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SOME CONCLUSIONS FROM THE STUDIES OF STELLAR ABERRATION

The summary of the papers [1-10] on stellar aberration published in nineties by the author together with some of her colleagues, is presented. The review [5,7] of the exposition of stellar aberration in physical and astronomical manuals since 1742 (see [15]) up to our days, permitted to conclude that there were some principal difficulties in the problem before the XX century. Due to relativistic interpretation of the phenomenon, which contradicts the experience of astronomers, the problem was confused more than before. In relativistic literature there are neither adequate phenomenological description of stellar aberration, nor rigor in its mathematical interpretation. In [1-10] the development of the classical theory is presented and precise formulae of reduction for stellar aberration are derived. In general, the question of stellar aberration is not so simple, as the physicists suppose, defending or criticizing relativity; the deep insight into the problem requires understanding of the methods of construction of observational star catalogues (reference systems) by astronomers (astrometrists).

In order to overcome the SRT it is necessary to find its epistemological roots, i.e. to analyze the fundamental problems which presented some difficulties or were not completely solved in the frame of the classical physics and astronomy up to the start of the XX century. One of such problems is the aberration of light.

We have analyzed the question and the literature on stellar aberration in the papers [1-10]. In [4] two phenomena were considered: the aberrational shifts of stars' projections onto the celestial sphere and the angular displacements of the nearby bodies due to the motion of an observer. The former shifts are independent of stellar distances. The latter depend on the distances between the body and the observer: the nearer is the body the greater would be its observed angular shift in the direction *opposite* to the apex of observer's velocity. On the other hand, due to aberration the stars incline *towards* the apex of observer's velocity.

Being independent of the distance to the star, stellar aberrational shift *depends on the velocity of the observer,* whereas the aberrational shift of a planet or a nearby body in general case *depends on the* ***relative*** *velocity of the body and the observer* [1,4].

In spite of the mentioned phenomenological distinctions, the authors of the physical manuals (see [7]) make no difference between the two kinds of angular shifts. Evidently it was not understood that the two phenomena belong to the domain of different geometries: projective geometry is used in the case of stellar aberration and metrical geometry in the case of planetary aberration [5,8]. The motion of stars' **projections** onto the sphere of indefinite radius (often the radius is called "practically infinite") is considered in the first case, and the spatial motion of **bodies** in the second case.

This short presentation is devoted only to **stellar** aberration.

In the XX century stellar aberration is mentioned as one of the practical verifications of the SRT, although the exposition of stellar aberration given by Einstein [11.12], totally contradicts to the experience of astronomers since the XVIII century when the phenomenon was discovered, up to our days [2,6]. The Einstein's interpretation is a result of misunderstanding.

It was evident already to some of his contemporaries, and recently it was explicitly shown by H.Hayden in "Galilean Electrodynamics" [13].

Einstein tried to explain stellar aberration and Doppler effect simultaneously, he thought "the aberration of the light from infinitely distant objects" (stars) depends on the relative velocity of the observer and the star. He connected the coordinate systems S and S' [12] with the star and the observer on earth, and supposed the *relative motion* of the two *inertial* systems is responsible for stellar aberration.

The failure of his approach to the problem was never acknowledged openly, but since forties (e.g. D.Bergmann,1947) the relativistic minded physicists connect the system S not to the star, as Einstein has done, but to the Sun. It means, that now they assume the phenomenon of stellar aberration dependent on the relative velocity of the observer (the Earth) and the Sun; after that Doppler effect of the star light and stellar aberration are not explained simultaneously. Besides the relativistic theory of aberration is not the revolutionary one any more, since this "new" explanation of the phenomenon coincides with the classical explanation of the *annual* stellar aberration.

Indeed the difference remains only in words: the relative motion of the Earth around the barycenter of the Solar system (roughly speaking around the Sun) is, in Newtonian sense, the absolute motion of the Earth – its orbiting [4]. In situation like this, one might ask whether the SRT is needed, if the relativistic explanation is now the same, as that of Bradley (1728) for the annual stellar aberration. In the frame of the classical (or Bradley's) theory all kinds of stellar aberration have been unambiguously explained without the resort to *ad hoc* hypotheses, such as the contraction of space-time.

