Search for Anisotropic Light Propagation as a Function of Laser Beam Alignment Relative to the Earth's Velocity Vector

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A laser diffraction experiment was conducted to study light propagation in air. The experiment is easy to reproduce and it is based on simple optical principles. Two optical sensors (segmented photo-diodes) are used for measuring the position of diffracted light spots with a precision better than 0.1 μm. The goal is to look for signals of anisotropic light propagation as function of the laser beam alignment to the Earth's motion (solar barycenter motion) obtained by COBE. Two raster search techniques have been used. First, a laser beam fixed in the laboratory frame scans in space due to Earth's rotation. Second, a laser beam mounted on a turntable system scans actively in space by turning the table. The results obtained with both methods show that the course of light rays are affected by the motion of the Earth, and a predominant first order quantity with a $\Delta c/c = -\beta(1 + 2a)\cos\theta$ signature with $\bar{a} = -0.393 \pm 0.032$ describes well the experimental results. This result differs in amount of 21% from the Special Relativity Theory prediction and that supplies the value of $a = -\frac{1}{2}$ (isotropy).

1 Introduction

There are several physical reasons, theoretical and experimental, that could justify a search for anisotropies in light propagation. It is well known that Lorentz and Poincaré were the first ones to build the major part of the relativity theory on the basis of the ether concept as an inertial rest frame, and it is compatible with the Einstein's Special Relativity Theory (SRT). There are also some test theories of SRT, where the Lorentz transformations are modified. For example, an ether theory that maintains the absolute simultaneity and is kinematically equivalent to Einstein SRT was constructed [1]. These test theories are considered useful to examine potential alternatives to SRT. On the other hand, the reconstruction of the SRT, on the basis of the Lorentz-Poincaré scheme implies in an undetectable ether rest frame (non ether drift) at least in the first order [2].

This behavior of the Lorentz-Poincaré, as well as, of the Einstein theories arise because they do not govern the whole physics, for instance they do not involve gravitation. It is also well known that the presence of a gravitational field breaks the Lorentz symmetry.

On the other hand, periodic boundary conditions or close space-time topology, such as the Sagnac effect [3] where two opposite light beams travel in different time intervals the same closed path on a rotating disk, as well as the twin paradox, leads to preferred frame effects. This assumption of a preferred frame comes from an analysis made by Brans and Stewart [4] on the twin paradox, where a description of the close topology of the universe has imposed a preferred state of rest so that the principle of special relativity, although locally valid, is not globally applicable. Similar conclusion is obtained in the Wucknitz's paper [5], where standard notation of SRT using Lorentz transformations leads to coordinates which are valid locally. Periodic boundary conditions or close space-time topology, such as the Sagnac effect and the twin paradox, leads to preferred frame effects.

The above conclusion is reinforced by the generalized Sagnac effect [6] observed in a light waveguide loop consisting of linearly and circularly segments, any segment of the loop contributes to the phase difference between two counter-propagating light beams in the loop. Showing that the acceleration is not essential to take into account the effect.

A preferred frame emerge also from an analysis on the Global Positioning System (GPS) made by R. Hatch [7] and T. Van Flandern [8] where the preferred frame is not universal, but rather coincides with the local gravity field.

On the other hand, according to Fox [9], it is possible to preserve the general Lorentz Poincaré symmetry group without assuming the constancy of light speed. There are also the so called extended theories, where the SRT is modified in order to including the Planck scale parameters [10] (double relativity theories), suggesting several dispersion relations that include theories where an energy dependent speed of light [11] is claimed.

There are also evidences suggesting that the propagation of light over cosmological distances has anisotropic characteristics [12], with dependence on direction and polarization. This picture is in agreement with the interpretations of the COBE [13] measurements giving the Earth's "absolute" velocity in relation to the uniform cosmic microwave background radiation (CMBR). Of course, there are also interpretations claiming that the COBE measurements give only a velocity for the "relative" motion between the Earth and the CMBR [14]. For instance, it is possible to obtain a "virtual" image, where an isotropic distribution of CMBR with small fluctuations ($\delta T/T \sim 10^{-5}$) can be seen, by removing the Earth motion.

So far, several tests about violation of the isotropy of the speed of light have been made. In most cases, the tests involve the so called round-trip test of light-speed isotropy like Michelson-Morley experiment and all its variants. Particularly, Miller [15, 16] has claimed a non-null results in the M-M experiments. These aspects are presented in Appendix.

