"THE "AHA" TRIANGLE" : ARYSTARH FROM SAMOS, HYPARH FROM NYKKEYA, ARYSTARH FROM MOSCOW

SVETOSLAV JORDANOV BILCHEV
CENTRE OF APPLIED MATHEMATICS AND INFORMATICS
PEDAGOGICAL FACULTY, UNIVERSITY OF ROUSSE,
7017 ROUSSE, BULGARIA
slavy@ami.ru.acad.bg , slavy_bilchev@yahoo.com

ABSTRACT

The article studies the life and the extraordinary achievements of three great astronomers: *Arystarh from Samos, Hyparh from Nykkeya and Arystarh from Moskow,* who are mutually connected with some of their achievements and, by destiny's will, with their names. The genius, talent and courage of *Arystarh from Samos, "the Kopernicus of the ancient world"* are paid the due tribute.

INTRODUCTION

Where destiny, common interests and great achievements meet people from different times and societies, there is always admiration for the genius, outgoing his time and looking into the most cherished secrets of nature and World.

In the present study three great astronomers meet (in the author's opinion all of them are Greeks): *Arystarh from Samos, Hyparh from Nykkeya and Arystarh from Moscow*, forming **"The "AHA" Triangle",** whose *"sides"* are the connections between *their origin, names and great achievements* ([1], [2], [3]).

1. ARYSTARH FROM SAMOS (AROUND 310 – 230 B.C.)

There was a man in the antiquity, about whom we know that he asked himself not only *"senseless" questions* but also questions incomprehensible for the scientists of that time. This is ***Arystarh from Samos***, who, according to **Plutarh's words *"moves the centre of the World"*** and decides to determine the sizes of heavenly bodies and the distances between them. *Arystarh was born on **the island of Samos***. At that time the island was not such an important cultural centre, as at **Pythagoras' time (the second half of VI c. B.C**.). In the course of almost **150** years (**479 – 322 B.C.**) ***Samos*** was under the domination of ***Athens*** and only in the year **322 B.C.** received "autonomy" from **Alexander the Great**.

Arystarh's teacher was **Straton** when **Ptolemeus II** founded *the Alexandrian library at the Museyon* (a society of scientists and scholars) to it. *The Alexandrian library* outnumbered **700,000** manuscripts. It was here the development of natural sciences occurred on the basis of mathematical methods and observations.

There are reasons to consider that *Arystarh* was well - acquainted with the achievements of **Babylonian astronomy** as well. Around **282 B.C. the Babylonian priest Beroe** moved to **the Greek island of Kos**. He organized an observatory there and wrote a three volumes' work on *Babylonian history and astronomy*. Right away we should add that although ancient Babylonian astronomers could predict the position of the planets on the heavenly sphere, they were not interested at all in the question of distances and sizes of the heavenly bodies.

As far as ancient Greek philosophers are concerned, all figures about the size of the World in their works were fabricated and groundless. Undoubtedly, a lot of Greek philosophers before Arystarh had admired the Moon and had observed its movements among the stars. But nobody had guessed that the change of the Moon's phases and eclipses provided an opportunity to determine the distances in **the system Sun – Earth – Moon**.

It was what Arystarh succeeded in doing. His only completely preserved work is called *" On the sizes and distances of the Sun and the Moon"* (**265 B.C.**). It could be dated to the early period of Arystarh's works, which is clear mainly from the fact that he still stuck to *the geocentric hypothesis*. Besides, in the basis of his calculations, Arystarh accepted a too high value of **2°** for the visible angle diameter of the Moon, while we know from *Archimedes' works* (**287 – 212 B.C.**), that Arystarh used a more precise value – half a degree at the time of creation of ***his heliocentric theory***.

