ARCHITECTURAL EVOLUTION OF ASTRONOMICAL OBSERVATORIES

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Abstract. We review the development of an astronomical observatory mainly from the architectural standpoint and less via astronomical knowledge or instruments evolution. Our approach is an attempt to summarize the evolution of the buildings from the stage of instruments to the complex modern stage with many functions and even with their cultural role.

Key words: history of astronomy – observatories – architecture.

1. INTRODUCTION

Astronomy is the oldest natural science, dating from Antiquity, and even earlier. The Arabs named it "the queen of sciences" since it lies at the basis of many sciences, such as physics and mathematics. The origin of this science is to be found in the religious, mythological and astrological practices of prehistory. Early astronomy consisted of the observation of the rhythmicity of the celestial bodies' apparent motion on the vault of heaven. Especially the Sun, the Moon, the planets and comets were observed, as well as phenomena as eclipses. The Sun's motion referred to so-called fixed stars led to the elaboration of the calendar, and to time measurement, as well. This proved to be strictly necessary to the social life and to the activity on planet Earth.

Astronomical observations have known several stages and epochs, and along the centuries several branches of this science developed, such as celestial mechanics, astrometry, astrophysics, solar physics, cosmology, etc. The techniques used also developed in keeping pace with the problems studied. It was the same as regards the requirements for the location of observatories, which have evolved from the prehistoric Stonehenge to genuine space laboratories.

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In this paper we intend to synthesize the evolution of the astronomical observatories along the time, with a particular emphasis on their architectural aspects. Such an endeavor has to take into account the functions of the instruments and of the buildings housing them. The objectives of our analysis are discussions of their functionality, the plan situation, materials used and design of the buildings. We tackle these aspects throughout time, considering the historical epochs: prehistory, Antiquity, Middle Ages and Renaissance, the modern and contemporary epochs.

It is worth mentioning that astronomy and astrophysics celebrated several important events in the last years. Thus, the period February 2007 – February 2009 was called *The International Heliophysical Year*. This event was occasioned by the anniversary of fifty years since the launch of the first artificial Earth satellite, Sputnik 1, and the beginning of the space era. If in 1957 the research priority was the study of Earth and magnetosphere (the magnetic field surrounding the Earth) and the influence of the solar activity on our planet, the year 2007 changed the knowledge frontiers from the magnetosphere to the Heliosphere (the region of the cosmic space under the influence of the activity and magnetic field of the Sun).

Another special event is celebrated in 2009, which has been declared *The International Year of Astronomy*. It will be a global celebration of astronomy and of its contributions to society and culture, set off by the 400th anniversary of the first use of an astronomical telescope by Galileo Galilei.

2. THE PREHISTORIC EPOCH

We know from the prehistoric epoch few structures with possible functions of astronomical observatories, but certainty they had mainly religious functions. In those times priests had astronomical knowledge and their interest in the celestial bodies motions in the sky was applied to the social life needs. The Newgrange megalithic passage tomb (3200 B.C.) is the oldest known astronomically orientated monument.

Stonehenge is the most famous prehistoric monument known with this double function. This monument, situated in England (Wiltshire), is made up of stones arranged circularly around a central one (see Fig. 1). Its building registered roughly three phases, extending along more than 1600 years.

The first monument consisted in a circular line and a ditch around the precincts made from chalk, having a diameter of 110 meters (360 ft), with a great entrance to the North-East and a smaller one to the South. It was raised in a lane, on slope easily seen from a distance but not on the spot. The builders placed stag and yoke bones in the lower part of the ditch, as well as several stone instruments. The bones were considerably greater than the stag horns used, and were probably used for digging. This first stage dates from around 3100 B.C. The exterior border of the zone was closed with a circle of 56 holes, each one with a diameter of 1 meter (3.3 ft), known under the name of Aubrey, after John Aubrey.