On the other hand, there are also several one-way test of light isotropy experiments. In most cases, they have claimed a null result [17, 18, 19, 20]. Particularly the NASA's Deep Space Network [21] using hydrogen-maser frequency have to obtained a crude bound $\Delta c(\theta)/c < 4.5\times10^{-6}$ for the anisotropy of the one way velocity of light and refined to $\Delta c(\theta)/c < 3.5\times10^{-7}$. However, according to their own conclusions the validity of these limits rest upon the assumption that the prediction phase variations were not partially canceled. There are also experiments that have claimed success [22, 23]. Particularly, Silvertooth has claimed an experimental detection of the ether drift velocity using a device capable of detecting the beams arriving in opposite directions [23]. Silvertooth reported in 1986 a light anisotropy toward the direction of Leo constellation and compatible with COBE results. The experiment is an unusual double interferometer, an arrangement of light paths and detectors hard to be reproduced. In addition, the presence of a feedback into the laser is quite probable.

In this paper, we report results of a search for anisotropic light propagation as a function of the laser beam alignment relative to the Earth's velocity vector, using a diffraction device. The method is based on simple optical principles. Initial attempts have used digital images of the diffraction spots. However, this method was working in the limit of sensitivity. In other words, the signal's size was close to the measurement resolution. Now, our results are obtained by using the highly sensitive segmented photo-diodes to measure the position of diffracted light spots. In Section 2, the experimental setup and the basic operating principles of the diffractometer are presented. The Earth's velocity vector on the basis of the Doppler shift of the CMBR results are presents in Section 3. In Section 4, the two scanning methods and their results are presented, and finally Section 5 contains our conclusions.

2 Experimental setup and method

The diffraction experiment is installed on the campus of the Universidade Federal Fluminense, Niterói, Rio de Janeiro-Brazil at sea level. The position is given by $22°54'33''$ S latitude and $43°08'39''$ W longitude. The diffraction experiment is mounted on a horizontal rotating circular table.

The layout of the diffraction device is shown in Fig. 1. A laser beam transverse to a diffraction grating is diffracted in several rays. In order to determine the position of the

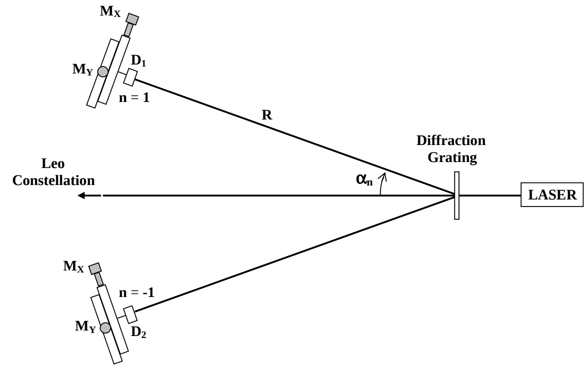

Fig. 1: General layout of the diffraction experiment. Two segmented photo-diodes (D_1 and D_2) are positioned using two vertical platforms with two positioning system (micrometers $M_x - M_y$) to detect two diffracted rays produced by a HE-Ne laser on a grating diffraction device. The relative position of a light spot with respect to the center on a segmented photo-diode is obtained by simply measuring the output current of each segment. The setup is mounted on a turntable system

light spots, we have used two segmented PSD photo-diodes divided into two segments, separated by a gap (see Fig. 2). The position of each photo-diode coincides with the positions of the maxima intensity of the diffraction images, for $n=+1$ and $n=-1$ respectively, as shown in Fig. 1. Two precision multi-axis positioning systems, and each one consist of a vertical platform with two independent (X–Y) micrometers, have been used to mount the photo-diodes.

Following Fig. 1, it is possible to see that the maxima of intensity of the diffraction images (rays) satisfy the condition

$$\sin\alpha_n = \pm\, n\,\frac{\lambda}{\eta\,\delta}, \quad \text{with} \quad n = 0, 1, 2, \dots\,, \tag{1}$$

where $\lambda\,(= 632.8\,\text{nm})$ is the wave length, $\delta\,(= 1/600\,\text{mm})$ is the diffraction grating step and $\eta\,(= 1.000226)$ is the refraction index of air. The wave length λ can be obtained as the ratio between the speed of light c and the light frequency ν resulting in $\lambda = c/\nu$. An expression for c as a function of the angle α can be obtained as

$$c = \frac{\eta\,\nu\,\delta}{n}\,\sin\alpha_n\,. \tag{2}$$

Under the assumption that ν and η remain constant during the experiment, and if c depends on the direction of propagation, variations of the diffraction spot positions, α_n, for instance, as a function of the laser beam alignment, relative to the Earth's velocity vector, can be interpreted as an indication of violation of the isotropy of c. The relative variation can be expressed as

$$\frac{\Delta c}{c} = \frac{\Delta(\sin\alpha_n)}{\sin\alpha_n} = \cot\alpha_n\,\Delta\alpha_n\,. \tag{3}$$

We look for this anisotropic light propagation signal through measurements of $\Delta\alpha_n$ as a function of the Earth's

