Motion toward the Great Attractor
from an ether-drift experiment

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Abstract

Since the end of 80's, the region of sky of galactic coordinates ($l \sim 309^o$, $b \sim 18^o$), corresponding to a declination $\gamma \sim -44^o$ and right ascension $\alpha \sim 202^o$, usually denoted as the "Great Attractor", is known to control the overall galaxy flow in our local Universe. In this sense, this direction might represent a natural candidate to characterize a hypothetical Earth's "absolute motion". Our analysis of the extensive ether-drift observations recently reported by an experimental group in Berlin provides values of α and γ that coincide almost exactly with those of the Great Attractor and *not* with the values $\gamma \sim -6^o$ and $\alpha \sim 168^o$ obtained from a dipole fit to the anisotropy of the CMB. This supports in a new fashion the existence of a discrepancy between the observed motion of the Local Group and the direction obtained from the CMB dipole.

1. Introduction

Since the end of 80's, a region of the sky in the direction of the Centaurus cluster, the so called "Great Attractor", at galactic coordinates ($l \sim 309^o$, $b \sim 18^o$), corresponding to a declination $\gamma \sim -44^o$ and right ascension $\alpha \sim 202^o$, is known to play an important role in describing the deviations of galaxies from a pure Hubble flow in our local Universe, [1, 2, 3, 4, 5, 6]. In this sense, the Great Attractor, marking a preferred direction in space, might represent a natural candidate to characterize a hypothetical Earth's "absolute motion".

On the other hand, since the discovery of an anisotropy in the cosmic microwave background (CMB), it has been generally accepted that the kinematical parameters for such an absolute motion should coincide with those deduced from a dipole fit to the COBE data [7]. In this context, one predicts a velocity of the Solar System $v \sim 370$ km/s, an average declination angle $\gamma \sim -6^o$ and a right ascension $\alpha \sim 168^o$. These values have usually been adopted in the interpretation of the data from the ether-drift experiments in a laboratory.

However, the latest ether-drift experiments, combining the possibility of active rotations of the apparatus with the use of cryogenic optical resonators [8, 9, 10], have reached such a high precision ($\mathcal{O}(10^{-16})$ in the relative frequency shifts) to require a fully model-independent analysis of the data. In fact, the physical nature of a hypothetical preferred frame is still unknown. Therefore, assuming from the very beginning one particular set of values for (v, γ, α) one might introduce uncontrolled errors in the interpretation of the experimental results.

This is even more true noticing that a fully model-independent analysis [11] of the extensive ether-drift observations reported by Herrmann et al. in Ref.[9] provides an average (absolute) value of the declination angle $|\gamma| \sim 43^o \pm 3^o$ that would rather favour an alternative of the type represented by the Great Attractor. In this paper we'll further extend the analysis of Ref.[11] that, being limited to a restricted set of observables, could not determine the value of α and the sign of γ. As we shall illustrate, our new results, after inclusion of other observable quantities from Ref.[9], provide values of α and γ that are in remarkable agreement with those of the Great Attractor. For this reason, our results, while providing the first modern evidence for an ether drift from a laboratory experiment, support the indications obtained from the observed motion of galaxies.

The plane of the paper is as follows. In Sect.2 we shall report the relevant formalism used in the analysis of the ether-drift experiments and the basic experimental data of Ref.[9]. In Sect.3 we shall present our analysis of these data while in Sect.4 we shall summarize our

results and present our conclusions.

2. General formalism and experimental data

The starting point for our analysis is the expression for the relative frequency shift of the two optical resonators at a given time t. This is expressed as [9]

$$\frac{\delta\nu(t)}{\nu_0} = S(t)\sin 2\omega_{\rm rot}t + C(t)\cos 2\omega_{\rm rot}t \tag{1}$$

where $\omega_{\rm rot}$ is the rotation frequency of one resonator with respect to the other which is kept fixed in the laboratory and oriented north-south. The Fourier expansions of the two amplitudes $S(t)$ and $C(t)$ are predicted to be

$$S(t) = S_{s1}\sin\tau + S_{c1}\cos\tau + S_{s2}\sin(2\tau) + S_{c2}\cos(2\tau) \tag{2}$$

$$C(t) = C_0 + C_{s1}\sin\tau + C_{c1}\cos\tau + C_{s2}\sin(2\tau) + C_{c2}\cos(2\tau) \tag{3}$$

where $\tau = \omega_{\rm sid}t$ is the sidereal time of the observation in degrees and $\omega_{\rm sid} \sim \frac{2\pi}{23^h 56'}$.

