron) discovered by C. Anderson in a cloud chamber in 1932 studying Cosmic Rays (Credits: Carl D. Anderson, Physical Review Vol.43, p491 (1933))

At the same time, accurate measurements of the redshift of the spectra of galaxies performed by E. Hubble suggested that the universe is expanding, a revolutionary conclusion that undermines the stationary model of a universe which is always the same, a view of the cosmos characteristic of primitive cultures but shared by most scientists at that time, including Einstein.

After the Second World War another window opens on the cosmos: the daughter of radar, a strategic tool of the military victory of the English, radio astronomy began studying radio signals from deep space, exploiting the fact that these frequencies are not absorbed by the atmosphere. Soon after came the fundamental discovery of the cosmic microwave background, made by Penzias and Wilson, confirming the extraordinary intuition of Hubble and the cosmological theories predicting that the universe comes from a huge initial explosion, the Big Bang.

With the space race of the 1960's, new observational windows open providing a series of extraordinary observations. The infrared, ultraviolet, X-rays, gamma rays sky … colors of light to which man is blind, a limitation of evolution that has been remedied by rockets and newly developed detectors. Finally discovering all the colors of Universe, its magnificence, its immensity and acquiring a wealth of new knowledge, theories and hypotheses about the ultimate structure of nature, which makes the study of Universe one of the most dynamic areas of contemporary science.



Visible light is composed of various colors. But the universe has many more colors the human eye can see, for which technology must be used.

Also the study of the other messenger of the universe, elementary particles, advanced significantly.

By studying in detail the composition of cosmic rays before they are absorbed by our atmosphere we have obtained indications of new physical phenomena that could confirm the existence of a dominant component of the mass of the universe consisting of particles that do not emit light, the so-called dark matter. These observations seem to confirm measurements made in the last decade by experiments placed in the underground Gran Sasso Laboratories. This would be a new kind of matter from 6 to 8 times more abundant than that of which we are composed. We might be at the threshold of an important discovery which could be crucially confirmed using the large accelerator built at CERN, the Large Hadron Collider (LHC).

We can also reveal extremely energetic cosmic rays which are not significantly deflected by interstellar magnetic fields in their path between the source and our detectors. These energetic particles of matter have the energy of a golf ball concentrated within an elementary particle; an energy hundreds of millions of times higher than what can be reached by the most powerful accelerators. Finding the sources of these particles with extreme energy is one of the challenges of research in this field.

The same is true for neutrinos, particles without any electric charge, which do not suffer from being deflected except by the gravitational effects. Under the Gran Sasso Laboratories we are already able to see the image of the sun, using the solar neutrinos crossing the rock of the mountain. To detect high energy neutrinos coming from the galaxy, we are building giant detectors placed miles beneath the ice on the South Pole or deep in the water of the Mediterranean Sea, in Sicily off Capo Passero and in France off the coast of Marseille.

Thanks to this research, in which the Italy has a world leading role, a new type of astronomy is making the first steps, based on particles of matter and not only on the rays of light.

The Large Binocular Telescope (LBT), Mt Graham (USA), one of the most powerful optical telescopes existing today, built using an important contribution of the Italy, INAF–Osservatorio of Arcetri.

There is also another form of radiation already foreseen by Einstein but very difficult to detect. Gravitational waves, another messenger of the universe, which are emitted when large masses are subjected to strong acceleration. Thanks to sophisticated laser interferometry experiments already operating on the ground and being developed for space, during the coming decades the sky will be filled with sources of gravitational waves, stars much cooler and less shiny than the ones we are used to for millennia, but not less interesting.

