Observation of a significant influence of earth's motion on the velocity of photons in our terrestrial laboratory

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ABSTRACT

The paper reports the positive results obtained with a stationary Michelson-Morley interferometer operating during two consecutive years (2003-2005) in Bogotá, Colombia. After subtracting the environmental periodical effects, there is still a periodic residual that is no longer correlated to the environmental variables. There is, however, a significant correlation between the daily fringe-shift residuals for each month and the velocity of motion of the earth relative to the center of our galaxy at that particular time. This hints to a possible dependence of the velocity of light in our terrestrial laboratory and the velocity of the earth. This result is contrary to the current model for the photon that postulates a constant speed of light. From our data we have calculated the solar velocity consistent with our observations: 500 km/s, right ascension 16h-40 min, declination -75°.

Keywords: speed of light, variable speed of light, speed of light constancy, violation of special relativity postulates, Michelson-Morley experiment, non-null Michelson-Morley experiment, velocity of solar motion, photon velocity, preferred frame photon velocity.

1. INTRODUCTION

Back in 1887 Michelson and Morley (MM) devised an experiment to determine the influence of earth's motion on the fringe-shifts of a rotating interferometer, which eventually became one of the most famous experiments in the history of physics.[1] As is well known, the idea was to determine the difference in the time of travel of photons along two different optical paths of the same length, under the assumption that the effective speed of photons would be different along the two paths due to earth motion. The relevant aspect is the orientation of the interferometer arms relative to the direction of the projection of the velocity of earth on the plane of the apparatus, which cyclically varies as the interferometer turns around. The experiment consisted of 36 turns of the interferometer performed during six sessions in three consecutive days, six turns per session. MM actually observed a monotonous shift of the central fringe during each turn, of the order of half-a-fringe to one fringe during a complete turn of the interferometer; on top of this trend there were small cyclic variations. After their data reduction process, MM concluded that (ref. 1, p. 458): "*the relative velocity of the earth and the aether is probably less than one sixth the earth's orbital velocity, and certainly less than one fourth.*" This means that, according to their interpretation, MM found a motion of earth relative to the preferred frame that certainly was less than 7.5 km/s, and probably less than 5 km/s. These values are no doubt smaller than MM's incorrect expectations –30 km/s, due to orbital motion only, without taking into account the larger solar speed– but certainly they are non-zero.

The usual interpretation of the MM experiment is that the small speed values obtained are due to experimental error, and that the experiment gave a negative result, in the sense that the speed of light is not affected by the motion of the detector. This result slowly led to the notion that it was impossible to determine the motion of earth by optical and by mechanical experiments carried out in our terrestrial laboratory, idea that was elevated by Poincaré to the level of a *Principle*.[2] In 1905 Einstein took the next step, and *postulated* that the speed of light is a constant independent of the motion of the observer, thus predicting a null-result in any MM-type experiment. The current model of a photon propagating at constant speed c independently of the motion of the observer is based on Einstein's theoretical assumption.

It is less known that from 1902 until his retirement, Morley teamed up with Dayton C. Miller to repeat the MM experiment with more sensitive apparatuses having light-paths of 32 m, about three times the path of the 1887 MM

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apparatus.[3] The Morley and Miller observations were made at various epochs from August 1902 to November 1905 with wooden and metal interferometers for a total of 995 turns (i.e., more than 25 times the number of turns in the MM experiment). Morley and Miller reported a small *positive* effect of the motion of earth upon their observations, amounting to a terrestrial speed between 7 and 10 km/s (see ref. 3, p.207); the observations were positive in the sense that the estimated experimental error was smaller than the observed variations. Technology and environmental control were similar in the MM and in the Morley-Miller experiments, so that one may wonder why the scientific community accepted the negative interpretation of the MM experiment, but rejected the positive interpretation of Morley-Miller, based on 25 times more data.