The evidences of the second stage (from around 3000 B.C.) are no longer visible. It seems that a wooden structure was build then inside the precincts in the first years. Several wooden logs were placed facing North-East of the entrance and posts were aligned parallel to the interior, South of the entrance. At least twenty-five Aubrey holes are known, which seem to have been included later, dating two centuries after the monument was built. It seems that, irrespective of the holes, the initial function was changed and the monument became a funerary one in time. Consequently, Stonehenge is considered to have been a crematory in the British Islands. Fragments of unburnt human bones were also found in the ditch.

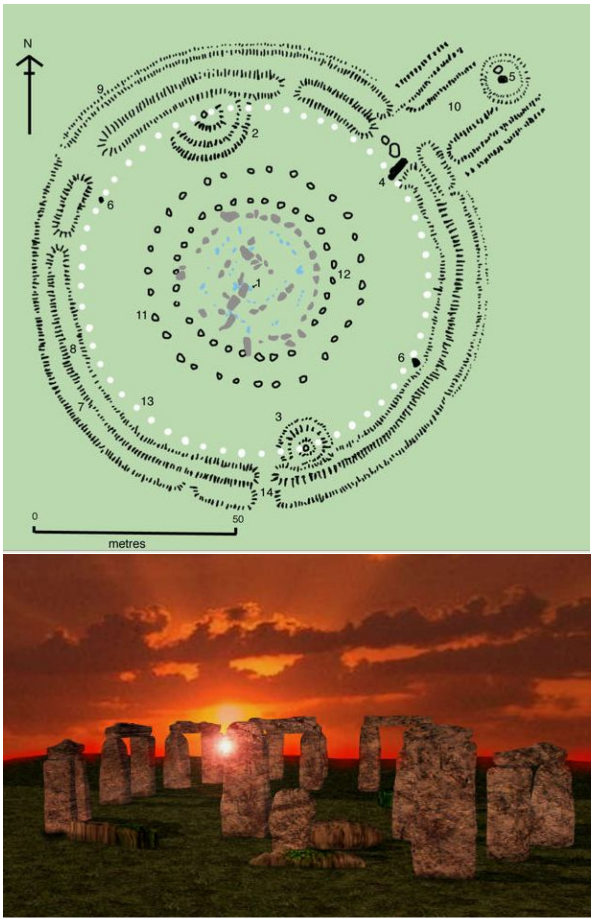

Fig. 1 – Stonehenge monument: plan (top) and perspective (bottom).

In the third period the monument underwent some changes. The first stones were strengthened with a series of blue stones. Then, the North-Western section of the blue stones was demolished, the structure getting the shape of a horseshoe. A wooden circle was also built in that period. The circle was oriented to sunrise on the point of the winter solstice, while an alley was aligned in keeping with the summer solstice. The last construction known at Stonehenge dates from the Iron Age.

It is believed that this monument was used for both religious and astronomical purposes, functioning as an astronomical observatory for the determination of the moments of the summer and winter solstices.

Sarmizegetusa Regia (in today's Romania) is another monument dating from the same Neolithic period. A complex of sanctuaries and a civil settlement, being also the capital of the Dacian state, accompanied it. The sanctuaries were dedicated to the cult of the Sun and to astronomical observations. The constructions here made up an ingenious calendar, surprisingly precise for the respective epoch.

This complex of seven sanctuaries is situated at an altitude of 1200 m, in Orăştie Mountains, on an artificially terraced plateau. All was kept away from the uninitiated eyes, and seems to have been intended to the deciphering of the astral mechanisms and of the great cosmic cycles.

These sanctuaries correspond to the five naked-eye visible planets: Mercury, Venus, Mars, Jupiter, Saturn; one corresponds to the Moon, whereas the seventh one signifies the Pantheon. Most historians estimate that they were built in the 3rd – 2nd centuries B.C., but there are also other calculations (in relation to the summer solstice day), which indicate that they are 600 years older.

The most important (and the best known) of them are the great circular sanctuary and the andesite Sun, presented in Fig. 2.

