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THREE TRAPS IN STELLAR ABERRATION

The effect of aberration seems to be one of the simplest phenomena in astronomical observations. Nevertheless, it has a long and pertaining history of misunderstanding and wrong interpretation. In the time just before the advent of the theory of relativity, aberration and drag of the aether (as found in Michelson's experiment) are interpreted as contradiction. This contradiction vanishes with the theory of relativity. More obstinate is the misunderstanding that the aberration depends on the relative velocity of source and observer. In the twenties, some physicists and astronomers believed that the consequences of such a relativity, wrongly supposed but never found, would constitute a firm argument against Einstein's theory (Hayn, Tomaschek, Osten, v.Brunn, Courvoisier, Mohorovičić). History forgot their argument, but it is difficult to find a correct explanation of their error (Emden). Instead, the subject is forgotten, and one can conjecture that it is because of the political side of the argument. This attitude takes its revenge: Misunderstandings are still handed down from textbook to textbook.

1. The emission velocity of the light is not to be composed additively with the velocity of the source.
2. In the mechanistic wave picture, the wave-front normals do not show aberration.
3. If the emission event is given, there is no aberration due to the motion of the source.

- Aberration is the difference between the apparent positions found by observers in relative motion.
- The model of streaming particles is used in the simplest explanation (Fig. 3). It falls in contradiction to the then natural assumption that the isotropic emission velocity from a source must be added to their own velocity (Fig. 5). In contrast to this expectation, the emission velocity is not to be composed additively with the velocity of the source.
- The mechanistic wave picture correctly describes the lack of this composition, but the wave-front normals do not show aberration (Fig. 4).
- Fresnel overcame this difficulty because conventional telescopes did not state the direction of wave fronts but only the direction of parts of a wave (i.e. wave groups, signals) which move like particles due to their locality (Fig. 6).
- There is no aberration of wave fronts without relativity of simultaneity, i.e. without Einstein's theory of relativity (Fig. 7).
- It was Einstein's theory of relativity that reminded us that only relative velocities may lead to measurable effects. However, that does not imply that aberration answers the relative motion between source and observer. There is no aberration due to the motion of the source (if the emission event is given) (Fig. 8).
- The aberration is a conformal map of the apparent sphere onto itself. The group of these conformal maps is isomorphic to the Lorentz group.
- The map of the apparent sphere can be extended to a map of the space when we convene on stereoscopic view. The resulting map depends essentially on the orientation of the pair of eyes to the observer's velocity (Fig. 1 and 2).

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Caveat

A lot of confusion was created by the fact that an angle can be formed of the locations of the source at emission and observation time with the position of the observer at observing time, and that this angle vanishes when there is no relative velocity between source and observer. Too fast, it is concluded that this angle, combined from stellar aberration and motion in the retardation time, depends only on the relative velocity of source and observer. But this angle, given emission and observation event, depends on velocities and position in an involved fashion. Only after the convention that the relative position of the emission event in the rest frame of the observer is fixed, this angle depends only on the expected relative velocity, but this is trivial now. The combination of stellar aberration and motion in the retardation time produces in any case a calculated angle, which can be observed in special cases only.

Bradley's explanation is found everywhere, beginning with

BRADLEY,J. (1728): An account of a new discovered motion of fixed stars, *Phil.Trans.London* **35**, 637, 1729, reprinted in W.Magie ed., A source book of physics, Cambridge MS, Harvard 1935.

The retardation in the particle picture is, for instance, noticed and tested in

HERSCHEL,J.F.W. (1844): Schreiben an den Herausgeber, *Astron.Nachr.* **22**, 249-254 (520).
ZURHELLEN,W. (1914): Zur Frage der astronomischen Kriterien für die Konstanz der Lichtgeschwindigkeit, *Astron.Nachr.* **198**, 1-10 (4729).

The absence of wave-front aberration (in aether theories) is noticed in

FRESNEL,A. (1814): Lettre à son frère Léonor, 4.Juillet 1814, *Oeuvres complètes* **2**, 820-824, Paris, Imprimerie impériale 1868.
STOKES,G.G. (1845): On the aberration of light, *Phil.Mag.(3)* **27**, 9-15.