Introducing the colatitude of the laboratory $\chi (\sim 37.5^o$ for Berlin), one finds the expressions reported in Table I of Ref. [9],

$$C_0 = -K\frac{\sin^2\chi}{8}(3\cos 2\gamma - 1), \tag{4}$$

$$C_{s1} = \frac{1}{4}K\sin 2\gamma\sin\alpha\sin 2\chi, \tag{5}$$

$$C_{c1} = \frac{1}{4}K\sin 2\gamma\cos\alpha\sin 2\chi, \tag{6}$$

$$C_{s2} = \frac{1}{4}K\cos^2\gamma\sin 2\alpha(1+\cos^2\chi), \tag{7}$$

$$C_{c2} = \frac{1}{4}K\cos^2\gamma\cos 2\alpha(1+\cos^2\chi) \tag{8}$$

where

$$K = (1/2 - \beta + \delta)\frac{v^2}{c^2} \tag{9}$$

and $(1/2 - \beta + \delta)$ indicates the Robertson-Mansouri-Sexl [12, 13] (RMS) anisotropy parameter. The corresponding $S-$quantities are also given by $S_{s1} = -C_{c1}/\cos\chi$, $S_{c1} = C_{s1}/\cos\chi$, $S_{s2} = -\frac{2\cos\chi}{1+\cos^2\chi}C_{c2}$ and $S_{c2} = \frac{2\cos\chi}{1+\cos^2\chi}C_{s2}$. It might be interesting that these relations can also be derived from an old paper by Nassau and Morse, published in the Astrophysical Journal about eighty years ago (see Eqs.(20-24) of Ref.[14]).

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Table 1: The experimental values of the $C-$coefficients for the 15 observation periods of Ref.[9].

Observation i	$C_{s1}[\text{x}10^{-16}]$	$C_{c1}[\text{x}10^{-16}]$	$C_{s2}[\text{x}10^{-16}]$	$C_{c2}[\text{x}10^{-16}]$
1	-2.7 ± 4.5	5.3 ± 4.8	-3.2 ± 4.7	1.2 ± 4.2
2	-18.6 ± 6.5	8.9 ± 6.4	-11.4 ± 6.5	-5.0 ± 6.4
3	-0.7 ± 3.9	5.3 ± 3.6	5.0 ± 3.5	1.6 ± 3.8
4	6.1 ± 4.6	0.0 ± 4.8	-8.1 ± 4.8	-4.0 ± 4.6
5	2.0 ± 8.6	1.3 ± 7.7	16.1 ± 8.0	-3.3 ± 7.2
6	3.0 ± 5.8	4.6 ± 5.9	8.6 ± 5.9	-6.9 ± 5.9
7	0.0 ± 5.4	-9.5 ± 5.7	-5.5 ± 5.6	-3.5 ± 5.4
8	-1.1 ± 8.1	11.0 ± 7.9	0.9 ± 8.3	18.6 ± 7.9
9	8.6 ± 6.5	2.7 ± 6.7	4.3 ± 6.5	-12.4 ± 6.4
10	-4.8 ± 4.8	-5.1 ± 4.8	3.8 ± 4.7	-5.2 ± 4.7
11	5.7 ± 3.2	3.0 ± 3.4	-6.3 ± 3.2	0.0 ± 3.5
12	4.8 ± 8.0	0.0 ± 7.0	0.0 ± 7.6	1.5 ± 7.7
13	3.0 ± 4.3	-5.9 ± 4.3	-2.1 ± 4.4	14.1 ± 4.3
14	-4.5 ± 4.4	-2.3 ± 4.5	4.1 ± 4.3	3.2 ± 4.3
15	0.0 ± 3.6	4.6 ± 3.4	0.6 ± 3.2	4.9 ± 3.3

Notice a critical detail for the separation of the signal in its elementary components. A small mismatch in the definition of the sidereal time, say $\tau^{\text{true}} = \tau + \Delta\tau$, induces a rotation of the various parameter pairs of angles $\Delta\tau$ and $2\Delta\tau$ with a corresponding re-definition of the right ascension $\alpha_{\text{true}} = \alpha + \Delta\tau$.

The experimental data reported in Ref.[9] were obtained during 15 short-period observations performed from December 2004 to April 2005. As suggested by the same authors, it is safer to concentrate on the observed time modulation of the signal, i.e. on the quantities $C_{s1}, C_{c1}, C_{s2}, C_{c2}$ and on their S-counterparts. In fact, the constant components $\bar{C} = C_0$ and $\bar{S} \equiv S_0$ are most likely affected by spurious systematic effects such as thermal drift (see also the discussion in Ref. [8]).