In the first place in his work Arystarh formulated some general principles, one of which said that "when we see the Moon cut in half, its distance to the Sun is less than a quarter of a circumference without one thirtieth of that circumference”. This means, that when we see the lighted half of the Moon disc, the angle distance between the Moon and the Sun is equal to **90° - 90°: 30 = 87°.** Hence Arystarh deduced that the Sun outlay at **19** times bigger distance from the Earth than the Moon (in fact it is **400** times bigger). We see that Arystarh made a too big mistake, the reason of which was not the incorrectness of the method but the incorrectness of the measuring. It is not possible with such imperfect tools, as those used in the antiquity, to catch the moment when the lighted part of the Moon is equal to the dark one. This is difficult to do even now, because *the terminator* (the line, separating the lighted side from the dark one) is not a straight line but a complicatedly broken line.

This was the first work in the history of astronomy, in which the distances between the heavenly bodies were determined on the basis of observations. Despite the inaccurate determination of these distances *Arystarh* reached another very important conclusion:*”The Sun has a ratio to the Earth bigger than **6859** to **27**, but less than **79507** to **216** ”*. Here he compared the volumes of the Sun and the Earth: *Sun’s volume exceeded the Earth’s volume **343** times. Probably these calculations made Arystarh conclude that the Sun as a big heavenly body was in the centre of the World and the Earth together with the other planets went round it.*

Archimedes said the following for this ***first heliocentric system of the World*** in his work **“Calculating Grains of Sand**“: ”… according to the notions of some astronomers the World has the form of a globe, whose centre coincides with the centre of the Earth and its radius is equal to the straight line connecting the centres of the Earth and the Sun. But in his **“Hypotheses”** *Arystarh from Samos*, refusing the above hypothesis, reaches the conclusion that the World has a considerably bigger size than the cited above. *He assumes that the immovable stars and the Sun don’t change their position in the space, that the Earth goes on a circumference round the Sun, which is in its centre, and that the centre of the immovable stars’ sphere is such that, according to him, the circumference made by the Earth has such a ratio to the distance of immovable stars as the centre of the globe has to the surface of the same globe ...”*

Regrettably the above mentioned **“Hypotheses”** *by Arystarh* haven’t been preserved till the present days. That is why we practically don’t know more about the evidence with the help of which *Arystarh proved the correctness of his heliocentric model of the World. Arystarh’s theory* did not win public recognition because there were uncoordinated between themselves assertions, but above all because of the fact that *it was exceptionally bold for its time*. By the time when **the heliocentric system** is established and rediscovered by **Kopernicus** many centuries will have passed.

Despite that fact Arystarh from Samos remains "the Kopernicus of the ancient world", as he is called by numerous philosophers, astronomers, researchers.

2. HYPARH FROM NYKKEYA (II c. B.C.)

"The greatest astronomer of that time and probably of all times" – so calls **Hyparh** the academician **N. Bonev**, an eminent Bulgarian astronomer.

We know very little about *Hyparh's life*. It is accepted that he was born in ***Nykkeya*** (nowadays the town of ***Iznick*** in Turkey). He visited the great centre of ancient culture – ***Alexandria***, but there is not direct information about him being a member of the Alexandrian school. ***Hyparh worked on the island of Rodos*** and built an astronomical observatory, in which he made numerous observations. **Ptolemeus** mentioned *Hyparh's observations*, made in **146 – 126 B.C.,** as well as a single observation in **161 B.C**. .Therefore, *the most productive period of Hyparh's work was the middle of **the II c. B.C***. .

Unfortunately, only one of his books, which is of second rate importance, has been preserved nowadays. The whole information, which we receive about *Hyparh's works*, is from **"Almagest"** *by* **Ptolemeu***s*, who lived and worked three centuries later on.

At that time ***the theory of crystal spheres*** *of* **Evdox** *and* **Aristotle** underwent reassessment. For example, *the Alexandrian mathematician* **Apolonius from Perg (III c. B.C.)** rejected their existence and considered that heavenly bodies moved uniformly on concentric circumferences, whose radiuses increased, beginning with the Moon and finishing with the stars. In the centre of these orbits was the Earth.