The Pantheon is devoted to the whole cosmos, representing the "Universal Egg" from which the Universe was born. Its structure proves the knowledge on the gold section. The two big gates are oriented to the solstices direction, the Men Gate corresponding to summer solstice (Cancer astrological sign) and the Gods Gate corresponding to winter solstice (Capricorn sign).

The andesite Sun presents ten radial inlays and seems to have been used as a sacred altar. The inlays prove knowledge of astrology and also indicate the exact latitude of Sarmizegetusa place.

It is worth mentioning the striking resemblance between the plans of the great circular sanctuary at Sarmisegetuza Regia and that at Stonehenge, which is so obvious that it gives the impression the plans were designed by the same person (there are differences only concerning the dimensions and the construction materials).

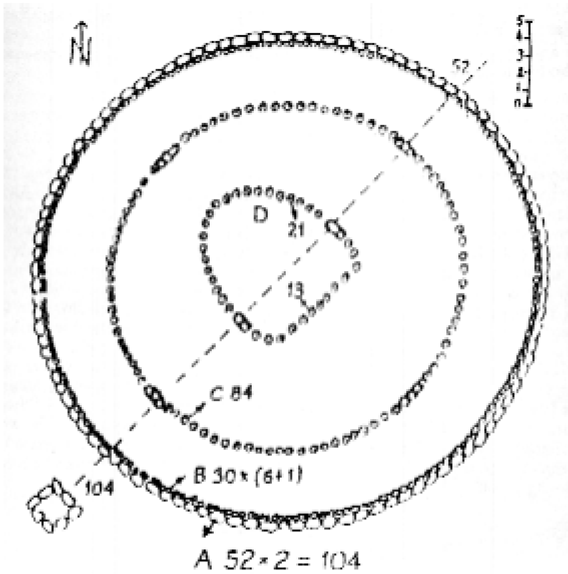

Fig. 2 – Sarmizegetusa Regia: plan of the great circular sanctuary (top); perspective of the great sanctuary and the andesite Sun (bottom).

The architect Silvia Păun has published numerous works dedicated to Sarmizegetusa. By adopting a scientific, multidisciplinary approach, correlating data from various fields (ranging from architecture, archaeology, astronomy, up to ethnography) of Romanian and foreign researchers, the author came to the conclusion that, starting even from the Neolithic, man benefited by unitary astronomical knowledge over vast areas, preceded in their turn by long preparatory stages. As a result of the comparative analysis and of the architectural elements details concerning the location in the ensemble, form, dimensions, orientation, construction stages, placement in the area, the author discovered 16 common aspects, from which at least 5 stand out:

– the horizontal sundials with the same diameter of 30 m;

– the stone rotunda with a horseshoe in the middle, oriented to the solstices (through the long axis of the ellipse to which it belongs);

– the horseshoe – determined through the same number (34) of vertical landmarks (a fact noticed in 1982 also by the astronomer Maurice Chatelain, a NASA researcher);

– discovery of a common measurement unit of 7.7 m or of 1.925 m (namely the fourth part of the first, i.e., the value of the fathom official approved on the Romanian territory by Prince Şerban Cantacuzino);

– the presence of triangles with Pythagorean relations in tracing, with sides marking important astronomical directions.

Similarities were also found between the andesite Sun and the famous Maya calendar. The way in which the building was made in a relatively short period of time and the materials were brought from at least 100 km away constitutes a still unanswered question.

3. ANTIQUITY, MIDDLE AGES AND RENAISSANCE

The Maya civilization is well known mainly for its precise calendar and its astronomy knowledge. There are four surviving written documents (called Dresden, Madrid, Paris and Grolier Codices) containing an ephemeris that charts the heliacal risings and settings in the synodic cycle of Venus, and an eclipse table. Important astronomical complexes are situated in Uaxactun, Peten, and in Guatemala.