Observer	Year	v_E, km/s	α, hour	δ, degree
Pensias & Wilson (ground) [27]	1965		I s o t r o p i c	
Conklin (ground) [28]	1969	200±100	13±2	30±30
Henry (balloon) [29]	1971	320±80	10±4	−30±25
Smoot et al. (airplane) [30]	1977	390±60	11.0±0.5	6±10
COBE (satellite) [32]	1991	371±0.5	11.20±0.01	−7.22±0.08
WMAP (satellite) [33]	2003	368±0.2	11.20±0.01	−7.22±0.08

Table 1: Vector velocity of the Earth (solar system) relative to the CMBR rest frame, measured using the anisotropy of the CMBR in several experiments.

velocity vector. The search has been made by using two independent types of scanning, and the methods as well as the results are presented in Section 4.

The determination of the position of the light spots is made by measuring the output photo-current in each segment of the photo-diodes. A symmetric spot, positioned at the center, generates equal photo-currents in the two segments. The relative position is obtained by simply measuring the output current of each segment. The position of a light spot with respect to the center on a segmented photo-diode is found by

$$\Delta l = l_0 \left(\frac{I_1 - I_2}{I_1 + I_2} \right) , \tag{4}$$

where l_0 is a proportionality constant. The method offers position resolution better than 0.1 μm, and the angular variation can be obtained as

$$\Delta\alpha_n = \frac{\Delta l}{R} = \frac{l_0}{R} \left(\frac{I_1 - I_2}{I_1 + I_2} \right) . \tag{5}$$

For the diffraction experiment with $R = 30.0$ cm, the angular resolution is better than 3.3×10^{-7} rad.

We have used the data acquisition system of the Tupi muon telescope [24, 25, 26], which is made on the basis of the Advantech PCI-1711/73 card. The analog output signal from each segmented photo-diodes is linked to the analog input of the PCI card. The PCI card has 16 analog input channels with a A/D conversion up to 100 kHz sampling rate. All the data manipulations such as the addition and the subtraction of currents are made via software, using the virtual instrument technique. The application programs were written using the Lab-View tools. A summary of the basic circuit is shown in Fig. 2.

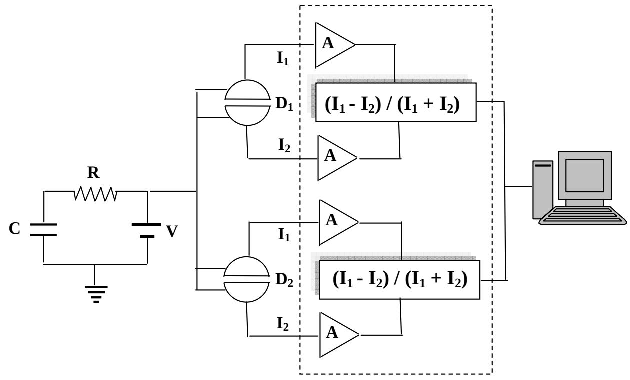

Fig. 2: Block diagram of the diffraction experiment data acquisition system. D_1 and D_2 represent the segment photo-diodes.

3 The Earth's velocity vector

The discovery of a pervasive background radiation from the universe by Penzias and Wilson [27] in 1965 is probably the strongest evidence for the hot Big Band model. The CMBR is a 2.7 Kelvin thermal black body spectrum with a peak in the micro wave range, and it is considered a relic of the Big Bang. In the past when the Universe was much smaller, the radiation was also much hotter. As the Universe expanded, it cooled down to the present level.

In Penzias-Wilson's data, the radiation appeared as highly isotropic. However, in the next round of experiments [28, 29, 30] temperature anisotropies were found. These anisotropies are expressed using the spherical harmonic expansion, and the Earth's motion with velocity $\beta = v/c$ relative to the CMBR rest frame of temperature T_0 produces a Doppler shift as

$$\frac{\Delta T}{T_0} = \beta \cos\theta + \frac{\beta^2}{2} \cos 2\theta + \mathrm{O}(\beta^3) . \tag{6}$$

In Table 1, measurements of the velocity vector of the Earth (solar system) in several experiments in chronological order using the anisotropy of the CMBR are summarized. Southern Hemisphere airborne measurements of the anisotropy in the cosmic microwave background radiation by Smoot and Lubin [31] (1979 — Lima, Peru) are in essential agreement with previous measurements from the northern hemisphere and the first-order anisotropy is readily interpreted as resulting from a motion of the Sun relative to the background radiation.

The COBE data [32] indicate a big temperature anisotropy in the cosmic background radiation which is represented by a dipole form with an amplitude of $\Delta T/T_0 = 1.23 \times 10^{-3} = 0.123\%$. This arises from the motion of the solar system barycenter, with a velocity $v = 371 \pm 0.5$ km/s (β =0.001237±0.000002) at 68%CL, relative to the so called

"CMBR rest frame" and towards a point whose equatorial coordinates are $(\alpha, \delta) = (11.20^{\rm h} \pm 0.01^{\rm h}, -7.22° \pm 0.08°)$. This direction points to the Leo constellation. Recently, the WMAP [33] mission has improved the resolution of the angular power spectrum of the CMBR and has verified the COBE results.