Hyparh developed **Apolonius' hypothesis** first about the Moon and later on about the stars and correspondingly modified and completed it. First and foremost he analyzed the visible movement of the Sun and the Moon on the heavenly sphere. Defining more accurately the data of his predecessors, Hyparh determined that the period of time between ***the vernal and autumnal equinoxes*** had **187** days, while the period between ***the autumnal and the vernal equinoxes*** had **178** days. This represented a direct proof that the Sun moved ununiformly on the heavenly sphere. In order to explain this ununiformity, which according to Hyparh was only visible, he considerd that the Sun moved ununiformly on a circular orbit, but the centre of this circumference did not coincide with the centre of the Earth. This orbit, introduced for the first time by **Apolonius from Perg** was called *an eccentric orbit*. According to Hyparh's calculations the movement aside of the Sun's orbit centre in relation to the Earth's centre (called eccentricity of the orbit) was **1/24** or **0,042** from the value of the orbit's radius. Nowadays we know that the visible movement of the Sun is due to the Earth's movement round it on an ellipse with eccentricity of **0,017**. *But Hyparh was not satisfied to give just the scheme of the Sun's movement. He also made a table, with the help of which the position of the Sun on the heavenly sphere could be determined for the every day of the year.*

The Moon's movement is considerably more complicated and Hyparh made up a more complicated scheme about its explanation. He defined *the duration of the synodical and syderical months* and determined that the Moon's way on the heavenly sphere was sloped to the ecliptic at an angle of **5°.** This gave him the possibility to develop *the theory of the Sun's and the Moon's eclipses*, which in its turn gave the possibility to calculate the moments of eclipses in advance.

In **143 B.C.** Hyparh observed an outburst of a new star in *the constellation of Scorpio*. This made him think that in the world of stars **"certain changes occur, some of which run extremely slowly to be noticed even by some generations".** In order to determine them later on, Hyparh made up a catalogue – a list of about **850** stars, for each of them he measured the ecliptic longitude and latitude. Except the purely astronomical data, Hyparh provided one more characteristic of these stars in the catalogue. This was the so-called **"star magnitude"** – a concept introduced by him, which represented numeric measure of *the stars' brilliance*. The *"star magnitude"* was introduced by Hyparh in a simple way: he "classified" the stars in **6** groups according to their brilliance. The brightest ones he called stars of the sixth magnitude, those belonging to the second group – stars of the fifth magnitude, etc. and those less visible with a naked eye were "classified" as stars of the first magnitude.

The term *"star magnitude",* which is also used nowadays in astronomy, *was probably introduced by Hyparh*, as he, like everybody at that time, considered that the stars are at equal distance from the Earth. In addition, if we consider that all stars have equal surface brightness, it follows that the bigger their sizes are, the stronger their brilliance will be. Although the term is used nowadays too, today a much more different content is included in the concept of *"star magnitude"* which doesn't concern the geometrical sizes but the radiation physics of the stars. Besides, the scale of *"star magnitude"* is widened for the weaker and the weakest visible with naked eye stars as well and it is specified as follows: a star of **m** *star magnitude* is **2,512** times brighter than another star of **m+1** *star magnitude*. *The making up of the catalogue brought Hyparh to a remarkable discovery, probably the most striking of all discoveries*. Comparing his observations of some stars with the observations of **Arystil** and **Tymoharis** (**the first half of III c. B.C.),** that had been made a century before, Hyparh noticed that the distances of these stars to *the vernal equinox point* (their ecliptic longitudes) had been changed. Thus for the bright star called *Spika* (from the *constellation of Virgo*) the distance to *the vernal equinox point* had been increased by **2°** for **150** years, i.e. by **48"** a year. The same difference of two degrees was noted for other stars as well. It was obvious that the longitudes of all stars had been increasing, without changes of their latitudes. The equinox point is one of the crossing points of the equator's and ecliptic's planes. Therefore one of these planes changes its position. *Hyparh determined from observations that the slope of the ecliptic to the equator did not change. From here he arrived at the conclusion that the equator was moving slowly in a direction opposite to the movement of the Sun, preserving a constant slope to the ecliptic.*

The low limit of the year's movement value of the vernal equinox point was determined by Hyparh as equal to **36°.** Today we know that this value is **50",2**. Despite the considerable difference in the value determined by Hyparh, this was a remarkable achievement, bearing in mind the fact what the observation possibilities were at that time. What can we say about the discovery itself of the moving of *the vernal equinox point* – ***the precession***? The described shifting of the equator leads to an interesting consequence: the Sun, moving from the vernal equinox point in its year's journey on the ecliptic, returns to the new position of the equinox point a little earlier than the moment when it will resume its former position to the stars, i.e. *the next equinox will come a little earlier. That is why the described phenomenon is called precession*. But because of that, as Hyparh noticed, it is necessary to distinguish a *tropical year* – the period, after whose elapsing the Sun returns to its former position to the equinox point.