Miller resumed alone the interferometer experiments in 1921. During 1921 and 1924 he made observations at Mount Wilson involving 1,181 turns of the interferometer, during 1922-1924 he took data in Cleveland involving 1,146 turns of the apparatus, and again at Mount Wilson in April 1, August 1, and September 15, 1925 and February 8, 1926 Miller performed 6,402 turns of the interferometer. Once again, Miller observed positive results between 9.3 to 11.2 km/s, and additionally uncovered an annual periodicity in the variation of light-speed.[3] By the time that Miller completed his analysis of data around 1930, Einstein's theory of special relativity (TSR) was well established, and Miller results were received with great skepticism.

Up to this day the majority in the physics community do not take seriously Miller's experiments because they claim that after 1930 the MM experiment has been repeated many times using modern technology, and that the results have always been in accordance with the original MM experiment. A precision is required here. Starting with the Kennedy-Thorndike (KT) experiment,[4] the data reduction process suffered a change. Up to that turning point, the fringe-shifts were analyzed in an effort to detect variations that would lead to a measurement of different velocities of light along the two arms of the interferometer. About that time a consensus emerged that the (presumably) null-results of the MM experiments could be interpreted as empirical proof of the length-contraction predicted by TSR. For instance Robertson[5] declared that (p. 380): "*No significant difference in* [travel] *times was found, and since the original experiment and its repetitions were carried out at various orientations and at various times of the year, we would seem justified in interpreting this null-result as* [a velocity of light independent of direction]". It is noteworthy that in 1949 Robertson completely ignored Miller's results that were published in the very same journal sixteen years before. As a consequence, the analysis of data in KT-type experiments significantly differs from the data reduction in the original MM experiment. Indeed, in a KT-type experiment, the lengths of the arms of the interferometer are assumed to be shorter than the physical value, according to the Lorentz length-contraction; hence, light apparently takes a shorter time to travel along the shortened arms. The observed fringe-shift (null, or otherwise) is then interpreted as a measure of time dilation with respect to the difference of apparent travel times along the two shortened arms. Since the observed data are subject to various manipulations during the interpretation of a KT experiment, it is quite difficult to assert from the data reported in the open literature whether a particular KT experiment exhibited fringe-shift relative to an external frame of reference, say a system of coordinates attached to the galactic center.

However, since the 1990's, there has been a renewed interest in Miller's work; several authors independently consider that Miller's results are real, instead of mere experimental artifacts;[6-10] in particular, Allais uncovered novel annual periodicities in Miller's data.[10] The present writer revised in detail all the MM-type experiments (including Miller's), and uncovered various systematic errors that throw serious doubts on the validity of the experimental protocols and the data reduction procedures.[11,12] Rather than entering sterile controversies on the interpretation and/or the validity of previous experiments, we decided to repeat the MM and Miller experiments, very much as in the initial setups, but introducing some small modern improvements: a laser light, a stationary table, and automatic gathering of the fringe-patterns with a video camera.

This paper describes the results of an experiment carried out at the International Centre of Physics in Bogotá, Colombia, from the end of 2002 to the beginning of 2005. Section 2 describes the experimental setup, section 3 the reduction of observed data, section 4 the comparison of data to a theoretical model, and section 5 the main results: a cyclic variation of the fringe-shifts over 24-hours periods, highly correlated to earth's motion, and determination of the velocity of solar motion, which happens to be consistent with a motion toward the center of our galaxy.

2. DESCRIPTION OF THE BOGOTA EXPERIMENT

The original MM experiment was arranged on a rotating stone table, in a room without control of the environmental variables; there were six punctual sessions of one-hour duration. Miller experiments had a similar arrangement, using even the same stone table, and mercury bath. In both experiments the interference pattern was observed at 22.5º angular intervals. However, for the last and longer series of measurements at Mount Wilson between April 1925 and February 1926, Miller used continuous rotations of the interferometer over the 24-hours of the day, so that he could identify the direction of solar motion from his observations.[3] Sir Oliver Lodge, an acid critic of Miller, noted with irony that *"it is rather surprising that the readings were made by a peripatetic observer, with the instrument in constant and <u>not very slow rotation</u>……… one would have thought that a stoppage of the frame and a reading of the fringes by <u>a seated observer in many azimuths</u>, would have been more satisfactory,"* emphasis added.[13]

To avoid criticisms related to the stability of the interference pattern in a rotating table, we designed our experiment on a stationary table. This design has the additional bonus of generating a very uniform slow rate of revolution (one turn in 24 sidereal hours), as a consequence a one-minute sampling rate of the interference pattern is equivalent to observing the interference pattern at 0.25º angular intervals, which means that the spatial resolution in our experiment is 22.5/0.25 = 90 times better than in the MM and Miller setups.