4 Raster search techniques

We look for an anisotropy signal in the light propagation as a function of the Earth's velocity vector. At our latitude ($\sim 23°$ S) there are two passages of the Leo constellation on the horizon every 24 hours. The first one is near the West direction, and the second is approximately 12 hours later, and it is near the East direction. Consequently it is possible to mount a laser diffraction experiment on a horizontal turntable system and point the laser beam toward the Leo constellation. The raster search can be made by using two methods as are described below.

4.1 Passive raster search system due to Earth's rotation

This method consists in to fix the laser beam direction toward the first or second passage of the Leo constellation on the horizon. As the Earth rotates, the laser beam will be aligned to the first or second passage of the Leo constellation (CMBR apex according to COBE) on the horizon over a 24 hour period.

As the laser, the diffraction grating, and the detectors are always fixed, the method is free of mechanical perturbations, which can be introduced, for instance, when the system is rotated. However, the method requires measurements over a long period of time (at least 12 hours) and several days and this introduces the so called DRIFT-long-term timing variation by aging due to temperature variations (diurnal and semi-diurnal temperature dependence). In the case of diffraction experiments, this effect is amplified due to the temperature dependence of the refraction index. Even so, the situation is not critical, because the angular variation of the diffracted rays is obtained from the ratio $(I_1 - I_2)/(I_1 + I_2)$ and the systematic effects tend to the cancel.

There is also the JITTER-timing (short term) noise due to statistical fluctuations of the signal (shot and thermal noises), and they have a "white" frequency distribution, where the spectral power densities are constant.

If the CMBR apex has an altitude, h, and an azimuth angle, θ_A, the projection of the Earth's velocity, v, on the laser beam direction is

$$v_p = v \cos\,(\theta_A - \theta_{beam}) \cos h\,, \qquad (7)$$

where θ_{beam} is the azimuth of the laser beam and coincides with the CMBR apex azimuth when it is on the horizon. Consequently, the values $\theta_A = \theta_{beam}$ and $h = 0$ represents the CMBR apex culmination on the horizon.

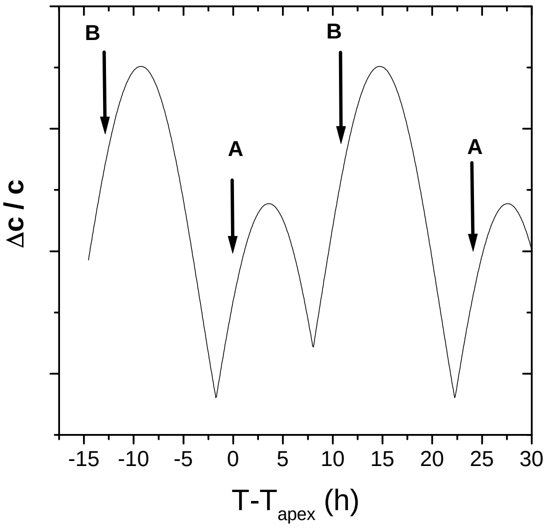

Fig. 3: Expected variation of the one way light speed anisotropy relative to the CMBR dipole direction for a period of 24 hours according to Mausouri and Sexl test theory (with $a \neq -\frac{1}{2}$) and modulated by the altitude variation of the CMBR apex due to Earth rotation. The curve was obtained for the Latitude $= 23°$ S. The vertical arrows A and B indicates the moment of the passage of the CMBR apex for the horizon. In A (B) the laser beam is parallel (anti-parallel) to the Earth velocity vector.

On the other hand, we have analyzed the experimental data using the test theory of Mausouri and Sexl [1]. according to this test theory, the one way speed of light is anisotropic by an among

$$c\,(\theta) = c - v\,(1 + 2a) \cos\theta\,, \qquad (8)$$

where θ is the angle between the velocity, v, of the moving system (i.e. the Earth motion) and the direction of light propagation. In our experiment $\theta = \theta_A - \theta_{beam}$. The value $a = -\frac{1}{2}$ correspond to the isotropic SRT prediction, and $a \neq -\frac{1}{2}$ represents an anisotropic signal in the one-way path speed of light. According to Eq. 7 in the passive raster search system, the Mausouri and Sexl equation is modulated by the altitude variation and can be expressed as

$$c\,(\theta, h) = c - v\,(1 + 2a) \cos\,(\theta_A - \theta_{beam}) \cos h\,, \qquad (9)$$