The answer of the relativistic physicists was that the classical formulae have only first order terms in *v/c,* and relativistic formulae, having second order terms, are more precise and valid for velocities, comparable with that of the light. This answer was misleading. We shall prove that second order terms can be derived when necessary, from the precise (mathematically rigor) classical formulae.

We have shown in [7] that in physical manuals *only approximate* formulae for the aberrational shift

$$\theta = \varphi - \varphi' \tag{1}$$

are considered. Those are:

$$\varphi = \varphi' + \frac{v}{c} \sin\varphi', \quad \text{or} \quad \theta = \frac{v}{c} tg\varphi, \quad \theta = \frac{v}{c} tg\varphi' \quad \text{et cetera.} \tag{2}$$

Here φ' is the apparent (observed) angular distance between the star's projection and the apex of the observer's velocity, and φ is the aberrationless angle between the star and the apex, traditionally called by astronomers "the true angle". (Explanation of the terminology is given in [5], p.78-81). Astronomers use as the initial expressions, the formulae

$$\sin\theta = \frac{v}{c} \sin\varphi \tag{3}$$

and

$$sin\,\theta = \frac{v}{c} sin\,\varphi' . \tag{4}$$

One can see the so called "symmetry" in the formulae (2) – (4), which means that in the corrections for aberration φ might be replaced by φ' and vice versa. Evidently **(3) and (4) cannot be precise (mathematically rigor) simultaneously**. Let us suppose (3) rigor (our choice will be explained later). Then from (1) and (3) follows:

$$sin\,\theta = sin(\varphi - \varphi') = \frac{v}{c} \frac{sin\,\varphi'}{\sqrt{1 - 2\frac{v}{c} cos\,\varphi' + \frac{v^2}{c^2}}} . \tag{5}$$

Whence

$$sin\,\varphi = \frac{sin\,\varphi'}{\sqrt{1 - 2\frac{v}{c} cos\,\varphi' + \frac{v^2}{c^2}}} \tag{6}$$

and

$$sin\,\varphi' = sin\,\varphi(\sqrt{1 - \frac{v^2}{c^2} sin^2\,\varphi} - \frac{v}{c} cos\,\varphi). \tag{7}$$

Expressions (6) and (7) testify that there is no symmetry in the formulae which are mathematically correct. As one could guess already from (1),(3) and (4), the symmetry, so highly appreciated in relativistic physics, is due to the fact, that in practical cases it makes no difference whether one uses the formula (3) or (4), since φ- θ ≅ φ. Expanding in powers of *v/c* up to second order terms, one obtains:

$$\varphi = \varphi' + \frac{v}{c} sin\,\varphi' + \frac{v^2}{2c^2} sin\,2\varphi' , \tag{6'}$$

$$\varphi' = \varphi - \frac{v}{c} sin\,\varphi. \tag{7'}$$

The angle φ – φ' is small as long, as $v << c$. When v is comparable with c the precise formulae are preferable to series, especially nowadays when computers are available.

From the relativistic point of view formulae (6) – (7) and (6') – (7') are not "beautiful" because they lack "symmetry". We think mathematics is appreciated due to its rigor *[1] and hence objectivity, whereas the apprehension of beauty is never free from subjectivism. Here lies the yawning gap between the relativistic and the classical approach: Einstein counterposed "practical geometry" to the axiomatic one. He wrote about attaching the special significance to the comprehension of geometry as a practical science (see our comments in [14], p.52-53). Thus he reduced geometry (mathematics) to algorithms used in its different applications. There are no errorless measurements, this is one of the reasons why "practical geometry" could not be an exact science; from Einsteinian ideology originates the negligence in mathematics, which is so typical to relativistic literature.

The only criterion for truth not yet denied in modern philosophy of science, is practical verification of the formulae*[2]. In the SRT only the case of rectilinear and uniform motion is considered, whereas astronomers have studied the general case of spherical motion.