A Michelson interferometer with two equal arms (2.044 m long), oriented west-east and south-north, was mounted on top of a 13.5 metric ton reinforced concrete table placed on top of vibration dampers; dimensions of table: 4.48 m long, 2.57 m wide, 0.32 m thick, height of table relative to the floor is 0.77 m. The table is placed inside a room with dark walls, and polystyrene thermal insulation in the former windows, located in the ground floor of the International Center of Physics (CIF, Centro Internacional de Física), housed at the campus of National University in Bogotá, Colombia, located at west longitude (ϕ) 74 º-05', north latitude (λ) 4 º-38', and an elevation of 2,556 m above the mean sea level.

We used a stable green light source (Λ= 532 nm) generated by a Nd:YAG diode pumped laser, model DPY 325/425II, manufactured by Adlas (Germany), whose maximum output power is 200 mW. The laser light propagates along the west-east direction, the apparatus being located at the SW corner of the interferometer, on top of a metal supporting plate (35 cm × 35 cm × 5 cm), fastened to the main concrete table. The laser's power supply is placed outside the anti-vibration table. The horizontality of the laser beam was checked with a precision level (0.1 mm in 1 m). The light beam splitter is a prism (equivalent to the semi-transparent mirror in the original MM setup), located on top of another independent metallic supporting board (81 cm x 81 cm x 5cm), attached to the main concrete table. The mirrors are placed on top of small brass tables (10 cm x 10 cm), with legs of adjustable height fastened directly to the concrete table, and placed at the end of each arm.

To decrease effects due to air motion, the optical trajectory is enclosed inside a plastic tubing (approximately 3 cm diameter). To stabilize the air temperature, the tubing is surrounded by polystyrene insulation (approximately 5 cm thick). The beam splitter is also covered with thermal insulation fabricated of the same material. The small tables supporting the mirrors are also surrounded by polystyrene insulation; additionally, there is another layer of thermal insulating material mounted on wood. This second level of protection is intended to decrease effects due to vibration of the mirrors induced by sonic vibration of the air (i.e. to control noise from the street, and from low-flying airplanes). Additionally, there are cloth curtains surrounding the main concrete table along the south and west sides, to avoid noise vibrations from a main street (outside the campus) that is about 100 m away. These measures are not intended to be a controlled environment, but simply to simulate conditions similar to the quiet environment existing a century ago during the original MM and Miller experiments at Cleveland and Mount Wilson.

The interference pattern is recorded with a video camera focused upon a small frost glass screen (6 cm x4 cm) placed about 1 mm in front of the camera lens; the glass screen is 20 cm south from the beam splitter. The camera is oriented along the south-north direction, and is placed on the south border of the concrete table. The video signal is sent by a 1m cable to a computer placed in the same room, but outside the concrete table.

The interference fringe patterns produced in our stationary interferometer were automatically recorded every minute in several-day-long sessions lasting from 24 hours to several weeks during the period from January 2003 to February 2005. We analyzed twenty four series taken around the middle of every month, except for May and June 2004 when no data was taken due to hardware failure. The interference patterns typically depicted 4 or 5 black fringes that slowly moved back and forth across the computer screen, exhibiting 24-hour cycles.

3. ANALYSIS OF DATA

For the analysis, the images were converted to numerical scales of brightness, where dark fringes yield the minima, and bright fringes the maxima. The evolution of the pixel position of a given minimum relative to the pixel position of the same minimum at time zero represents the relative pixel-shift of the corresponding dark fringe. Since interference fringes do not exactly have the same width, the computer program automatically selected from two to four sharp minima in each image, and obtained an average pixel-shift. From the latter, using the average fringe-width for that image, the average fringe-shift was calculated. In all, 1,440 average fringe-shift data were obtained every day.