Hyparh also determined the duration of the tropical and star year with considerable precision. He determined *the duration of the tropical year* comparing the moments of the Sun's stays and equinoxes, which other astronomers before him had determined, with these moments, obtained by his own observations. *For example, comparing the date of the Sun summer's stay in **280 B.C.,** determined by **Arystarh from Samos**, with the Sun's stay in **135 B.C.**, Hyparh found that the generally accepted duration of the year, equal to **365,25** days should be decreased by **1/300** of the day or almost **5** minutes. Thus the duration of the tropical year was determined as equal to **365** days **5** hours and **55** minutes, which differs from the value known today with only **6** minutes.* Using the data about the *precession*, Hyparh determined that *the star's year duration* is **10** minutes longer than **365,25** – which also is a result wholly coinciding with the data of modern science.

Hyparh's studies of the duration of different months and the prediction of the Moon's and the Son's eclipses are not less precise; they are of great importance for science. He determined that the *synodic months* (the period of time between two equal successive phases of the Moon) has **29** days, **12** hours, **44** minutes and **2,5** seconds. The plane of the Moon's orbit is sloped to the plane of the ecliptic at an angle of **5°** - a fact, which was also determined by Hyparh for the first time. Therefore the Moon's orbit crosses the ecliptic in two points, called knots. Hyparh discovered that the knots were constantly moving from east to west, returning in their starting points for **18,6** years. He determined the duration of the so-called *draconic month* with great precision. This is the period of time, after which the Moon returns to the same point in relation to one of the knots in its orbit. Hyparh also determined that the *apsis line* in the Moon's orbit (the line connecting the apogee and the perigee of the orbit) was also movable – the apogee and the perigee were moving so that they did a full revolution for **8,85** years. As this movement is in the same direction as that of the Moon, the so-called *anomalous month* is longer than *the syderic one*, after whose elapsing the Moon takes the same position in relation to the stars. On the basis of his discoveries, Hyparh could explain the Sun's and the Moon's eclipses and also made a table for their calculation in advance.

Hyparh developed and specified **Arystarh's method** *for calculating the distance to the Moon and the Sun*. For the distance Earth - Moon he got **7** million kilometers. This value is **20** times less than the real one because of the comparatively inaccurate observations, but it was in use for ten centuries.

Hyparh developed the bases of the mathematical cartography.

Hyparh's **great contribution to astronomy** has found the best appraisal in the words of **the French historian of astronomy D'Alamber**: *"When examining everything discovered and improved by **Hyparh,** when thinking over his numerous works and the quantity of the calculations* *comprising them, you by necessity will number him to the most amazing men from the antiquity and will call him the greatest of them not only in the sphere of purely speculative sciences, but also in the sphere of those demanding a combination of geometric knowledge with knowledge of phenomena, susceptible to observations in conditions of attention and perfect tools."*

3. ARYSTARH APOLONOVICH BELOPOLSKY (ARYSTARH FROM MOSCOW) (1854 – 1934)

Arystarh Apolonovich Belopolsky is one of the first Russian astrophysicists. His works on the Sun's rotation round its axis, on the planets Mars, Jupiter and Saturn, his successful application of photography in observations and especially the wide application of the spectroscope in the study of the movement, physics and multiplication of the stars, won him world fame during his life-time. He was and remains one of the remarkable astronomers from the end of the 19^{th} and the beginning of the 20^{th} century.