One of them, one of the first known astronomical observatories in the world, was composed of three buildings aligned North-South. From an observation point situated on the Masks Temple, the early Maya astronomers could observe the Sun rise at solstices and equinoxes.

Monumental vestiges situated in the great Maya settlements in the land of Yucatan and on the high plateaus of Guatemala, as well as the rich inheritance to be found at present in archeological collections throughout the world, constitute evidences of the relatively developed level of the old Maya culture.

Architectural alignments of buildings provide to Maya people skills to measure celestial cycles. The duration of the year was set at 365.242129 days. No other people of those old times obtained closer estimates of the duration of the astronomical year, which is accepted now to be of 365.242198 days. The date set by the old Maya approximately two millennia ago contains an error of only 0.000069 days, i.e., a little bit more than half a second in a year. The Maya priests used methods of an amazing accuracy also for the calculation of the solar eclipses. The Tzolk’in is the sacred calendar of the Maya and is based on the cycles of the Pleiades. The cycle of the Pleiades uses 26,000 years that the Sun orbiting Alcyone, the brightest star of the Pleiades, but is reflected in the calendar we are using by encompassing 260 days. The Maya knew the exact length of the true solar year with an error of –0.0002, while our present Gregorian calendar has an error of +0.0003. The solar calendar Haab was devoted to current social life needs.

A monument with a strange architecture in Chichen-Itza, of an unknown type in other parts of the new world, is the charcoal, or the "snail", as the archeologists called it. It is a circular building placed on two superposed terraces, with four openings to the four cardinal points. In the wall of a circular corridor there are other four smaller openings oriented N-V, N-E, S-V, S-E. In the center of the second circular corridor there is the central pier of the building: the "snail" axis from Chichen-Itza. This building served the Maya priests of the new empire epoch as an astronomical observatory; there they did studies of the celestial bodies and calendar calculations.

Relatively advanced studies of astronomy have proved also the fact that a great part of the constructions, especially the commemorative stars, have a certain orientation in relation to various celestial bodies or constellations. Of a special importance to this effect is Venus, which the old Mayas identified with Quetzalcoatl-Kukulcan.

The Maya noted not only the extremes of the Sun at solstices, but also the equinox. Consequently, besides the zenith transits and the eclipses, this must have been an important part of Maya observations. Venus was the most interesting of all planets. They believed that it was even more important than the Sun itself. It was followed attentively with respect to its phases, and it was estimated that 584 days were necessary for Venus and the Earth to align in the same position by comparison with the Sun. It takes about 2922 days for the Earth, Venus, the Sun and the stars to return to the same position.. When it rises for the first time in the morning sky, the stage is called heliacal rising because then Venus rises at the same time with the Sun, this being Venus' most important position.

The Egyptian astronomy began in prehistoric times (fifth millennium B.C.) and is linked to religious life. The precise orientation of the great pyramids gives a high demonstration of stars observation: the pyramids were aligned in relation to the Polar Star, which at that epoch was Thuban star, a weak star in the Draco constellation. The Great Temple was aligned to sunrise at the winter solstice. Astronomy played a considerable part in religious matters, allowing the setting of festivals' dates and the determination of night hours. Astronomers were simply priests – their main duty was to calculate the time of the Nile flood, which occurred at the summer solstice, when the bright star Sirius rose before the Sun. In the Ptolemaic period the scientist reached fair conclusions on the Earth's rotation around the Sun and of the approximate geosphere of the planet. The Giza complex pyramids are astronomically oriented on the fundamental directions N-S and E-W. The plan disposition of them is a representation of the former position of the Orion belt. There are scientists who assert that the Great Sphinx statue is a reference to Lion constellation and its orientation as well as the Great Pyramid and Nile River is connected to Lion and Orion constellations and respectively to Milky Way. A date of 10,500 BC is chosen as start period of the Sphinx and in that period Leo rose exactly at the East of the statue at the vernal equinox.