As already mentioned in a previous section, the room was not air conditioned, so that there were temperature variations during the day of the order of 0.2ºC, and occasionally 0.4ºC. Of course, there also existed uncontrolled humidity and pressure variations. The effect of ambient temperature as a significant source of experimental error was already mentioned by Michelson in his 1881 experiment,[14] but was ignored in his analysis of the 1887 MM experiment.[1] Miller also recognized the importance of temperature and built apparatuses in different materials, to check for the effect of different coefficients of thermal expansion; additionally, Miller verified for the effect of temperature variations in his laboratory, and checked whether it was possible to reproduce the periodical variations of the fringe-shifts with temperature gradients in the interferometer room.[3] Even the recent Stanford experiment —carried out at a temperature close to absolute zero with an extremely tight control of temperature variation, within 10^{-5} K— attributed the observed periodical frequency-shifts to mechanical effects induced by temperature.[15] Our experiment was mounted upon a concrete table that has a low coefficient of thermal expansion, but the supports for the mirrors and the beam splitter, fixed directly to the concrete, were fabricated in brass. Hence, thermal effects due to expansion of the metallic parts must be expected. However, a theoretical estimate for the required temperature correction is out of question. On the other hand, the effect of pressure and humidity upon the empirical observations was mentioned neither by MM, nor by Miller, and its effects are even harder to estimate. In view of such limitation, it was decided to implement stochastic corrections for the effect upon fringe-shifts of the three environmental parameters: relative humidity (H), pressure (P), and temperature (T).

Temperature and humidity were logged at 3 to 5 minute intervals; from this information, we obtained the stochastic correlation (i.e. the linear regression) between T and the observed fringe-shifts. A similar procedure was used to get the stochastic correlation for H. Microbarometers to read the absolute atmospheric pressure in the experimental room were not available, so that synthetic pressure curves were constructed for every session based on a 20-year record taken by a meteorological station in the same campus.[16] The stochastic correlation between the synthetic pressure curves P and the observed fringe-shifts was also obtained. Using the stochastic correlations for T, H and P, the effect of these variables was subtracted from each average fringe-shift datum. The resulting corrected series depict negligible correlations with each one of the environmental variables,[17] which means that we were successful in eliminating the environmental effects upon the observed fringe-shifts.

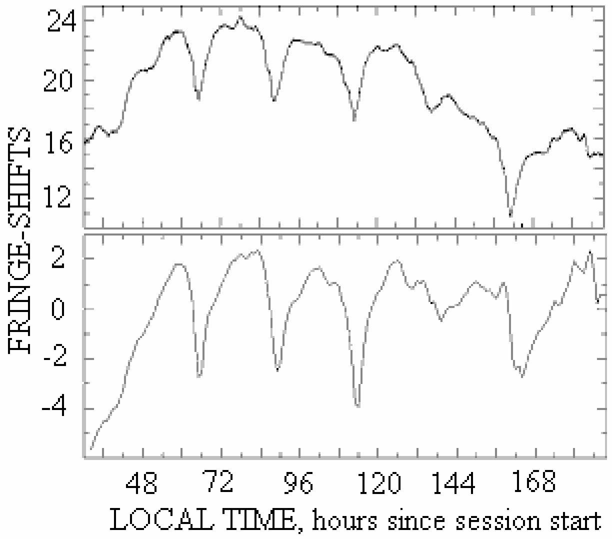

Fig. 1. Fringe-shift versus local time. Above: raw data as observed in the period 2-8 September, 2003. Below: residual fringe-shifts after correcting for ambient humidity and pressure. A correction for temperature variation was applied afterwards. The corrected residual curve exhibits well defined minima with a periodicity similar to the original curve, and a significantly smaller amplitude.

As shown in figure 1, the corrected series has an amplitude significantly smaller than the uncorrected observations, but still exhibits a remarkable 24-hour periodicity, that, it must be stressed, is not correlated to the environmental variables T, H, and P. The large correction provided by the stochastic approach eliminated the environmental effects, without entering into the details of the physical mechanisms that produced fringe-shifts via the variations of T, H and P.