Before the analyses of the formulae for the general case, we must emphasize that the theory of stellar aberration could have been obtained only from the observations of the variable motions. **In the case of the inertial motion one can only apply** the formulae, already known from the studies of the mentioned experience, **not verify the formulae** by means of observations. If the SRT is supposed to be valid *only for inertial motions*, and the periodic motions should be explained in the frame of the other theory – the GRT, then no possibility remains for practical verification of the SRT formulae for aberration [3].

On the other hand it is convenient to start the mechanical explanation of the phenomena with the simplest (i.e. inertial) motion, since in the frame of the classical kinematics any complex motion might be regarded as an integral sum of the simplest motions with variable parameters.

Modern physicists insist, there should be "the symmetry of transition from φ to φ' and vice versa", as it is in the SRT, where second order terms reveal the required "symmetry". The relativistic idea about the symmetry of transition from one coordinate system to another, complies with the form of the approximate (linear) algorithms used by the astronomers in previous centuries. Some physicists have mistaken these algorithms for the final expressions, possible in the frame of the classical mechanics.

In fact, expressions (2) are rough approximations, and (4) is valid as long as θ is small. Indeed, in the case of the annual aberration θ does not exceed 20.5″ and it was not important for practical cases which of the formulae, (3) and (4), is precise, and which is approximate. The formulae for aberrational displacements in spherical coordinates, used by astronomers, show the same "symmetry":

$$\lambda = \lambda' + \frac{v}{c} cos(\lambda_{\otimes} - \lambda') sec \beta', \quad \beta = \beta' + \frac{v}{c} sin(\lambda_{\otimes} - \lambda') sin \beta' \tag{8}$$

and

$$\lambda' = \lambda - \frac{v}{c} cos(\lambda_{\otimes} - \lambda) sec \beta, \quad \beta' = \beta - \frac{v}{c} sin(\lambda_{\otimes} - \lambda) sin \beta \tag{9}$$

It is well known, that (8) and (9) are approximate formulae, their accuracy was sufficient for all practical cases since the discovery of stellar aberration.

Now, when the accuracy of measurements became about 100 times higher than in the XIX century, the formulae (8) and (9) should be revised. The precise formulae are needed to account for the annual and "spacecraft" aberrations [6,9,10]. The amplitude of the shifts due to the diurnal aberration does not exceed 0.32″, and the former formulae are accurate enough. Usually there is no need to take the secular stellar aberration into account [3].

In the case of the annual stellar aberration *v* is the orbital velocity of the Earth, the apex of observer's velocity (A) lies in the ecliptic plane, hence its latitude $\beta_A = 0$. Its longitude λ_A is changing in 360º per year and dependent on the longitude of the Sun λ©.

Here $\lambda_A = \lambda_\oplus - 90 - \eta$, where the value of η is known in celestial mechanics, it depends on the on the unevenness in Solar motion on celestial sphere (or on variations of the orbital velocity of the Earth, since berycentric motion of the Earth is not considered here).

The corrections for stellar aberration in spherical coordinates λ and β have been derived in the manuals on Spherical Astronomy. The principal mathematical aid that is .required in spherical astronomy and astrometry, is **spherical trigonometry**. It means that instead of a plane surface upon which aberrational shifts are analyzed in the case of the inertial motion, the curved surface *[3] is used; the radius of its curvature is constant and indefinite (it is projective geometry). The curved surface, called the celestial sphere, is shown in fig. 1.

According to the Bradley's law, *the aberrational displacement of a star is measured by the arc of the great circle which intersects the celestial sphere in two points: S' – the apparent place of a star and S – its true (aberrationless) place. S' is always nearer to the apex of observer's velocity than S', i.e. AS'< AS. The value of the displacement is proportional to v/c, where v is the absolute velocity of the observer, in the case of annual aberration v is orbital velocity of the Earth*

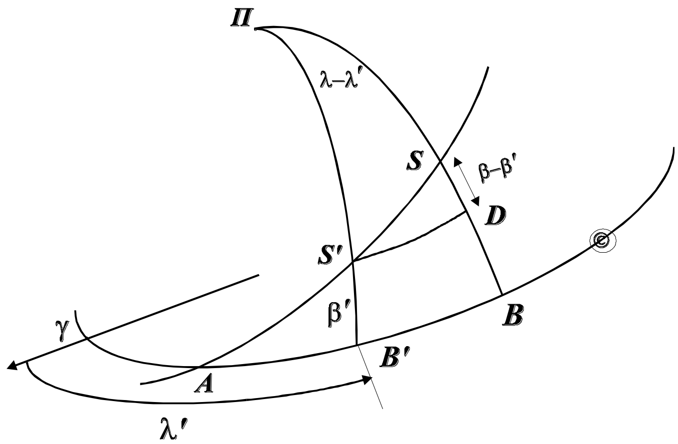

Figure 1.