Babylonia (ancient empire of Mesopotamia, present day Iraq), was a great civilization in astronomy study roughly 3000 B.C. The Babylonians dedicated themselves to the study of the Moon and Sun motions and to establish an accurate calendar. They built astronomical observatories under the form of towers, called ziggurats. The most famous example to this effect is the Tower of Babel.

Astronomical ideas played an important role in the Chinese culture. The Chinese astronomers made naked-eye observations of eclipses and other phenomena. The first record of a solar eclipse was made in 2136 B.C. in China. Observatories were the launching pads for exploring the mystical ties between the mundane and the cosmic, where the astronomers brooded solar eclipses and sunspots.

Emperor Zhengtong of Ming dynasty (A.D. 1442) built an observatory in the ancient Beijing, in the Southern part of the city. This was a platform of 46 ft high, which sustained 8 bronze astronomical instruments.

In India, the first reference to the astronomy is found in *Rig Veda*, dating from 2000 B.C.. In those times, the astronomy was interwoven with astrology. Many temples of the Sun were built in India for a double purpose, religious and astronomical, a very famous one is the temple from Konark. Noticeable is the fact that ancient Indian astronomers believed in a heliocentric theory of planetary motion. The temple from Nabagraha refers to the nine planets of the solar system. There are nine lingas inside the Nabagraha Temple that represent the nine planets or ‘grahas’. This temple was a place designated to the astronomy and astrology study.

In Europe, among the well-known personalities of Ancient Greece, it is worth mentioning names such as Thales of Miletus, Pythagoras, Anaxagoras, Heraclides Ponticus, Aristarchus, Archimedes, or Ptolemy. The early Greek astronomers knew many of the geometrical relationships of the heavenly bodies.

The Greek astronomer Hipparchus built the most important observatory of antiquity in Rhodos Island, where he used the first astronomical instruments. He also invented the instrument called astrolabe, drew up a modern catalogue of stars, where he noted stars’ positions on the heavenly vault. He also had many other contributions to the study of celestial bodies. Hipparchus is considered the father of modern astronomy as a science. Greek astronomers contributed to the foundation of the modern astronomy.

The Antikythera Mechanism is a two thousand years old machine made in Greece, which was discovered a century ago in a shipwreck. The device was used to calculate the astronomical cycles, but also the timetable of the Olympic games. The device had intermeshed toothed wheels that represent calendar cycles. By turning the wheels, a user could figure out the relationships between astronomical cycles to deduce the relative positions of the Sun and Moon and forecast eclipses. The mechanism is considered to the oldest known astronomical computer.

During the mediaeval period astronomers built observatories in order to make precise measurements of stars' and planets' positions in the sky. Thus, Nasir-ul-din Al Tusi, a Persian astronomer, built an observatory in Maraga in A.D. 1295.

Ulugh Beg built a famous observatory in Samarkand (1425), where astronomers observed stars' positions. This observatory was set up on a high hill and had three round buildings with a diameter of 46 m and a height of 30 m. In the main room were placed the instruments for Moon, Sun and stars observation. This construction was something unique for the time. One of the most important instruments was a goniometer to measure the angles – it was built under the form of a vertical circle with a radius of 40.212 m and an arc length of 63 m. The main instrument was the sextant, oriented in the meridian plane (see Fig. 3). The astronomers working at Samarkand observatory drew up a very precise star catalogue.

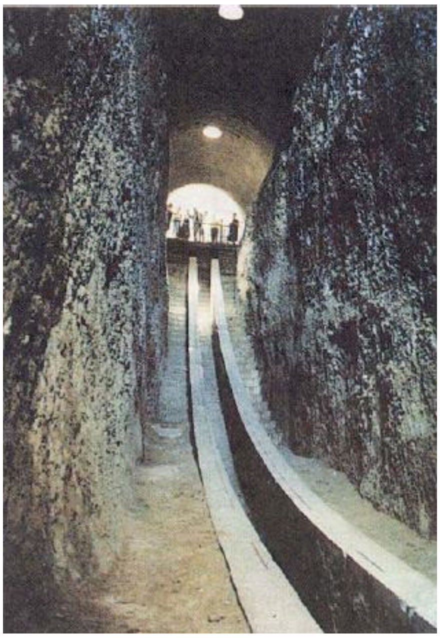

Fig. 3 – The sextant of Ulugh Beg Observatory.