Corrected curves similar to figure 1 were obtained for all other series in our experiment, that typically consisted of observations several-day long. Each long series was collapsed to an average series lasting 24 sidereal hours, as shown in figure 2. The consistent existence of periodical daily and annual effects on the observed fringe-shifts (after correction for environmental variables) hints to the existence of unexplained aspects in the current photon model.

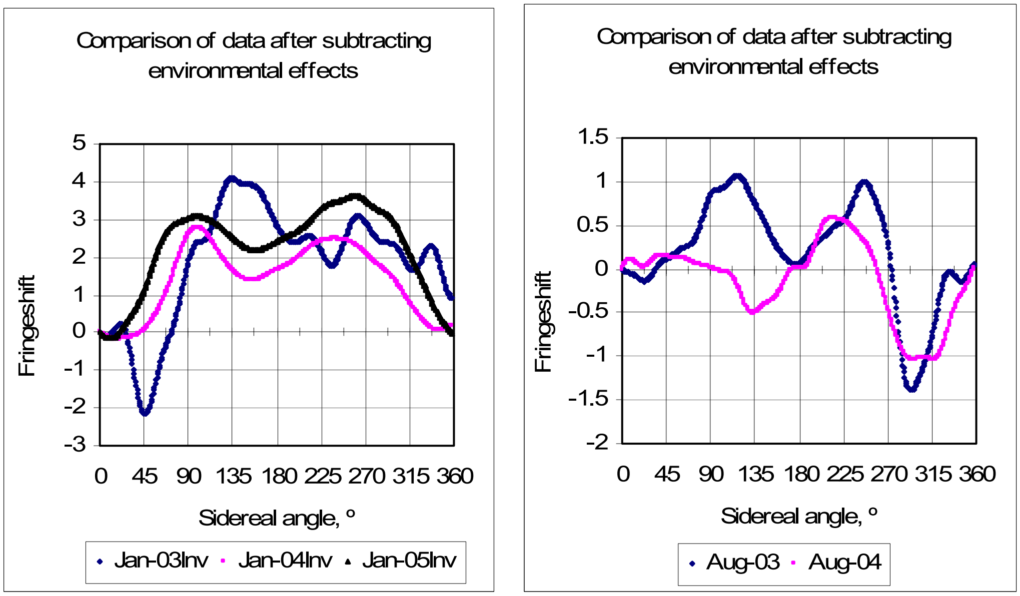

Fig. 2. Average 24-hr series used for the final analysis. The series correspond to different years, and exhibit inter-annual consistency. Note that the shape and amplitude depends of the month.

4. COMPARISON TO A THEORETICAL MODEL

To determine the correlation between the observed fringe-shifts and earth's motion we proceeded as follows. The velocity of earth's center of mass $\mathbf{V}(t)$ relative to an external frame of reference, say a system of coordinates attached to the center of our galaxy, is the vector addition of $\mathbf{V}_{\mathrm{O}}(t)$, the orbital motion of the center of mass of earth around the sun, plus $\mathbf{V}_S$, the velocity of our sun relative to the same galactic system:

$$\mathbf{V}(t) = \mathbf{V}_S + \mathbf{V}_O(t) \tag{1}$$

Of course, the solar velocity is the vector addition of the sun's orbital motion around the center of the galaxy, plus any additional motion of the sun relative to the galactic center. For the observational periods of a few years relevant to this paper, $\mathbf{V}_S$ is assumed to be constant. For the calculations, we used celestial equatorial coordinates and assumed that the earth moves circularly on the plane of the ecliptic, with an orbital period of 365.25 solar days, and a tangential speed V_O of 29.8 km/s. With this approximate model it is simple to calculate $\mathbf{V}_P(t)$, the projection of earth's center of mass velocity $\mathbf{V}(t)$ upon the plane of the interferometer for different months of the year and times of the day,[17,18] provided that the solar velocity $\mathbf{V}_S$ be known. We carried out calculations for different values of $\mathbf{V}_S$ in the literature, and found a significant dependence of the shape of the daily curve of $\mathbf{V}_P(t)$ with the direction of solar motion, while the speed of solar motion determines the amplitude of the $\mathbf{V}_P(t)$ curve.[18]

