Doppler Effect, Absolute Stellar Aberration, Stellar velocity, Stellar distance and Speed of the light

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Abstract

Our assumption is that the Doppler Effect and Absolute Stellar Aberration are two complementary phenomena. This means that if we are able to use the result obtained by measuring DE to determine the radial velocity, then by using the result obtained by measuring ASA we should be able to determine the transverse velocity with which the star moves in relation to the observer. We will prove that if we know the velocity of the star, we can determine its distance in relation to the observer and the speed of light emitted from the star in the direction of the observer.

Keywords: *Doppler effect, Stellar aberration, Stellar velocity, Stellar distance, Speed of light*

1. Introduction

We assume that it is possible to detect and measure Absolute Stellar Aberration, a single measurement, caused by the movement of the observer in relation to the star. Bradley's (relative) stellar aberration represents only the difference between two ASA measurements [1].

2. Telescope and its coordinate system

Suppose we observe an arbitrarily chosen star, denoted by (Z) Fig [1]. At the instant t' the photon (electromagnetic wave) hits in a perpendicular direction at the center of the top plane of the telescope noted by S'. At the instant t the photon (electromagnetic wave) hits the bottom plane of the telescope noted by A. We define a Telescope Coordinate System $(T) \equiv (S, x_t, y_t, z_t)$ as it follows. Its origin is noted by the point S and the positive z_t coordinate is determined by direction SS'. We will assume that the star and the axis of the telescope SS' lie in the same *meridian* plane. The positive x_t coordinate is determined by direction in which the earth rotates on its axis [1].

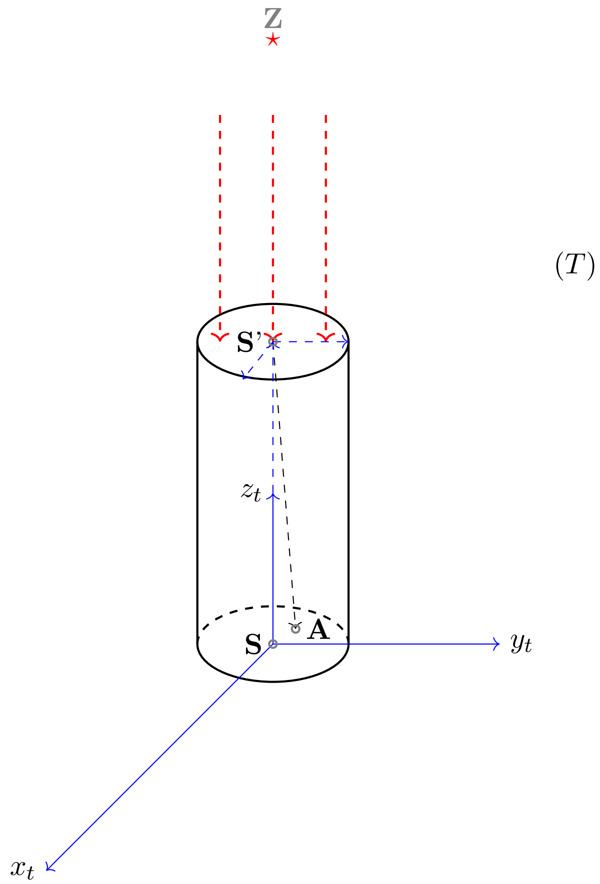

Figure 1: The Telescope and the Telescope Coordinate System

The telescope is constructed in such a way that it is possible to measure DE and ASA simultaneously.

3. Determining a radial velocity of the star

We denote by (K) the Ecliptic Coordinate System and define velocities $\mathbf{u}, \mathbf{v}$ and $\mathbf{w}_q$ in the following way:

(i) $\mathbf{u}$ - the velocity at which a star moves relative to the Ecliptic Coordinate System (K)
(ii) $\mathbf{v}$ - the velocity at which the Earth moves relative to the Ecliptic Coordinate System (K)
(iii) $\mathbf{w}_q$ - the velocity at which the telescope moves relative to the Equatorial Coordinate System

$$\mathbf{u} = (u_x, u_y, u_z) \tag{1}$$
$$\mathbf{v} = (v_x, v_y, v_z) \tag{2}$$
$$\mathbf{w}_q = (w_{q_x}, w_{q_y}, w_{q_z}) \tag{3}$$

The velocity $\mathbf{w}_q$ is transformed from the Equatorial Coordinate system to the Ecliptic Coordinate System and denoted as $\mathbf{w}$ [1].

$$\mathbf{w} = (w_x, w_y, w_z) \tag{4}$$

In relation to the Ecliptic Coordinate System Fig.[1] a unit vector $\mathbf{a}$ is defined as it follows

$$\mathbf{a} = [a_x, a_y, a_z] = \frac{\mathbf{SZ}}{||\mathbf{SZ}||} \tag{5}$$

From Doppler equation [2] it follows that:

$$f' = \frac{c + \mathbf{a} \cdot (\mathbf{v} + \mathbf{w})}{c + \mathbf{a} \cdot \mathbf{u}} f \tag{6}$$

$$c + \mathbf{a} \cdot \mathbf{u} = \frac{f}{f'} (c + \mathbf{a} \cdot (\mathbf{v} + \mathbf{w})) \tag{7}$$

$$\mathbf{a} \cdot \mathbf{u} = \frac{f - f'}{f'} c + \frac{f}{f'} \mathbf{a} \cdot (\mathbf{v} + \mathbf{w}) \tag{8}$$

where

f - the frequency of the emitted light
f' - the frequency of the observed light
c - the speed of light (in the vicinity of the telescope)