Arystarh Apolonovich Belopolsky was born on **13. 07. 1854** in the family of Russian intellectuals. Frequent visitors to the family were people from Moscow cultural society. The family was in close relations with a famous botanist, who often talked to the boys, showing interest in nature where they spent a considerable part of their time. **Arystarh** and his brother **Olympus** grew up in a free and easy atmosphere.

In **1873 Arystarh Apolonovich** finished high school and entered the **faculty of mathematics and physics** at **Moscow University**. During his studies there the director of **Moscow observatory** was **F**. **Beredihin**, who laid the foundations of the Russian astrophysics, an idol and favourite of the students and an eloquent lecturer. During one lecture he addressed the students with an appeal to help the observatory to repair some damaged appliances**. Arystarh Apolonovich** responded to that request and not before long the student became a necessity for the observatory, joining the astronomical observations.

In **1877** *Arystarh Apolonovich* graduated from the university and on **F. Beredihin's** proposal was left *"to prepare for the title of a professor"* – the Russian form of the present **Ph.D. degree**. At that time the assistant at the observatory got ill and Arystarh Apolonovich accepted his responsibilities with pleasure.

Arystarh Apolonovich worked **11** years at **Moscow observatory** under the direct guidance of **F. Beredihin**, from whom he acquired interest in astrophysical research. He used a meridian circle, observed comets, planets, stars and the Sun. During these years photography entered the astronomy as a new and perspective method. Arystarh Apolonovich himself made photographic emulsion and became a very good photographer. He took pictures of *the Moon's eclipse* from **04. 11.1884** and of the *total Sun's eclipse* of **19. 11.1887**. He paid special attention to the photographing of the Sun.

In **1887** Arystarh Apolonovich defended his master's thesis on **"The Sun's spots and their movement".** It summarized observations of many years on the Sun's spotting activity. Quite remarkable was the demonstration, which he made at the defence of his thesis. In order his results about the Sun's rotation to be convincing and visualized, he used a glass balloon, filled with water, which could be either set in quick rotary motion or stopped. At that motion the stearin pieces put in the liquid continued rotating with their speed gradually decreasing from the equator's part to the poles. This could be read quantitatively by means of a coordinate net of lines, graduated on the flask. This visually demonstrated the rotation of the Sun round its axis, which, as it was well-known, did not rotate as a solid. Its rotation was the fastest in the area of the equator, decreasing toward the poles. Later on he returned, even though for a short time, to his favourite subject matter – the rotation of the Sun's surface. During the period from **1881** to **1883** he classified and worked on **511** photographs of the Sun, taken at the **observatory in Pulkovo**. He put forward a new method for determination of the period of rotation round the axis, applying the observations of the Sun's torches, which were best observed at the edge of the Sun's disk.

Arystarh Apolonovich studied the rotation of the **planet Jupiter** as well. Even with a training telescope it could be seen that there are two dark stripes, symmetrically located at either sides of Jupiter's equator. From observations it was known that the limited by the stripes part of the equator rotated faster than the rest of the planet. Working on observations made in a period of around **200** years and on his own as well, Arystarh Apolonovich showed that the planet really had two main periods of rotation round its axis: the equator turned for **9** hours **50** minutes, and the rest of the surface – for **9** hours **55** minutes. Modern precise observations confirm that the planet Jupiter does not rotate as a solid. Today it is clear that this planet does not have solid surface like that of the Earth.

In **1888** Arystarh Apolonovich started working full time at **the observatory in Pulkovo**. At that time the observations there were focused on determination of stars' precise positions. In the beginning he began working with the passage instrument and the results of these observations were published in **1899**.

At the end of the **19th century** there was a discussion concerning the question to what **extent Dopler's principle**, well-known with sound phenomena, is applicable to light phenomena. There was a search for an experiment by means of which the movement speed of a light source and the value of spectrum lines' movement aside could be measured. *Arystarh Apolonovich* suggested and did such an experiment in **1900**.