At the beginning of the 17th century, the Maharajah of Jaipur built several observatories in five parts of India, in keeping with the model of Ulugh Beg's observatory. Huge sundials were built for Sun's observation. An instrument with the shape of half of a huge sphere of 27 ft in diameter was built in Delhi. Another instrument in use was a sextant – a huge concave arch with an opening of 60 degrees, with a radius of 28 ft). The buildings housing these instruments had huge holes in the roof that allowed the observation of the celestial bodies. Such a skylight in the roof yielded an image of the Sun of 75 mm in diameter and sunspots could be also observed. This instrument also determined the Sun's height and declination at each meridian passage of the Sun. At Jaipur was also built the greatest solar clock in the world.

It is worth mentioning that at that time the instruments were built in the same way as the buildings and consequently were an integral part of the architectural ensemble.

An important castle-observatory (called Uraniborg; see Fig. 4) was built in Europe, on Hveen Island, by the king of Denmark, for the famous astronomer Tycho Brahe, during the last quarter of the 16th century. This observatory (as well as the smaller Stjerneborg) was endowed with the most modern instruments for that time.

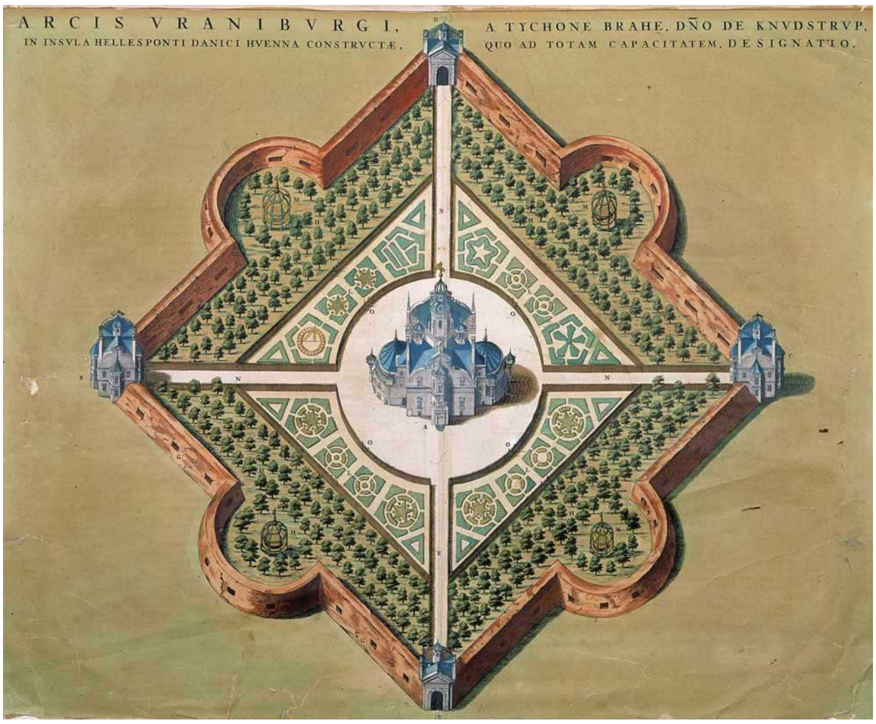

Fig. 4 – Tycho Brahe's Uraniborg.

4. THE MODERN AND CONTEMPORARY EPOCH

In 1609, in Venice, Galileo Galilei used a refractor (combination of lenses) for the first time in astronomical observations. This arrangement provided limited magnification (up to 30 times) for Galileo and a narrow field of view. With Galileo, considered the father of modern astronomy, begins the epoch of modern astronomical instruments and, on this account, the buildings housing them got new shapes in keeping with the new functionalities.