As a first step towards quantification of our findings, we calculated the correlation between the corrected fringe-shifts (as in figure 2) and the average $\mathbf{V}_P(t)$ curve, calculated over the 24 months of our experiment. Using a solar speed of 370 km/s, as in the COBE experiment, we determined the direction of solar motion that maximizes the correlation between the observed fringe-shifts and the average $\mathbf{V}_P(t)$ curve. A highly significant correlation was found.[19]

The final step is to produce a model for the fringe-shifts to be expected in the interferometer at the location of the experiment. It was assumed that light propagates with constant speed *c*, independent of direction, with respect to a frame of reference attached to the center of mass of our galactic system. The effective speed of light in the terrestrial system depends of the direction and magnitude of earth's motion, according to Galilean velocity addition. The procedure to calculate the expected fringe-shifts F_E is straightforward.[18] Once again, the shape of the daily variation of the F_E curve strongly depends upon the direction of solar motion. Figure 3 shows typical examples of predicted fringe-shift curves (F_E-curves).

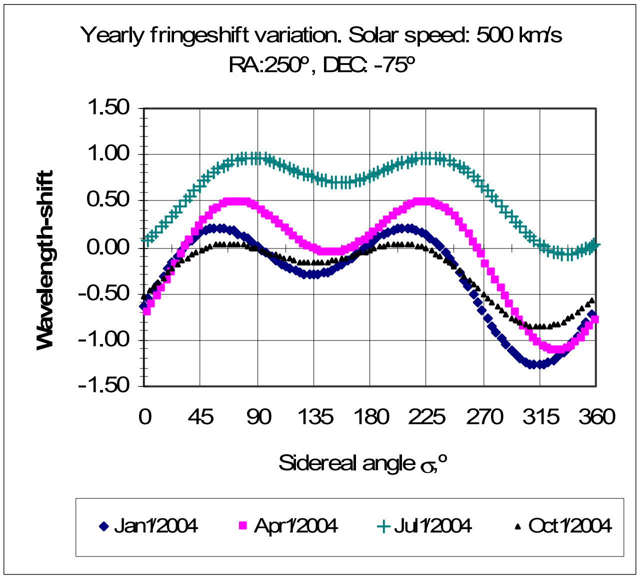

Fig. 3. Expected daily fringe-shifts for the interferometer used in our experiment at the latitude of Bogotá, for different months during the year 2004, for a solar speed of 500 km/s in the direction RA 250º, declination -75º. Note the variations in shape during the year (position of the minimum), and the variation in amplitude of the curves

Using a solar speed of 500 km/s which is consistent with amplitude of the observed fringe-shift curves (as in Figure 2), we determined the direction of solar motion that maximizes the correlation between the observed fringe-shifts and the average of the 24 monthly expected F_E-curves. Figures 4 and 5 demonstrate the optimization procedure that allows identification of solar declination, and right ascension. In short, for each month the series of corrected fringe-shift observations was correlated to the series of predicted fringe-shift for a given direction of solar motion; the average correlation over the 24 monthly series was calculated for each solar motion direction. Hence, we obtained the direction of solar motion that maximizes the correlation between corrected observations and the theoretical calculation. A solar velocity of 500 km/s in the direction of right ascension 250º (i.e. 16h-40 min) and south declination -75º leads to an average correlation of 0.55 (standard deviation of the correlation 0.29) between predicted and observed fringe-shifts.

5. CONCLUDING REMARKS

Our interferometric observations over 24 months consistently exhibited diurnal variations correlated with earth motion. This means that the local speed of light depends of the velocity of the observer, finding that runs contrary to the currently accepted model for the photon.

It must be stressed that our corrected daily variations are not significantly correlated to the local environmental variables, so that they are due to other factors. The shape of our daily fringe-shifts have the same qualitative appearance as those obtained in other recent experiments,[15] that were interpreted as thermal environmental effects. However, we do not share that interpretation.