and the relative variation is

$$\Delta c(\theta, h)/c = -\beta\,(1 + 2a) \cos\,(\theta_A - \theta_{beam}) \cos h\,, \qquad (10)$$

where $\beta = v/c$. As we know the equatorial coordinates of the CMBR $(\alpha, \delta) = (11.20^{\rm h} \pm 0.01^{\rm h}, -7.22° \pm 0.08°)$ according to COBE. The transformation from equatorial coordinate system (α, δ) to the horizontal coordinate system (θ_A, h) permits to obtain a correlation between θ_A and h as

$$h = \arcsin\,(\sin\phi \sin\delta + \cos\phi \cos\delta \cos H)\,, \qquad (11)$$

$$\theta_A = \arcsin\,(-\cos\delta \sin H / \cos h)\,, \qquad (12)$$

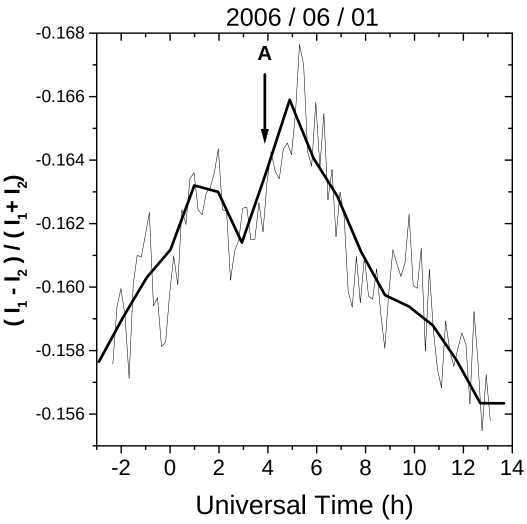

Fig. 4: Histogram obtained in the passive scan system averaging the raw data in blocks of 10 minutes The vertical arrow indicates the moment of the passage of the CMBR apex (according to COBE) for the horizon. The bold line represent a polynomial fit on the data.

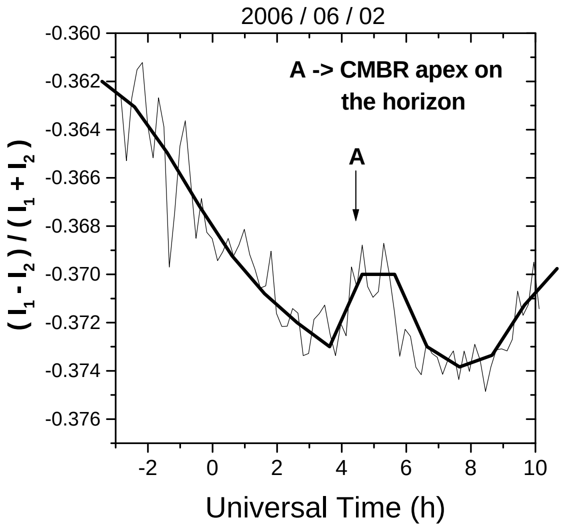

Fig. 5: The same as Fig. 4.

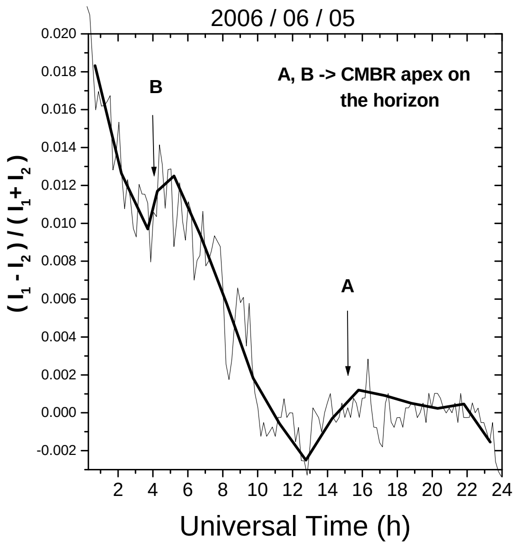

Fig. 6: The same as Fig. 4

where $\phi\,(=-23^\circ$ S) is the latitude and $H\,(=T-\alpha)$ is the hour angle and T is the sidereal time. Under this conditions, the behavior of $(\Delta c/c)$ given by the Eq. 10 is reproduced in Fig. 3, where the vertical arrows A and B indicates the moment of the passage of the CMBR apex (according to COBE) for the horizon. In A (B) the laser beam is parallel (anti-parallel) to the Earth velocity vector.

In the experiment $\Delta c/c$ is inferred from $\Delta\alpha_n$ measurements (see Eq. 3 and Eq. 5 from Section 2). Examples of raster scans (in the passive mode) were obtained in the first set of measurements (June of 2006) as shown in Fig. 4, Fig. 5 and Fig. 6. Four months after we have repeating the experiment and the result obtained on November of 2006 is shown in Fig. 7. In all cases, built-in a DRIFT-long-term it is possible to see peculiar signatures (see Fig. 3) where the culmination of the CMBR apex on the horizon is between a depression and a peak of the $\Delta c/c$.