In 1704, Sir Isaac Newton announced a new concept of telescope, where a curved mirror substituted one glace lens. The reflector telescope that Newton designed opened the door to magnifying objects millions of times – far beyond what could ever be obtained with a lens. Also in England, in the 18th century, William Herschel constructed the first building, called the observer's house, which accommodated astronomical instruments. He also built a new type of telescope, based on mirrors.

In the modern epoch the buildings of the modern observatories were constructed under the consecrated form with round domes, housing astronomical instruments. The domes were built from wood on the system of ships and were covered with sheet iron.

In our times, metallic structures and modern materials have taken the place of the classical ones. The astronomical domes have got various forms, from oval to square ones, while the buildings have become ever more complicated, depending on the instruments incorporated in them, sometimes like real plants. Modern observatories are made up of several buildings of various shapes adapted to the technical requirements of the instruments, which, in turn, became extremely complex, being intended for very specialized astronomical observations.

Fig. 5 – Hida Solar Observatory, Japan.

Such an example is represented by the solar towers, which have a height of approximately 60–70 m and house a complex of instruments intended for Sun observation (refractors, coelostats, spectrographs, magnetographs). These towers also contain a zone built underground.

The construction of the new buildings must also take into account the place were they are set up, modern requirements calling for ever more challenging environments. Thus, the observatories in Antarctica are built on piers to prevent windy snow from piling around them. Similarly, the location of the observatories should take into account the astroclimate conditions (searching for conditions favourable to astronomical observations). Referring to the Northern hemisphere, the domes must be oriented Southward. The building ensemble must be well calculated, so that the domes should not screen one another, and the South direction should always remain free. It is preferable that astronomical observatories be placed in mountain or sub-mountain areas, or in zones with favorable weather conditions, away from other buildings and luminous sources.

The greatest telescope in the world, with a mirror of 42 m diameter, will be built by ESO (European Southern Observatory). The dome scale-model that will house it was presented at the European Conference of Astronomy, in 2008, in Vienna (Fig. 6).

Fig. 6 – The scale model of the 42 m telescope (ESO).

5. ASTRONOMICAL OBSERVATORIES IN ROMANIA

After the prehistoric observatory of Sarmizegetusa, in the 15th century, a scholar, theologian and scientist, the Transylvanian bishop Ioan Vitez (1408–1462) set up the first astronomical observatory on Romanian land, in Oradea. He was the tutor of Prince Iancu of Hunedoara's sons and studied literature, art, music and astronomy. He was also the observer of the Bishop Court. We remind, for comparison, that the famous observatory of Tycho Brahe was built in Denmark only in 1576.

During the 18th century, in Transylvania, other observatories were built, as well: the astronomical tower of Maximilian Hell was finished in 1759 and that of Ignatius Batthyany, in Alba Iulia, in 1785 (Fig. 7). An important library was added to the latter one in 1860.

Fig. 7 – Batthyaneum observatory.

In 1860 the University of Jassy was founded and a small astronomical observatory began to function for the students' training in this field. The first meridian hall was built in Jassy, in 1875. A similar hall was built in Bucharest, at the end of the 19th century.

As a result of the academic astronomical education development, the necessity of new and modern observatories grew up. So, the astronomical observatory in Bucharest was set up in 1908. A Belgian architect, who also made the Astronomical Observatory in Bruxelles, designed the observatory in Bucharest. Both main buildings have the same design. In 2008, the Bucharest Observatory of the Astronomical Institute of the Romanian Academy celebrated its centenary.

Bucharest Observatory (Fig. 8) was placed on 25,000 m^2 in Carol I Park, in the Southern part of the town. In this area already existed two previous patrimony buildings. One of them is Constantin Bosianu's house (Fig. 9), constructed maybe in 1856 by the architect Luigi Lipizer, that became the Observatory library. Another one is the Solar House, erected in 1893, the actual headquarters of the solar group.