Fresnel's explanation is found more rarely, beginning with

FRESNEL,A. (1818): Sur l'influence du mouvement de terre dans quelques phénomènes d'optique, *Oeuvres complètes* **2**, 627, Paris, Imprimerie impériale 1868.

The absence of the aberration of wave-front normals is overlooked, for instance, by

JOOS,G. (1956): *Lehrbuch der theoretischen Physik*, Leipzig, Geest & Portig, 9.Aufl..
LIEBSCHER,D.-E. (1973): *Theoretische Physik*, Berlin, Akademie-Verlag, S. 201, erste Formel.
HERLT,E., SALIÉ,N. (1978): *Spezielle Relativitätstheorie*, Berlin, Akademie-Verlag.
GOY,F. (1996): Aberration and the question of equivalence of some ether theories to special relativity, *Found.Phys.Lett.* **9**, 165-174.

The aberration of wave-front normals requires a relativity of simultaneity. This can be found in

DRUDE,P. (1900): *Lehrbuch der Optik*, Leipzig, Hirzel.
SOMMERFELD,A. (1959): *Vorlesungen, IV. Optik*, 2.Aufl., Leipzig, Geest & Portig.
BOHM,D. (1965): *The special theory of relativity*, W.A.Benjamin.
FÜHRT (1970): *Fundamental principles of modern theoretical physics*, London, Pergamon Press.
ATWATER,H.A. (1974): Non-simultaneity in the aberration of starlight, *Amer.J.Phys.* **42**, 1022-1024.

The aberration should be a matter of relative velocity between observer and source. This error is, for instance, outspoken explicitely or tacitly implied in

V.LAUE,M. (1911): *Das Relativitätsprinzip*, Vieweg, Braunschweig.
EINSTEIN,A. (1916): *Über spezielle und allgemeine Relativitätstheorie*, Braunschweig, Vieweg.
PAULI,W. (1921): Relativitätstheorie, *Enzyklopädie der mathematischen Wissenschaften* **V/2**, S. 563.
MELCHER,H. (1974): *Relativitätstheorie*, Berlin, Deutscher Verlag der Wissenschaften.
TORETTI,R. (1984): *Relativity and Geometry*, Oxford, Pergamon.
TREDER,H.J. (1985): Aberration und Rotation des Kosmos, *Ann.d.Physik* **42**, 71-72.

An active aberration is (erroneously) expected by

CAMERER,J.W. (1797): Über die tägliche Aberration der Gestirne, *Astronomisches Jahrbuch für das Jahr* **1798**, 139-142.
HOUZEAU,J.C. (1844): D'un nouvel effet de l'aberration de la lumière particulier aux étoiles doubles qui possèdent un mouvement propre, *Astron.Nachr.* **21**, 241-248 (496), 273-278 (498).

No active aberration is observed. This is (correctly) stated by

NYRÉN,M. (1888): Zur Aberration der Fixsterne, *Bull.Acad.Imp.St.Petersburg* **32**, 402-412.
SEELIGER,H. (1884): Ueber die Aberration der Fixsterne, *Astron.Nachr.* **109**, 275-280 (2610).

The absence of active aberration is (erroneously) believed to be an argument against the theory of relativity by

HAYN,A.N. (1920): Didaktisches zur Aberration II, *Astron.Nachr.* **212**, 81-88 (5070).
TOMASCHEK,R. (1925): Über die Aberration, *Z.Physik* **32**, 397-402.
OSTEN,H. (1925): Aberration und Relativität, *Astron.Nachr.* **224**, 66-67 (Nr.5356).
MOHOROVIČIĆ,ST. (1928): Optik bewegter Körper, *in: E.Gehrke, Handbuch der physikalischen Optik* **2**, 917 ff., Leipzig, J.A.Barth.
MARMET,P. (1996): Stellar aberration and Einstein's relativity, *Physics Essays* **9**, 96-99.
SPENCER,D.E., SHAMS,U.Y. (1996): Stellar aberration and the postulates on the velocity of light, *Physics Essays* **9**, 476-483.