In order to extract the Earth's velocity from these experimental data, it is necessary to remove the DRIFT-long-term timing variation, because they are obtained in different days. Meantime this procedure is not free from experimental bias. The calibration will be done in the next search with active rotation which is free of the DRIFT-long-term timing variation.

Before publication of this paper we were informed by V. Gurzadyan [34, 35] of a similar study on anisotropy of the one way velocity of light relative to the dipole of the CMBR based on the Compton edge of laser photons scattered in electron beam at GRAAL ESRF (Grenoble) accelerator, where a similar behavior in the time series was obtained (see Fig. 4 from ref. [35]). However, according to the authors this variations comes probably from temperature variations. We were also informed that is in progress an analysis with new data.

4.2 Active raster search with a turntable system

In this active system, the laser beam is first pointed toward the direction of the Leo constellation (CMBR apex) when it is exactly on the horizon. Then the turntable, upon which the entire laser diffraction experiment is mounted, is rotated in steps of 30 degrees up to 180 degrees. At every angular step, the output current of the photo-diodes is registered during one minute at a counting rate of 10 readings per second. A complete set of measurements can be done in less than ten minutes. Consequently the measurements are free from DRIFT-long-term timing variations. They are influenced only by the JITTER-timing uncertainties (noise in the system by statistical fluctuations of the signals). However, this method requires a careful rotation of the system in order to avoid mechanical perturbations. The measurements, after a gaussian fit in the raw data, are shown in Fig. 8 for seven angular

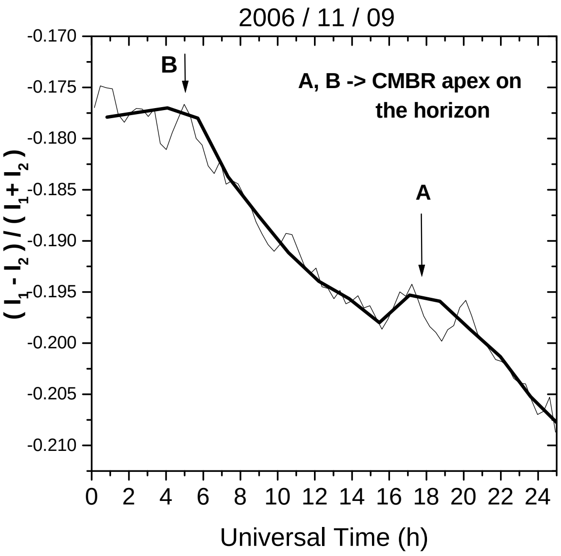

Fig. 7: The same as Fig. 4

regions, and the one-way light path anisotropy can be extracted from

$$\frac{\Delta c}{c} = \cot\alpha\,\Delta\alpha\,, \tag{13}$$

with

$$\Delta\alpha = \frac{l_0}{R}\left[\frac{I_1 - I_2}{I_1 + I_2}\right], \tag{14}$$

where the calibration factor obtained for these measurements is $l_0\,(= 0.407 \pm 0.034\,\text{mm})$.

We have analyzed the experimental data using also the test theory of Mausouri and Sexl [1] where the one way speed of light is anisotropic by the among

$$c\,(\theta) = c - v\,(1 + 2a)\cos\theta\,. \tag{15}$$

The parameter a can be obtained by fitting the test theory to the experimental results using the expression

$$\frac{\Delta c}{c} = \cot\alpha\,\Delta\alpha = -\beta\,(1 + 2a)\cos\theta\,, \tag{16}$$

where $\beta\,(= 0.001237 \pm 0.000002)$ is the COBE Earth's velocity parameter. The comparison between our measurements and the test theory is shown in Fig. 9, where an offset such that $(I_1 - I_2)/(I_1 + I_2) = 0$ at $\theta = 90^\circ$ has been used. The experimental results seem to agree to a $\beta\,(1 + 2a)\cos\theta_A$ signature, and the parameter a extracted from our data is

$$a = -0.4106 \pm 0.0225\,, \tag{17}$$

which differs from the $a = -\frac{1}{2}$ SRT prediction, as well as, some experimental upper limits using the Mössbauer effect [19].

The measurements above shown were made on June of 2006, they were confirmed in a new set of measurements (including a new calibration) in November of 2006 and the result is presented in Fig. 10. The parameter a extracted from this new data is $a = 0.3755 \pm 0.0403$ in agreement with the previous value.