Fig. 8 – Main building of the Bucharest Observatory.

Fig. 9 – Bosianu’s House, Astronomical Institute of Romanian Academy.

During the International Geophysical Year (1957) new instruments and buildings appeared at Bucharest Observatory as a consequence of the set up of new scientific directions: solar researches and artificial Earth satellite tracking, and later stellar photometry. Fig. 10 shows the astrophysics domes.

Fig. 10 – Solar (left) and stellar (right) domes, Bucharest Observatory.

As a matter of fact, at Dubăsarii Vechi, in Bassarabia (now Republic of Moldova), was built an observatory also in 1908, led by the astronomer Nicolae Donici, one of the founders of the International Astronomical Union.

Fig. 11 – Actual Cluj-Napoca University Observatory.

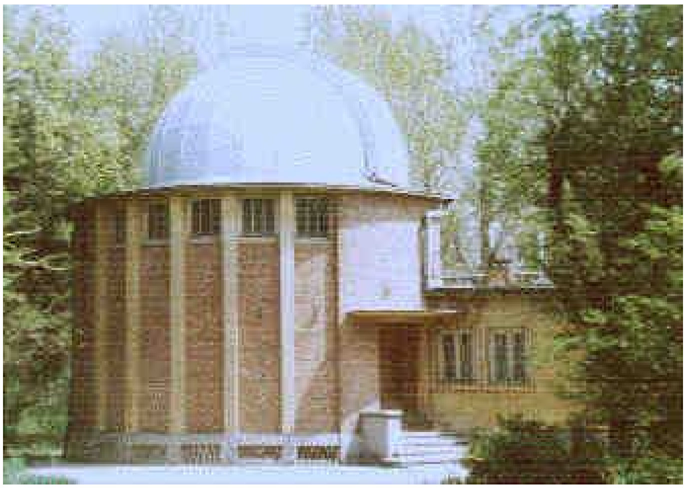

Fig. 12 – Timişoara Observatory.

Fig. 13 – "Admiral Vasile Urseanu" Observatory.

Several other observatories were set up on Romania's territory, such as: in Jassy (1913), Cluj (1920; Fig. 11 for the actual building), Timişoara (1960; Fig. 12). Later, planetariums or small domes were built in many towns, intended to astronomy outreach. We should remind here the "Admiral Vasile Urseanu" Astronomical Observatory (see Fig. 13), built in 1908, in a navy shape, and devoted to outreach and headquarters of amateur astronomers.

6. CONCLUSIONS

In Antiquity the astronomy was directly linked to religion and the buildings were devoted to Sun cult or to measures of the natural rhythms important for the social life. The buildings played the role of instrument themselves many times. We have reviewed some of most important astronomical observatories known in the world as patrimony of culture first of all. An important step in the science development, as well as for an observatory architecture concept, was registered four centuries ago, when Galileo resorted to an instrument with lenses for observations. Newton invented a much more powerful instrument, based on a mirror as objective. Herschel invented a new type of optical instrument and built a house to cover it.

A new stage of architectural concept started during the 18th century. The observatories are constituted in complexes of buildings and should respond to new functionalities, as sciences and instruments develop.

In Romania, the most recent construction of a professional astronomical observatory dates from fifty years ago. In present, the observatories are placed in the middle of towns, which in time have developed and surrounded them, so that the optimal seeing conditions for astronomical observations are no longer met. The observational technique and the scientific problems have evolved enormously for the last fifty years, so that the old instruments and buildings are no longer in keeping with the present requirements.

In view of all this, it is absolutely necessary that a new astronomical observatory be built in Romania, in an adequate zone and in keeping with the present level of technical and scientific development.

As a final remark, we are aware of the fact that the bibliography concerning this topic is huge. No selective bibliography will be representative for this paper, so we decided to renounce to any quotation. We direct the interested readers to the many easily available information sources.

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