The individual determinations of the various parameters, for each of the 15 short-period observations, as extracted from Fig.3 of Ref.[9], are reported in Table 1 and Table 2.

Table 2: The experimental values of the $S-$coefficients for the 15 observation periods of Ref.[9].

Observation i	$S_{s1}[\text{x}10^{-16}]$	$S_{c1}[\text{x}10^{-16}]$	$S_{s2}[\text{x}10^{-16}]$	$S_{c2}[\text{x}10^{-16}]$
1	11.2 ± 4.7	11.9 ± 4.9	1.8 ± 4.9	0.8 ± 4.5
2	1.8 ± 6.5	-4.3 ± 6.5	6.4 ± 6.4	1.8 ± 6.4
3	-3.3 ± 3.8	2.9 ± 3.8	-5.9 ± 3.8	4.6 ± 4.0
4	12.7 ± 5.1	14.3 ± 5.5	-1.9 ± 5.3	-3.3 ± 5.1
5	4.7 ± 8.4	-6.9 ± 7.3	-1.8 ± 8.0	-7.8 ± 7.0
6	5.2 ± 5.8	-3.0 ± 5.9	7.1 ± 5.9	-5.9 ± 5.8
7	11.1 ± 5.3	-13.4 ± 5.4	-4.5 ± 5.5	-9.8 ± 5.5
8	-12.1 ± 8.9	0.0 ± 8.8	-3.1 ± 9.0	1.4 ± 8.9
9	-4.8 ± 6.3	6.5 ± 6.4	-8.1 ± 6.3	3.5 ± 6.5
10	9.8 ± 5.0	4.8 ± 5.0	1.9 ± 5.0	-9.2 ± 4.8
11	0.0 ± 3.2	-3.9 ± 3.6	1.0 ± 3.1	-2.2 ± 3.4
12	-12.7 ± 7.7	8.5 ± 6.8	-8.3 ± 7.2	-7.1 ± 7.4
13	-7.9 ± 4.7	-4.3 ± 4.8	-1.9 ± 4.8	-6.2 ± 4.7
14	16.1 ± 4.9	12.0 ± 5.2	2.9 ± 4.9	-9.6 ± 4.8
15	13.9 ± 3.9	-7.0 ± 3.4	-3.3 ± 3.5	3.0 ± 3.6

3. Analysis of the data

The analysis of Ref.[11] was restricted to the combinations

$$C_{11} \equiv \sqrt{C_{s1}^2 + C_{c1}^2} \tag{10}$$

$$C_{22} \equiv \sqrt{C_{s2}^2 + C_{c2}^2} \tag{11}$$

$$S_{11} \equiv \sqrt{S_{s1}^2 + S_{c1}^2} \tag{12}$$

$$S_{22} \equiv \sqrt{S_{s2}^2 + S_{c2}^2} \tag{13}$$

This was useful to reduce the model dependence in the analysis of the data. In this way, in fact, the right ascension α and any possible uncertainty related to the definition of the sidereal time drop out from the theoretical predictions that will only depend on $|\gamma|$, and the

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Table 3: The experimental values of the combinations of $C-$ and $S-$ coefficients defined in Eqs.(10)-(13) as obtained from our Table 1 and Table 2.

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Observation i	$C_{11}[\times 10^{-16}]$	$C_{22}[\times 10^{-16}]$	$S_{11}[\times 10^{-16}]$	$S_{22}[\times 10^{-16}]$
1	5.9 ± 4.7	3.5 ± 4.6	16.3 ± 4.8	2.0 ± 4.9
2	20.6 ± 6.4	12.5 ± 6.5	4.6 ± 6.5	6.6 ± 6.4
3	5.3 ± 3.6	5.3 ± 3.6	4.4 ± 3.8	7.5 ± 3.8
4	6.1 ± 4.6	9.0 ± 4.8	19.1 ± 5.3	3.8 ± 5.1
5	2.4 ± 8.4	16.5 ± 8.0	8.4 ± 7.7	8.0 ± 7.1
6	5.5 ± 5.9	11.0 ± 5.9	6.0 ± 5.9	9.2 ± 5.9
7	9.5 ± 5.7	6.5 ± 5.5	17.4 ± 5.4	10.7 ± 5.5
8	11.0 ± 7.9	18.7 ± 7.9	12.1 ± 8.9	3.4 ± 9.0
9	9.1 ± 6.5	13.1 ± 6.4	8.1 ± 6.4	8.8 ± 6.4
10	7.0 ± 4.8	6.5 ± 4.7	10.9 ± 5.0	9.4 ± 4.8
11	6.4 ± 3.1	6.3 ± 3.2	3.9 ± 3.6	2.4 ± 3.4
12	4.8 ± 8.0	1.5 ± 7.7	15.3 ± 7.4	10.9 ± 7.3
13	6.6 ± 4.3	14.3 ± 4.3	9.0 ± 4.7	6.5 ± 4.7
14	5.1 ± 4.5	5.2 ± 4.3	20.0 ± 5.0	10.0 ± 4.8
15	4.6 ± 3.4	5.0 ± 3.3	15.6 ± 3.8	4.4 ± 3.5