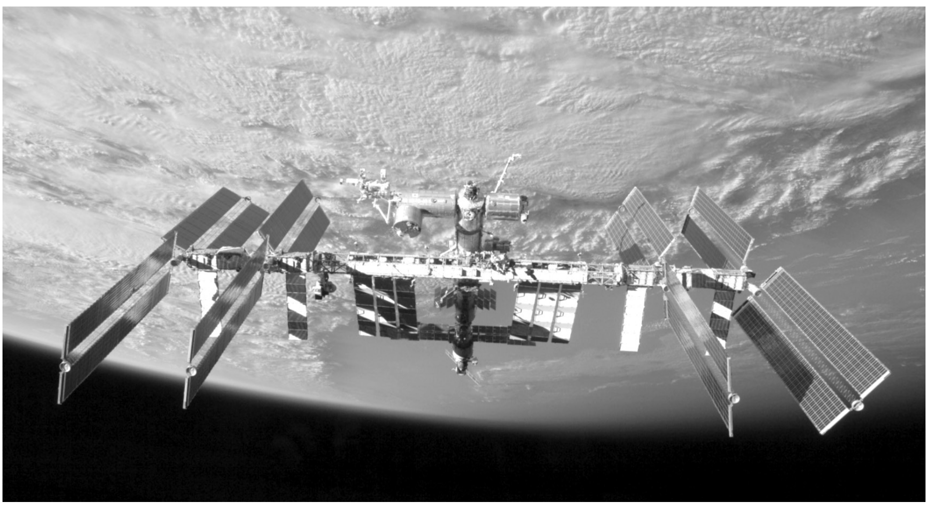
At the end of The 1800s we could not have imagined that the study of the laws of the infinitely small would have revealed so many things about the properties of the infinitely large. And only in the beginning of the last century did we begin to realize that the infinitely large could give us answers to the same problems that we were studying the infinitely small scale and vice versa.

With these tiny messengers, quanta of light and matter particles that travel at the speed of light in the immensity of space, we have an idea of the size of the cosmos, being able to see back in time when the universe was in its infancy. We study what it is composed of, as we follow the evolution of the stars that form it and discuss objects, space, time, dimensions that exceed our intuition. In this way, we travel with our minds to other places, at other times.

And that's how we learned how our universe is a mixture of things slow, cold, inert and violent phenomena, rapid and cataclysmic.

Thanks to light, we can see the harmonic dance of the planets around the sun or around distant stars, some of which could accommodate other lives, similar or different from that of Earth. Or we can get closer to the areas in which matter is transformed into energy, the blacks holes, gamma ray bursts, active galactic nuclei. Perennial cataclysms of enormous size.

Thanks to the particles, building bricks of the Universe, we can study what it is composed of, both the small part of it we can see as well as that the large fraction that does not emit light but which dominates the evolution of the Universe due to the effects of gravity.



Space is always more used for the study of the Universe. The search for primordial antimatter, for example, takes advantage of the large laboratory represented by the International Space Station, where in 2011 the AMS experiment has been installed, the first large space borne magnetic spectrometer built with the contribution of INFN and ASI.

Before our eyes there is a violent Universe, where there is a continuous mixing of matter and energy: a system whose parts communicate with time and energy scales which are very different than that of mankind. Even the planets communicate, exchanging fragments, bombarding each other with asteroids, sometimes colliding one with another. It is a living universe, where stars are born and die continuously, changing the very essence of the matter, the nuclei of atoms. Inside their enormous bodies they forge the light elements into heavy elements, which then form planets, and in some cases, systems of atoms and molecules that can replicate themselves, the life developing to such level of complexity to be able to observe and describe where it comes from!

Of course, in these studies we are dealing with time and space scales over which mankind and our civilization are infinitesimal. But the limited nature of man is transformed into extraordinary greatness when this tiny piece of the universe that we are is able not only to think abstractly about the immensity that surrounds it, but also to observe, measure, evaluate and then elaborate, using the tools and methods of modern science, the daughter of Galileo.

The main questions of astrophysics, cosmology and elementary particle physics today are closely interlinked: matter and dark energy, the number of forces at work in the first instants of the universe, how many kinds of particles exist; these are some of the fundamental questions faced today by the international scientific community.

The large accelerator LHC at CERN in Geneva, which sees a strong participation of italian physicists, has among its objectives the scientific answers to questions concerning the origin and evolution of the Universe.

This convergence has created extraordinary conditions, perhaps for the first time in the history of science: we know for certain that we do not know most of the answers to fundamental questions that we were able to clearly state. It is an extraordinary challenge for future generations of scientists.

It is a mysterious language, that of the Universe. It is a language that deserves to be decoded, understood. It is a language that has always fascinated people even when they had only their eyes to look at the Universe. It was thanks to the experimental study of the universe that science has made great strides, demolishing one after the other the false intuitions that we derive from everyday experience about the laws of motion or about the structure of space and time. But many more questions remain to be understood, it is necessary to pierce the veils, many more boundaries must be overcome.

The Italian scientific community is at the forefront of the study of the universe, focusing on elementary particle physics, astrophysics, cosmology, physics and space exploration: a community that often leads the world community. Creating extraordinary instruments to observe and study the Universe in an increasingly refined manner, we translate the messages that it sends to us into ideas, images, concepts, which are confirming or confronting theories, just as Galileo Galilei did, back in 1609.

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