If we transform velocity $\mathbf{u}$ from the Ecliptic Coordinate system to the Telescope Coordinate System (T) and denote it as $\mathbf{u}_t$

$$\mathbf{u}_t = (u_{x_t}, u_{y_t}, u_{z_t}) \tag{9}$$

then it follows that

$$u_{z_t} = \mathbf{a} \cdot \mathbf{u} \tag{10}$$

It remains to determine the components u_{x_t} and u_{y_t} of the velocity $\mathbf{u}_t$.

4. Determining a transverse velocity of the star

We will define the coordinate system (K'), so that its origin O' is the center of the star, and its coordinate axes have the same direction as the axes of the Ecliptic Coordinate System. Our assumption is that the ASA is caused by the movement of the observer in relation to the star. A velocity, denoted by $\mathbf{U}$, with which the telescope moves in relation to the coordinate system (K') is equal to:

$$\mathbf{U} = -\mathbf{u} + \mathbf{v} + \mathbf{w} \tag{11}$$

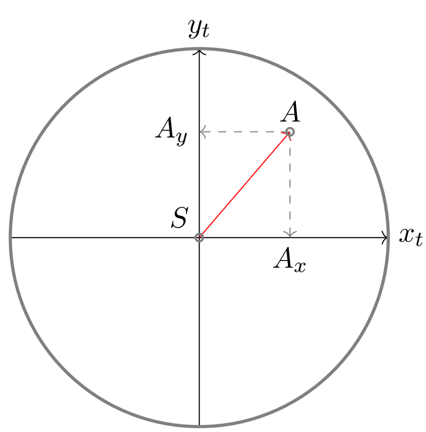

Figure 2: Due to the stellar aberration photons hit bottom side of the telescope at point A

The origin of the Telescope Coordinate System (T) is noted by S Fig[2], its axes are marked by x_t and y_t. Point A denotes the point where light hits the bottom plane of the telescope. Points A_x and A_y are the projections of point A on the x_t and y_t axes. We transform velocities $\mathbf{U}$, $\mathbf{u}$,$\mathbf{v}$ and $\mathbf{w}$ from the (K') Coordinate system to the Telescope Coordinate System and denoted them as $\mathbf{U}_t$,$\mathbf{u}_t$, $\mathbf{v}_t$ and $\mathbf{w}_t$ respectively.

$$\mathbf{U}_t = (U_{x_t}, U_{y_t}, U_{z_t}) \tag{12}$$
$$\mathbf{u}_t = (u_{x_t}, u_{y_t}, u_{z_t}) \tag{13}$$
$$\mathbf{v}_t = (v_{x_t}, v_{y_t}, v_{z_t}) \tag{14}$$
$$\mathbf{w}_t = (w_{x_t}, w_{y_t}, w_{z_t}) \tag{15}$$

Referring to Fig[1] it follows:

$$l = SS' \tag{16}$$
$$\Delta t = t - t' \approx \frac{l}{c - u_{z_t}} \tag{17}$$

$$\Delta t\, U_{x_t} = -A_x \tag{18}$$
$$\Delta t\, v_{x_t} + \Delta t\, w_{x_t} - \Delta t\, u_{x_t} = -A_x \tag{19}$$
$$u_{x_t} = \frac{A_x}{\Delta t} + v_{x_t} + w_{x_t} \tag{20}$$
$$\Delta t\, U_{y_t} = -A_y \tag{21}$$
$$\Delta t\, v_{y_t} + \Delta t\, w_{y_t} - \Delta t\, u_{y_t} = -A_y \tag{22}$$
$$u_{y_t} = \frac{A_y}{\Delta t} + v_{y_t} + w_{y_t} \tag{23}$$

It remains to transform the velocity $\mathbf{u}_t$ from the Telescope Coordinate System to the Ecliptic Coordinate System.

5. Determining a distance of the star

Suppose that the observed star Z is moving with a uniform, rectilinear space motion noted by $\mathbf{u}$ regarding the coordinate system (K) Fig[3]. Let us denote by τ_A the time when the signal was sent from the point noted by Z_1 and by t_A the time when the signal is registered at point noted by A. We assume that τ_A and t_A are expressed in the same units of time. The unit vector of the direction AZ_1 is denoted by $\hat{\mathbf{a}}$. In an analogous way, we will define triple $(\tau_B, t_B, \hat{\mathbf{b}})$ for the point (B, Z_2).