overall normalization $|K|$. The relevant numbers for these auxiliary quantities can be found in Table 3. Thus, we obtain the relations

$$C_{11} = \frac{1}{4}|K|\sin 2|\gamma|\sin 2\chi \qquad\qquad C_{22} = \frac{1}{4}|K|\cos^2\gamma(1+\cos^2\chi). \qquad (14)$$

The corresponding S-coefficients are also predicted as $S_{11} = C_{11}/\cos\chi$ and $S_{22} = \frac{2\cos\chi}{1+\cos^2\chi}C_{22}$. Using the weighted averages of the values in Table 3 for these coefficients

$$\langle C_{11}\rangle = (6.7 \pm 1.2)\cdot 10^{-16} \qquad \langle C_{22}\rangle = (7.6 \pm 1.2)\cdot 10^{-16} \qquad (15)$$

$$\langle S_{11}\rangle = (11.0 \pm 1.3)\cdot 10^{-16} \qquad \langle S_{22}\rangle = (6.3 \pm 1.3)\cdot 10^{-16} \qquad (16)$$

one gets [11] an average declination

$$|\gamma| \sim 43^o \pm 3^o \qquad (17)$$

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Table 4: The absolute value of the declination angle $|\gamma|$ and the normalization factor $|K|$, obtained from the data in Table 3 for groups of three observation periods.

Observations	$|\gamma|$ [degrees]	$|K|$[x10^{-16}]
(1-3)	46^{+7}_{-9}	29 ± 6
(4-6)	32^{+7}_{-9}	33 ± 7
(7-9)	39^{+6}_{-8}	43 ± 7
(10-12)	42^{+7}_{-9}	27 ± 5
(13-15)	41^{+6}_{-7}	36 ± 5

and an average normalization

$$|K| \sim (33 \pm 3) \cdot 10^{-16} \tag{18}$$

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To check the regularity of the data, one can also extract the average declination angle from various groups of observation periods. Packing the data in groups of three observations, one gets the results shown in Table 4. Notice the remarkable consistency among the various sets of data.

To extend the above analysis and get information on α and the sign of γ, we shall now try to re-construct the full amplitudes $S(t)$ and $C(t)$ of Eq.(1) or, more precisely, their variable parts $S(t) - S_0$ and $C(t) - C_0$. In this way, in fact, possible problems related to the deconvolution of the signal in its elementary components drop out. To this end, we shall use Eqs.(2) and (3)to generate a suitable signal where:

i) the individual $C-$ and $S-$ coefficients are fixed to their experimental values of Ref.[9] reported in our Tables 1 and 2

ii) the average times for the 15 individual observation periods are taken from Fig.3 of Ref.[9]. Once the figure is reproduced on the screen, these time coordinates can be extracted to a good accuracy from the number of pixels Npixel of the data points. In this way we get (in days since 1/1/2000) $t = \frac{(\text{Npixel} - 475)}{1.7} + 1900$ where Npixel= 317, 344, 351, 365, 377, 400, 412, 423, 427, 437, 470, 493, 496, 503, 507 for the 15 observation periods.

The resulting data sets are reported in Table 5.

Table 5: The re-constructed amplitudes obtained following the steps i) and ii) described in the text.