That no active aberration is to be expected, is (correctly) stated by

HERSCHEL,J.F.W. (1844): Schreiben an den Herausgeber, *Astron.Nachr.* **22**, 249-254 (520).
EMDEN,R. (1926): Aberration und Relativitätstheorie, *Die Naturwissenschaften* **14**, 327-335.
FOCK,V.A. (1960): *Theorie von Raum-Zeit und Gravitation*, Berlin, Akademie-Verlag.
LIEBERT,J. (1995): Die Aberration. Ein Gedankenexperiment zum Aberrationseffekt. *Die Sterne* **71**, 76-83.

1

Divertimento I

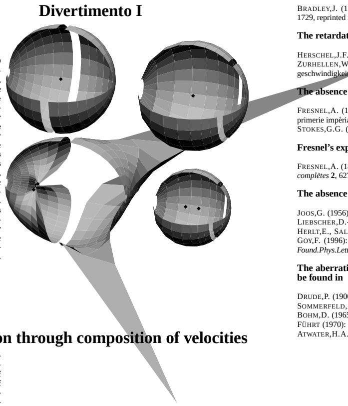
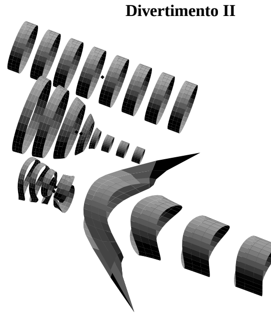


Fig.1. We show the 3D map of stereoscopic aberration. On the upper left, the sphere is shown with the equatorial region, the pole caps, and a meridional segment omitted. On the upper right, the conformal image produced by teh ordinary one-eye aberration can be seen. The observer moves to the right, the velocity is 0.7 c. On the lower right, two eyes are parallel to the velocity. The map is regular and shows a contraction. On the lower left, the eyes are across. Here, the velocity is only 0.4 c in order to obtain a not too extreme map. The black dots indicate the position of the eyes.

2

Divertimento II

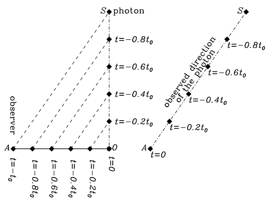


We show the stereoscopic aberration of a cylinder. First we draw eight segments as seen from an observer at rest. If the relative position of the eyes is parallel to the velocity, an observer moving from left to right sees at any given instant the form in the middle. If the eyes are oriented across, the moving observer sees the lower form (in both cases, the velocity is 0.7 c). The contraction apparent in the form in the middle is the immediate expression of the Lorentz contraction of the distance of the eyes.

3

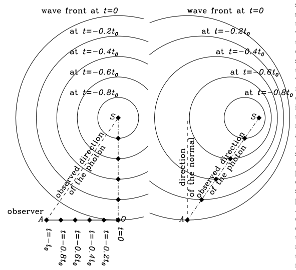
Aberration through composition of velocities

Bradley looked for the parallax and found the aberration. It was the proof of the motion of the earth, of the finiteness of the velocity of light, and of the composition of velocities as expected from Huygens' example. The problems begin with the particle model of light.
At left, the observer is in motion. When the photon is at S, he is at A. The observation, when both meet, happens at O. At right, all positions are referred to the actual position of A, i.e., we are in the rest frame of the observer. The photon moves along SA. In a spark chamber, this could be checked in detail. The angle between OS and AS is the stellar aberration.



4

The spherical wave for an observer in motion

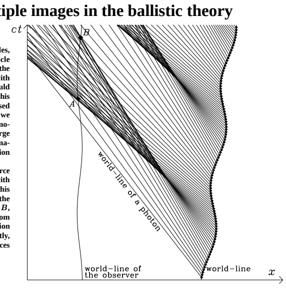


Zurhellen definitely proved that no additional composition of the velocities of source and emitted light takes place. This backs the wave theory of light, where the light velocity is independent of the velocity of the source. When we here stick to additional composition of velocities, the direction of ray and wave-front normal diverge for an observer in motion with respect to the medium. Wave-front normals do not show any aberration.
At left, we show the observer in motion and a spherical wave in isotropic propagation. On the wave crest, the position of some structure (wave group, photon, signal) is marked. At right, all positions are drawn with respect to the observer, i.e., the propagation is composed with its motion. The orientation of the wave-front normal does not show aberration but the signal does.