In fig.1, © is the position of the Sun. Longitude of the Sun, λ©, is reckoned along the Ecliptic from the Vernal Equinox γ ; *SS'* is aberrational shift. *SS'= SA – S'A,* and equation (3) becomes

$$sin\,SS' = \frac{v}{c}\,sin\,SA \tag{3'}$$

Similarly in the formulae (5)- (7), adapted for the spherical case, φ should be replaced by *SA* and φ' by *S'A*. Next from the relations between the elements of the three spherical triangles *AS'B'*, *ASB* and *SΠS'*, the two components, Δλ and Δβ, of the displacement *SS'* should be derived as a functions of coordinates λ,β and also as those of λ',β'. The former are required for transition from mean to apparent stellar places, the latter – vice versa: from apparent to mean coordinates.

Previously the displacement *SS'* was assumed infinitesimal due to $v \ll c$. Under this supposition the formulae (8) - (9) were obtained.

To satisfy modern requirements for the accuracy of reduction of observations, it is not allowed to consider the arc *SS'* as infinitesimal any more. We have derived the formulae for stellar aberration in ecliptic coordinates developing the classical theory of stellar aberration and using equations (6) and (7). In [10] the precise formulae for sin(λ- λ'), sin(β-β') and other trigonometric functions are obtained, necessary in the case of the precise observations and in the case, when $v \sim c$. In every *mathematical* theory rigor formulae are required. From them one might get any approximation valid for the practical purpose.

As is evident from expressions (6) and (7), there could be no "symmetry" in transition from λ,β to λ',β' and vice versa in rigor equations; in order words, the form of the precise formulae for corrections Δ = f(λ,β) and Δ = f(λ',β') is not the same. There is no "symmetry" in second order terms either.

Below the approximate formulae with second order terms for transition from apparent coordinates to the true ones, derived in [9,10], are given.

$$\left.\begin{aligned} \lambda - \lambda' &= \frac{v}{c}\cos(\lambda_\otimes - \lambda')\sec\beta' + \frac{v^2}{2c^2}\sin 2(\lambda_\otimes - \lambda')\sec^2\beta' \\ \beta - \beta' &= \frac{v}{c}\sin(\lambda_\otimes - \lambda')\sin\beta' + \frac{v^2}{2c^2}[\sin^2(\lambda_\otimes - \lambda')\sin 2\beta' - tg\beta'\cos^2(\lambda_\otimes - \lambda')]. \end{aligned}\right\} \tag{10}$$

When using this formulae, the variability of the values η and the orbital velocity of the Earth, *v,* should be taken into account; these effects are known from astronomical ephemerides.

We must mention two changes we had to introduce when deriving the precise formulae and the series with second order terms in [9,10]. One of the changes is easily understood by astronomers:

(i) Previously, when *SS'* was considered infinitesimal, the formulae (8)-(9) were derived under the condition that the angle *SΠS'* shown on fig 1, is small. Therefore the formulae of spherical trigonometry valid *only* for the narrow spherical triangle, were used. In our case (and when *v ~ c)* it is not allowed to consider the triangle *SΠS'* as the narrow one. So, when deriving the precise formulae, we have used the formulae valid for the general case.

(ii) The second innovation required some efforts to be accepted by astronomers. We had to correct the error which was common to all manuals, where stellar aberration was considered in the frame of the classical theory. Namely, we showed that formulae (3), and hence (3'), is precise (rigor) and (4) is approximate.

In spite of some differences and contradictions in interpretation of stellar aberration (see [5,7]), during about 250 years (at least since "Astronomie" by La Lande [15]) the formulae (4) was assumed as the precise one *4 due to supposition, that the grains of light move in the luminoferous ether and the rays of light and the static observer are fixed (immovable) relatively the ether (to the same coordinate system).