Observation i	$(C(t_i) - C_0)[\text{x}10^{-16}]$	$(S(t_i) - S_0)[\text{x}10^{-16}]$
1	2.7 ± 6.8	17.0 ± 6.9
2	19.0 ± 9.2	-7.6 ± 9.2
3	9.3 ± 5.5	0.9 ± 5.5
4	13.3 ± 6.8	12.1 ± 7.5
5	-13.6 ± 12.2	11.7 ± 11.3
6	-7.7 ± 8.3	-13.3 ± 8.3
7	-7.6 ± 8.1	-20.7 ± 7.8
8	-2.4 ± 11.7	-3.0 ± 12.6
9	3.1 ± 9.5	3.4 ± 9.1
10	12.0 ± 6.8	-6.3 ± 7.1
11	0.6 ± 4.9	-4.5 ± 4.9
12	-1.9 ± 11.3	-11.1 ± 10.5
13	4.1 ± 6.2	-0.2 ± 6.8
14	2.9 ± 6.4	-18.8 ± 7.0
15	-1.4 ± 5.0	-14.7 ± 5.1

We can now try to fit the values of Table 5 to the theoretical predictions ($\mu = \pm 1$)

$$C(t) - C_0 = \mu|K|(\frac{\sin 2\chi \sin 2\gamma \cos(\alpha - \tau)}{4} + \frac{(1 + \cos^2 \chi) \cos^2 \gamma \cos 2(\alpha - \tau)}{4}) \qquad (19)$$

$$S(t) - S_0 = \mu|K|(\frac{\sin \chi \sin 2\gamma \sin(\alpha - \tau)}{2} + \frac{\cos \chi \cos^2 \gamma \sin 2(\alpha - \tau)}{2}) \qquad (20)$$

to obtain information on $|K|$, α and the sign of γ.

Before presenting the results, we observe that the structure of the problem is such that one should first suitably constrain the fit. In fact, all together there are 16 possible choices arising from the 2 possible signs of μ, the 2 possible signs of γ and the 4 possible choices of α ($\sin \alpha = \pm|\sin \alpha|$ and $\cos \alpha = \pm|\cos \alpha|$). Considering all possibilities we have found that the various fits to the values of $C(t) - C_0$ do not provide any definite information. In fact, in all cases the quality of the chi-square is very close to that of the "null result" defined by $|K| = 0$ and the parameters cannot be constrained in any meaningful way.

Considering the values of $S(t) - S_0$ the situation is different. In fact the fit routine (MINUIT) finds in this case two configurations whose chi-square is definitely lower than the chi-square of the "null-result" (~ 38). The existence of multiple solutions had to be expected since the $C-$ (and $S-$) coefficients of Eqs.(4)-(8) are unchanged under the simultaneous replacements $\gamma \to -\gamma$ and $\alpha \to \alpha + \pi$. The absolute minimum, whose chi-square is ~ 16 (for 12 degrees of freedom), corresponds to $\mu = -1$ with the physical parameters being in the following ranges

$$|K| = (39 \pm 15) \cdot 10^{-16} \qquad \gamma = -30^{o}{}^{+16^{o}}_{-22^{o}} \qquad \alpha = 204^{o} \pm 12^{o} \qquad (21)$$

As one can see, the values for $|K|$ and $|\gamma|$ from our reconstructed amplitude for $S(t) - S_0$ are in good agreement with Eqs.(17) and (18), and with those reported in our Table 4, that were deduced from the average values of the positive-definite coefficients C_{11}, C_{22}, S_{11} and S_{22}.

We have no explanation for the different behaviour obtained using our re-constructions of $C(t) - C_0$ and $S(t) - S_0$. Perhaps this might be due to the asymmetric experimental set-up where only one cavity is rotated or, since the 15 data sets, each spanning from 24 hours to 100 hours in length, have been summarized into just a single point, the inherent inexactness in our re-construction affects differently the two sets of data. On the other hand, the indications we have obtained from $S(t) - S_0$ are so consistent with the previous results of Ref.[11], and with those reported in our Table 4, to suggest that they should still persist in a more refined analysis using the full raw data or after inclusion of new observations.

4. Summary and conclusions

The possibility of a large concentration of matter in the region of sky $\gamma \sim -44^{o}$ and $\alpha \sim 202^{o}$, the "Great Attractor", was proposed to describe the deviations of galaxies from a pure Hubble flow [1]-[4] in our local Universe. Its inclusion in multi-attractor models, see e.g. Ref.[15], provides a successful representation of the observed velocity field for large samples of galaxies, such as the ~ 3400 ones contained in the MARK III catalog [18].

The resulting motion of the Local Group is known to exhibit some discrepancy with respect to the direction obtained from a dipole fit to the anisotropy of the CMB. The value of the misalignment angle is both sample- and model dependent. For instance in the multi-attractor model of Ref.[15] it ranges from 11° to 49° with a typical value of $\sim 30^{o}$.