5

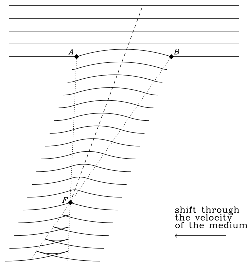
Multiple images in the ballistic theory

If light consists of particles, or if we observe particle emanation in general, the velocity of the particles with respect to the source should have a given value. If this velocity is to be composed with that of the source, we obtain for appropriate motions of the source and large enough distance an anomalously large time equation and multiple images.
In our draft the source has a periodic motion with radial component (only this component is shown). In the interval between A and B, the observer sees light from three different emission times and, consequently, from three different places simultaneously.



6

Aberration in wave theory



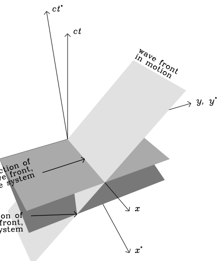
In order to explain aberration in wave theory, Fresnel was forced to refer to the construction of the telescopes of the time, i.e., to the existence of an aperture diaphragm. It cuts a piece out of the wave front. This piece moves like a particle because of its being localized and shows the usual aberration. To this end, the medium of wave propagation (which constitutes the reference frame of isotropic propagation) should move freely through all matter. The Michelson-type experiments show that this cannot be maintained consistently.

We see the motion of the wave front as constructed by Huygens's method. This motion is decelerated in the aperture lens and reaches a focus F. The wave fronts are shifted to the left with progressing time. The focus is found in the position expected by the particle-type aberration argument.

7

Aberration of a plane wave

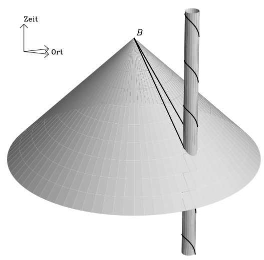
When we require that wave fronts and rays are to have the same aberration (which could be tested with adaptive optics, for instance), simultaneity cannot be absolute. We are forced to revise the notion of time and obtain the Minkowski world of the special theory of relativity.
We show a wave front propagating in the direction of the y axis. It is respresented by a plane in the (here (2+1)–dimensional) spacetime. Its position for a given instant of time (here $t = 0$) is the intersection with the corresponding plane of simultaneous events. If the simultaneity is absolute, i.e., if this plane is the same for all observers, no aberration of the wave-front normal is possible.



Consequently, such an aberration requires the relativity of simultaneity, i.e., every observer has its own orientation of the planes of equal time. In our draft, the second observer moves to the left (axis ct^*). In the Minkowski world, the plane of simultaneous events ($ct^* = 0$) is now tilted as indicated. it intersects the wave front in another line corresponding to the expected aberration. On the other hand, the requirement of equal aberration of wave-fronts and rays forces the planes $ct^* = 0$ to be tilted in the indicated way which is equivalent to the Minkowski geometry.

8

The apparent size of a Kepler orbit



The theory of relativity states that there is no particular frame of isotropic propagation of light in order to yield a reference for other velocities. Consequently, the dependence on velocity of any physical effect is reduced to the dependence on only relative velocities of material objects. When one forgets that the definition of an angle requires the positions of three objects, one easily falls into the trap of considering only the relative velocity between source and observer. This velocity, however, is not involved at all. The aberration is a conversion of apparent positions between two observers and depends only of their relative velocity.

In a space-time diagram, we draw the world-lines of all photons observed at the event B by the observer. Because the propagation velocity does not depend on the motion of the source, these world-lines form a cone. The world-line of a double stars of given average position is wound around a cylinder with axis parallel to the time axis. The apparent size of the orbit is equal to the apparent size of this cylinder. The observer obtains it by evaluating the angle marked on the cone. This angle (as well as the cylinder) does not depend on the velocity of the star on its orbit: There is no active aberration.