The experiment was realized really *"simply and exquisitely"* – the experimental equipment was compact and not complicated. Two flat mirrors were put on the periphery of two disks, and the discs themselves were fixed on two parallel axes. The discs were set in quick rotation facing one another and the light of an immovable source fell on a spectrograph after reflection on the mirrors. This experimental equipment provided the possibility to imitate the relative movement of a light source with speed up to **700 m/s**, and the measuring done by **Arystarh Apolonovich** *confirmed the applicability of Dopler's'principle with light as well*. That is why this effect with light is called sometimes **"the effect of Dopler and Belopolsky**".

In this way it was proved experimentally that the studying of stars' spectrum provided the possibility to examine the movement of the stars in relation to the observer – in respect of duration and speed. With this the biblical notion of "the immovable stars' sphere" was once and for all refuted: the comparison of ancient and modern observations showed changes in stars' mutual position; the researchers of multiple stars witnessed their movement in relation to each other; the observation of stars' spectrum not only set all the stars in motion but also allowed to measure their speed! Arystarh Apolonovich himself measured the radius speed of about **200** comparatively bright stars.

The outburst of a **new star** from **the constellation of Carter** was observed in **1892.** New stars change their brilliance by **8** to **15** star magnitudes, i.e. they increase their brilliance extremely quickly by **1600** to million times. After the outburst the star recovers its former brilliance for some moths gradually. During that period of time quick changes in the spectrum of the star are observed which witness for gradual changes in it. The new star from the constellation of Carter drew the attention of Arystarh Apolonovich and during the following decades he spent a lot of time researching the spectrum of various stars. He himself designed and made the spectrograph. Objects of his studies were the star β from **the constellation of Lyra** and the star δ from **the constellation of Cepheus**. The latter gives its name to a whole class of changeable stars, which change their brilliance at definite periods.

In **1896 Arystarh Apolonovich** successfully defended his **doctor's dissertation** at **Moscow University.** *The topic of his research were Cepheids,* about which he discovered that their radial speed changed together with the change of their brilliance. Arystarh Apolonovich suggested that the reason for these synchronous changes was the dual nature of *Cepheids,* i. e. that they were binary stars, which was quite natural for the stage of development of astronomy at that time.

The defence of his doctor's dissertation was connected with one *remarkable "incident"*. During the discussion **Professor N. Umov** *expressed the suggestion about the possible periodical contraction and expansion of Cepheids, which could explain their simultaneous change of brilliance and ray speed.* Today this great surmise is a generally acknowledged fact. A reverse process is observed with the *decreasing of Cepheids' brilliance* – the stars are expanding and because of that the ray speed shows movement in the observer's direction.

Very important are also the works of Arystarh Apolonovich on the **planet Saturn.** The theoretical researches showed that the ring of this planet could not be a monolithic one but probably it consisted of separate particles, which could not be observed directly. Arystarh Apolonovich found a way out of the situation applying the power of the spectrum method and using **Dopler's principle**. The spectrum lines showed that the linear speed of the rotation of the ring decreased with the planet's movement away, which was possible only if it consisted of separate particles, going round Saturn by virtue of **Kepler's law**.

The fact that **Arystarh Apolonovich** published **273 works** is indicative of the amount of his research work. This colossal in scope work, all these studies of great importance were done without research associates and processing equipment and their author won public recognition deservedly. From **1908** to **1916** Arystarh Apolonovich was a deputy director of **the observatory in Pulkovo** and its director from **1916** to **1918.** In **1900** he was voted into a member of **St. Petersberg's academy**, and six years later he was an academician. He was awarded with a number of prizes. He was voted into a member of **the Russian astronomical society,** of **the Italian spectrographers' society**, of **the English Royal society**. In **1908** he was presented with a medal by **the Paris Academy of Sciences** and in **1918** he was awarded **the Laland's prize**.

Living to a venerable age, **Arystarh Apolonovich Belopolsky** continued his work. In **1933** he was voted into *an honorary director of the observatory in Pulkovo*. During his last years his eye sight failed but this did not tear him either of his observations or of their processing.

Arystarh Apolonovich Belopolsky (Aristarh from Moskow) died on **16. 05. 1934** at the age of **80 years**. *He was buried in the grave - yard of the observatory in Pulkovo, in whose activities he participated most actively for almost half a century.*

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