In principle, the existence of this discrepancy might also show up in ether-drift experiments. Up to now, these have been analyzed assuming that the kinematical parameters of a

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hypothetical Earth's "absolute motion" should coincide with those extracted from a dipole fit to the COBE data. Rather, in our opinion, one should leave out the angular variables γ and α and the quantity $K = (1/2 - \beta + \delta)\frac{v^2}{c^2}$ as free parameters and check the overall agreement with the data.

In this paper, using the extensive ether-drift observations reported by Herrmann et al. [9], we have obtained evidence for an angular pair that sizeably differs from the values $\alpha \sim 168^o$ and $\gamma \sim -6^o$ obtained from a dipole fit to the anisotropy of the CMB. The motion we have detected points toward $\gamma = -30^{o+16^o}_{-22^o}$ and $\alpha = 204^o \pm 12^o$ and the central values coincide with those of the Shapley supercluster [16]. However, the error in γ is large. Therefore, we could use the result of Ref.[11] $|\gamma| = 43^o \pm 3^o$, to further sharpen our estimate. In this way, the angular parameters of the Earth's motion coincide almost exactly with those of the core of the Great Attractor ($\gamma \sim -44^o$ and $\alpha \sim 202^o$).

Actually, the agreement with the position of the Great Attractor is even too good. In fact, an ether-drift observation on the Earth contains, in principle, the effect of the solar motion ('sm') relatively to the centroid of the Local Group. For instance, using for this motion the values of Ref.[17], $v_{\rm sm} \sim (306 \pm 18)$ km/s, $\gamma_{\rm sm} \sim (51^o \pm 6^o)$, $\alpha_{\rm sm} \sim (332^o \pm 11^o)$, and using for the peculiar motion of the Local Group the values of Ref.[15] obtained fitting the multi-attractor parameters to the full MARK III catalog, namely $V_{\rm LG} \sim 488 \pm 80$ km/s (in the CMB frame), $\gamma_{\rm LG} \sim -50^o \pm 8^o$ and $\alpha_{\rm LG} \sim 202^o \pm 10^o$, one can predict a theoretical velocity through

$$\mathbf{v}_{\rm th} = \mathbf{V}_{\rm LG} + \mathbf{v}_{\rm sm} \tag{22}$$

obtaining the following values

$$v_{\rm th} = (276 \pm 71) \text{ km/s} \qquad \gamma_{\rm th} = -30^{o+18^o}_{-23^o} \qquad \alpha_{\rm th} = 240^{o+21^o}_{-28^o} \tag{23}$$

These might be compared with the results of our fit (21) and with our Eqs.(17) and (18) having a theoretical estimate of $|(1/2 - \beta + \delta)|$ to transform into a velocity value, through Eq.(9), the precise indication (18) on the normalization factor $|K|$.

To this end, we observe preliminarily that our model-independent analysis leads to rather large values of the RMS anisotropy parameter. In fact, using our result $|K| \sim (33 \pm 3) \cdot 10^{-16}$ and the theoretical range $v_{\rm th} \sim (276 \pm 71)$ km/s reported above, one obtains a range of the RMS parameter $25 \cdot 10^{-10} \le |(1/2 - \beta + \delta)| \le 70 \cdot 10^{-10}$ (with a central value $39 \cdot 10^{-10}$) in good agreement with the theoretical prediction $|(1/2 - \beta + \delta)|_{\rm th} \sim 42 \cdot 10^{-10}$ of Refs.[19, 20]. Equivalently, using the two theoretical inputs $|(1/2 - \beta + \delta)|_{\rm th} \sim 42 \cdot 10^{-10}$ and $v_{\rm th} \sim (276 \pm 71)$

km/s one predicts $20 \cdot 10^{-16} \leq |K|_{\text{th}} \leq 56 \cdot 10^{-16}$ (with a central value $36 \cdot 10^{-16}$) in good agreement with our Eq. (18).

This should be compared with the result of Ref.[9] (where the values $v \sim 370$ km/s, $\alpha \sim 168^o$ and $\gamma \sim -6^o$ were assumed) $|(1/2 - \beta + \delta)| \sim (2 \pm 2) \cdot 10^{-10}$. In this way, one would predict $|K| \sim (3 \pm 3) \cdot 10^{-16}$ which is one order of magnitude smaller than the value reported in our Eq.(18). In this sense, our results show that the very small RMS parameter reported in Ref.[9] , rather than being due to the smallness of the signal, might originate from more or less accidental cancellations among the various entries.

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