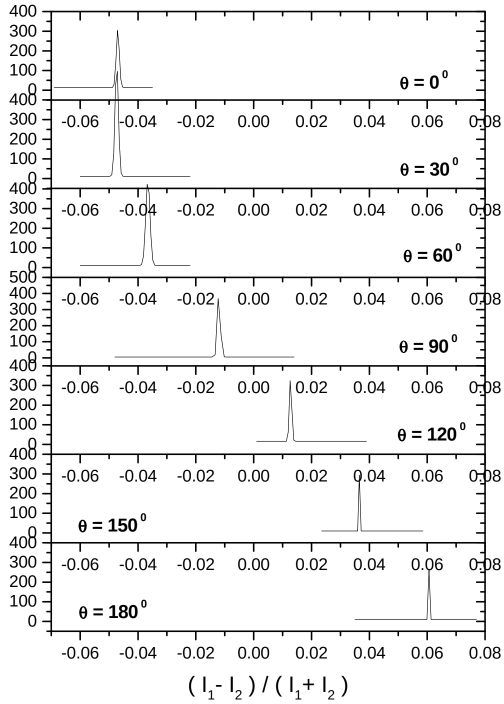

Fig. 8: Counting rate is plotted as a function of $(I_1 - I_2)/(I_1 + I_2)$ at a given laser beam alignment relative to the Earth's velocity vector obtained in June of 2006. The complete set of measurements was made in ten minutes.

5 Conclusions and remarks

The discovery of a dipole anisotropy in the CMBR is interpreted as a Doppler shift produced by the Earth's motion (solar barycenter). An experimental survey has been made in order to test if the Earth's velocity is relevant on light propagation in a quantity of first order. The measurements have been obtained by using a laser diffraction experiment mounted on turntable system. Two optic sensors (segmented photo-diodes) were used for measuring the position of diffracted light spots with a precision better than 0.1 μm. The experiment is easy to reproduce, and it is based on simple optical principles. Two raster search techniques (scan subjected to Earth's rotation and scan subjected to an active rotation) have been used to look for signals of anisotropic light propagation as a function of the laser beam alignment relative to the Earth's motion. The results obtained with both methods show that the course of the rays is affected by the motion of the Earth. They are susceptible of being interpreted by the test theory of Mausouri and Sexl [1] where the one way speed of light is anisotropic by the amount $c(\theta) = c - v\,(1 + 2a)\cos\theta$.

In the scan subjected to Earth's rotation, this pure* dependence is modulated by the variation of the altitude, h, of the CMBR apex and expressed as $\Delta c/c = -\beta\,(1 + 2a) \times \cos\,(\theta_A - \theta_{beam})\cos h$. Despite of the statistical fluctua-

*This meas $\cos\theta = \cos\,(\theta_A - \theta_{beam})$.

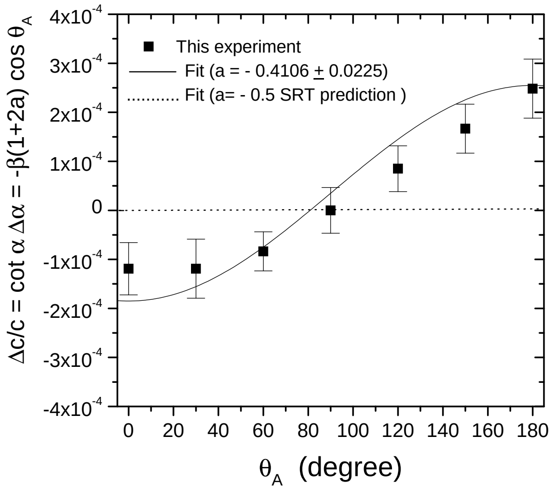

Fig. 9: Comparison between the one-way path light anisotropy $\Delta c/c = -\beta\,(1+2a)\cos\theta$ function, relative to the Earth's velocity vector and the experimental data obtained in June of 2006, for two different values of the fit parameter, $a=-0.4106$ and $a=-\frac{1}{2}$ respectively. Here $\theta_A=0$ represent the laser beam pointing to the CMBR apex on the horizon.

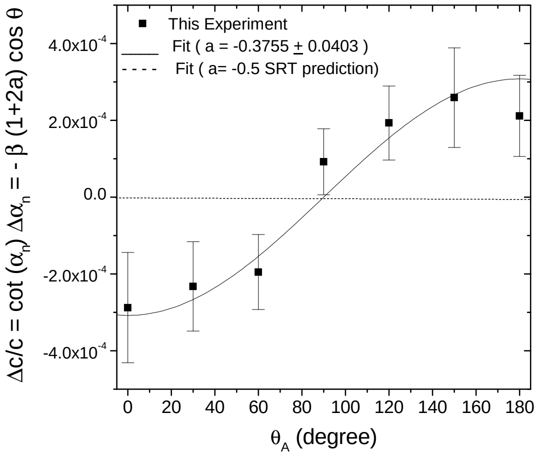

Fig. 10: The same as Fig. 9.

tions (short term noise), the results of these scans are in agreement with the prediction of the "modulated" Mousouri and Sexl test theory (with $a \neq -\frac{1}{2}$). In all cases, built-in a DRIFT-long-term it is possible to see peculiar signatures (see Fig. 3) where the culmination of the CMBR apex on the horizon is between a depression and a peak of the $\Delta c/c$.