In order to prove our suggestion (our choice of the precise equation), we have shown the error in geometric method of deriving the formula for aberration, used in many manuals, and explained its origin.. Besides we shoved in [9] that if one assumes (4) as rigor, one inevitably comes to the conclusion that the mean places of stars describe elliptic curves around the apparent places. What we observe is the opposite, and the only way to eliminate the paradox is to consider the formula (3) as the rigor one.

The last argument was helpful, and we succeeded in publishing two papers [9,10] in the Pulkovo observatory Bulletin.

In connection with stellar aberration the principal fallacy of **pre-relativistic physics** should be mentioned.

In the last decades of the XIX century, stellar aberration was discussed by astronomers and physicists with the idea to solve the problem once and forever, as if it were possible to find in Nature something stationary (immovable) and to connect the origin of ever fixed, "absolute", coordinate system to it. Some of the scientists imagined the absolute coordinate system, or the absolute space of the dynamic theory, might be connected to the ether. The idea is wrong since it is *impossible to measure* the coordinates, distances of bodies and velocities of their motion relatively to the ether.*5

Nevertheless the physicists assumed in the theory of stellar aberration, that the imaginary static observer is *at rest relatively to the ether*, and they compared the picture seen by this observer, with the picture (coordinates) seen by the observer *moving relatively to the ether*. Whereas to take account for stellar aberration (annual or diurnal) one should compare the coordinates seen by an observer orbiting (or rotating) round the center of masses, with those seen by the observer **at rest with respect to this center**. It is convenient to connect the origin of a coordinate system to the center.

It is the center of masses of the bodies of an isolated system, which is considered a rest point in Newtonian physics. Although it is not possible to place the observer into the center, it is possible to obtain (to calculate) the coordinates of a stars seen by the imaginary central observer, from **several observations made by the orbiting (or rotating) astronomer**. It would be possible even if the theory of aberration were absent. Central observer would have seen the "true" places, or coordinates λ,β instead of λ',β', seen by the orbiting observer. For the object with the zero parallax true and barycentric coordinates coincide.

Due to the hierarchic structure of the Universe, astronomers need and construct several reference systems of coordinates. They are not equivalent, hence do not satisfy the requirements of the SRT, therefore it is impossible to solve any problems of astronomy in the frame of relativistic conception.

Absolute motion of a body (according to Newton) is related not to the ether, but to the center of masses of the system, to which this body belongs. Newton's idea of absolute motion (see "Principia") was misunderstood initially by philosophers and then by physicists (although they thought themselves newtonians). Later his ideas about absolute space, time and motion were falsified in relativistic literature. As is well known, some of the relativistic physicists have gone so far in the criticism of the absolute motion, as denying the principal difference between the Ptolemaic and Copernican Systems of the World [16]..

Notes

1. We might say, the "beauty" of mathematics is its exactness (rigor).
2. The special relativistic treatment of stellar aberration was never verified by astronomers because second order terms are too small. It is only after seventies, when due to increasing accuracy of positional observations (VLBI and cosmic), the question was discussed, whether the second order corrections should be taken into account. This is not the same as verification of formulae by means of observations. It is evident from the papers by P.Stumpff [17,18]; see also our comments in ([6], p.96-99). P.Stumpff wrote: "For the moving observer, the direction of arrival of the radiation is completely determined by the laws of special relativity which do not need an astrometric proof" ([17], p. 229). Indeed, there was no proof in astrometry and astronomy.
3. A surface is the space with two dimensions. After noneuclidean geometries were developed, one might consider the celestial sphere as the Riemann's two– dimensional space with the constant radius of curvature.
4. Since the equation (4) was regarded as the precise one, the wrong sign (+) in formula (6) before the term $2\frac{v}{c}\cos\varphi'$ was obtained, and hence appeared the wrong sign (-) before second order term in (6').
5. Denying the ether as a possible reference system, we do not object to the existence of a medium ("ether", "neo-ether"), which might influence on some phenomena in astronomy.

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