The solar velocity that maximizes the average correlation between our observations and our predictions is 500 km/s within right ascension 250º (i.e. 16h-40 min) and south declination -75º. This leads to an average correlation of 0.55 (standard deviation of the correlation 0.29) between predicted and observed fringe-shifts. Recalling that the center of our galaxy is located at RA 17h-45min, declination -29º00', the solar velocity found in this work is consistent with a rotational motion of the sun around the center of the galaxy plus a free fall of the solar system towards the galactic center.

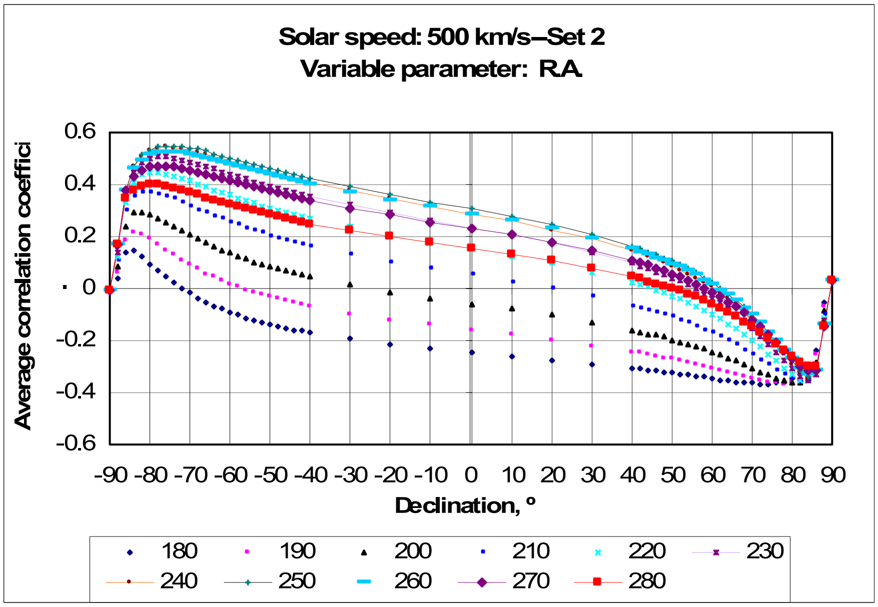

Fig. 4. Effect of declination of solar motion on the correlation between the observed and the predicted fringe-shifts, for different values of the right ascension (RA). The maximum correlation consistently attains around 75º. The maximum maximorum obtains for RA = 250º.

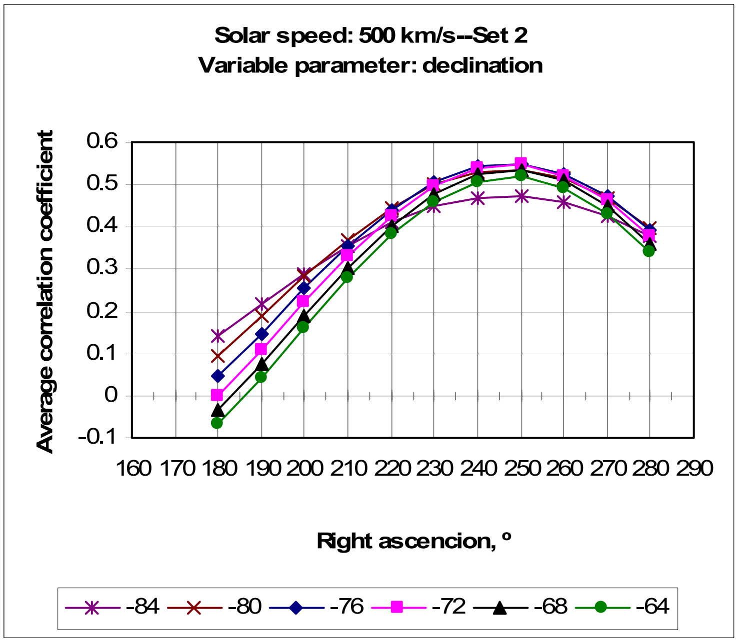

Fig. 5. Effect of right ascension of solar motion on the correlation between the observed and the predicted fringe-shifts, for different values of the declination. The maximum correlation consistently attains around RA=250º. The largest maximum obtains for declination around -75º.

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