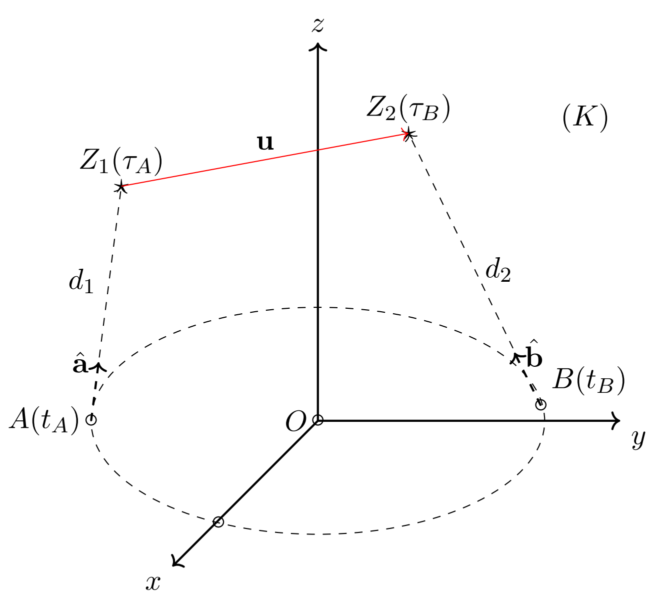

Figure 3: Star Z moves uniformly regarding the sun.

Coordinate system (K) is Heliocentric Ecliptic Coordinate System. Coordinate axes are determined in accordance with the *ICRS* standard. Referring to Fig[3] we have that:

$$d_1 = ||\mathbf{AZ}_1|| \tag{24}$$
$$d_2 = ||\mathbf{BZ}_2|| \tag{25}$$
$$\mathbf{A} = \mathbf{OA} = [A_x, A_y, A_z] \tag{26}$$
$$\mathbf{B} = \mathbf{OB} = [B_x, B_y, B_z] \tag{27}$$
$$\hat{\mathbf{a}} = [a_x, a_y, a_z] = \frac{\mathbf{AZ}_1}{||\mathbf{AZ}_1||} \tag{28}$$
$$\hat{\mathbf{b}} = [b_x, b_y, b_z] = \frac{\mathbf{BZ}_2}{||\mathbf{BZ}_2||} \tag{29}$$

$$\Delta\,\tau = \tau_B - \tau_A \tag{30}$$
$$d_1\,\hat{\mathbf{a}} + \Delta\,\tau\,\mathbf{u} - d_2\,\hat{\mathbf{b}} = \mathbf{AB} \tag{31}$$
$$d_1\,\hat{\mathbf{a}} - d_2\,\hat{\mathbf{b}} + \Delta\,\tau\,\mathbf{u} = \mathbf{AB} \tag{32}$$

We have obtained a linear system of three equations with three unknowns d_1, d_2 and $\Delta\,\tau$.

$$d_1\,a_x - d_2\,b_x + \Delta\,\tau\,u_x = B_x - A_x \tag{33}$$
$$d_1\,a_y - d_2\,b_y + \Delta\,\tau\,u_y = B_y - A_y \tag{34}$$
$$d_1\,a_z - d_2\,b_z + \Delta\,\tau\,u_z = B_z - A_z \tag{35}$$

After we have found d_1, d_2 and $\Delta\,\tau$ it remains to calculate the speed of emitted light.

6. Determining a speed of light

We denote by c' the *average* speed of light emitted from the star in the direction of the observer. Referring to Fig[3] it follows that:

$$\Delta\,\tau = \tau_B - \tau_A \tag{36}$$
$$\Delta\,t = t_B - t_A \tag{37}$$
$$\frac{d_1}{c'} + \Delta\,t = \frac{d_2}{c'} + \Delta\,\tau \tag{38}$$
$$c' = \frac{d_1 - d_2}{\Delta\,\tau - \Delta\,t} \tag{39}$$

In formulas (17) and (6) [2], c denotes the speed of light in the vicinity of the telescope.

Denote by ϵ some sufficiently positive small number. We will consider two cases:

i) $\mid c - c' \mid \leq \epsilon$
The speed of light emitted by the star is equal to the constant c. The measurements and our method are correct.
ii) $\mid c - c' \mid > \epsilon$
The first possibility is that a random measurement error was made. Another possibility is that the value of the constant c should be corrected. We will change the value of the constant c and denote it by c_0 (the speed of light in the vicinity of the telescope), redo the complete calculation, and choose a value for c_0 so that the expression $\mid c_0 - c' \mid$ is minimal.

If $\mid c_0 - c' \mid \leqslant \epsilon$ then the speed of light emitted by the star is constant and equal to c', but $c' \neq c$.

If $\mid c_0 - c' \mid > \epsilon$ then the *average* speed of light emitted by the star is not equal to the speed of light in the vicinity of the telescope.

7. Conclusion

Detection and measurement of ASA would have not only theoretical importance but also great practical value. It is obvious that this method would be an improvement over the parallax method, because the movement of the star in relation to the sun is also taken into the calculation. In addition, the comparison between the *average* speed of light emitted by the star and the speed of light in the vicinity of the telescope would be the ultimate test of the constancy of the speed of light.

8. Conflicts of Interest Statement

The author has no conflicts of interest to disclose.

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