In the scan subjected to an active rotation, the altitude of the CMBR apex is always $h=0$, because a complete set of measurements can be done in 10 minutes. The azimuth varies from zero to 180 degree relative to the Earth's velocity direction. Consequently it is free from DRIFT-long-term timing variations. In this case, the Mausouri and Sexl parameter is extract from a fit of the data giving $a=-0.4106\pm0.0225$ (from data obtained on June 2006), and $a=-0.3755\pm0.0403$ (from data obtained on November 2006), and they differs from SRT prediction where $a=-0.5$.

We remark that the CMBR dipole is a frame dependent quantity. According to Scott and Smoot [39], we can thus determine the "absolute rest frame" of the universe as that in which the CMBR dipole would be zero. In short, our results point out that it is not possible to neglect the preferred frame imposed by cosmology.

Acknowledgements

This paper is a memorial tribute to our professor and friend C. M. G. Lattes, who introduced us the non-conventional aspects of relativity. We are thankful to all the members of the laboratory of Thin Films of IF-UFF for implementing the techniques of using segmented photo-diodes. One of the authors (C.E.N) is thankful to R. Wang for the critics and useful comments.

Appendix: The Miller's ether drift direction

According to the theories that incorporate the length contraction principle (Einstein and Lorentz-Poincaré theories), experiments where two orthogonal light paths are compared (two way speed experiments) like the Michelson-Morley interferometer and all variants are incapable of detecting the Earth's motion (no ether drift) due to the length contraction of the interferometer arm parallel to the direction of the Earth's velocity.

Strictly speaking, a null result is expected only in vacuum where the refractive index is $\eta=1$. While, if $\eta\neq 1$ the Fresnel's drag effect in the rest frame of the medium (Σ) cancels the effect of the genuine Lorentz transformation to a moving frame (Σ'). Following the Lorentz transformation equations from Σ' with speed v to Σ, and taking into account the Fresnel relation of the speed of light in the medium $c'=c/\eta$, it is possible to obtain the so called two-way speed of light anisotropy as

$$\bar{c}'(\theta) = \frac{2c'(\theta)\,c'(\theta+\pi)}{c'(\theta)+c'(\theta+\pi)}\,, \tag{A1}$$

and the relative variation as

$$\frac{\Delta c'(\theta)}{c} = -\frac{v^2}{c^2}\left[\frac{\eta^2-1}{\eta^2}\Big(1-\frac{3}{2}\,\sin\theta^2\Big)\right]. \tag{A2}$$

We can see that the two-way speed of light anisotropy is null only in the case $\eta=1$ (vacuum). This prediction is in agreement with modern ether drift experiments in vacuum [36, 37], using two cavity-stabilized lasers and whose value is

$$\frac{\Delta c'}{c} \sim 10^{-15}. \tag{A3}$$

In the gaseous mode, for instance air ($\eta=1.000226$), a maximum value of $\Delta c'/c$ happens in reference axis parallel to Earth's velocity. The tiny fringe shifts, observed in various Michelson-Morley type experiments, represent a non-null effect for the two-way speed of light anisotropy. Dayton Miller [15, 16] was one of the first few in claiming that the Michelson-Morley data and his own data obtained in the mount Wilson are non-null results. Particularly, the mount Wilson data obtained in 1925–1926 is compatible with an obrvable Earth velocity of $v \sim 8.5 \pm 1.5$ km/s, when the data is analyzed on the basis of classical physics. While on the basis of a different calibration including the length contraction (see Eq. A2), the Miller result gives speeds for the movement of the Earth, larger than $v > 300$ km/s.

A review of the Dayton Miller's ether drift experiments made by James DeMeo [38] shows indisputable evidence that data collected by Miller was affected by the sidereal period and this is clear proof of a cosmological ether drift effect. However, the Miller's determination of the velocity direction of the Earth does not coincide with the direction obtained by COBE. The Miller's direction for the Earth velocity is almost perpendicular to the direction established by COBE, observing the CMBR anisotropy. In our opinion, Miller's result has the same problem as the first results of the CMBR survey as is shown in Table 1. For instance, both Miller and Conklin have obtained a non-null result on the two-way path light speed anisotropy and the dipole anisotropy of the CMBR, respectively. Nevertheless, both experiments have failed to obtain the coordinates of the Earth's velocity vector direction correctly.

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