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Dark flows and the cosmological axis

Christos G. Tsagas[1,2]⋆

[1]*Section of Astrophysics, Astronomy and Mechanics, Department of Physics, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece*
[2]*NORDITA, AlbaNova University Center, Roslagstullsbacken 23, SE-10691 Stockholm, Sweden*

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ABSTRACT

Recent surveys indicate coherent large-scale peculiar motions, commonly referred to as 'dark flows', considerably stronger than expected. At the same time, an increasing number of reports suggest the presence of a weak dipolar anisotropy in the supernova data. The Universe seems to accelerate slightly faster in one direction and equally slower in the opposite. Also, this 'cosmological axis' lies fairly close to the cosmic microwave background dipole. Since apparent, dipole-like, anisotropies are the trademark signature of peculiar motions, we consider the possibility that these, seemingly unconnected, observations are actually related. In the process, we find that observers living inside a dark flow could experience locally accelerated expansion in a globally decelerating Universe. Moreover, to these observers, the acceleration should appear slightly faster in one direction and equally slower in the opposite, as if there is a preferred axis in the universe. When combined, these results open, in principle at least, the theoretical possibility of addressing the supernova data and the cosmic acceleration by appealing to dark flows rather than dark energy.

Key words: cosmology: theory – large-scale structure of Universe.

1 INTRODUCTION

An increasing number of studies suggest that a weak dipolar anisotropy may reside in the supernova data (Kolatt & Lahav 2001; Schwarz & Weinhorst 2007; Gupta, Saini & Laskar 2008; Antoniou & Perivolaropoulos 2010; Cooke & Lynden-Bell 2010; Colin et al. 2011; Cai & Tuo 2012; Mariano & Perivolaropoulos 2012). The Universe appears to accelerate slightly faster in one direction and equally slower in the opposite. The dipole axis, which is sometimes referred to in the above literature as the *cosmological axis*, lies close to that of the cosmic microwave background (CMB) dipole. At the same time, other surveys (Kashlinsky et al. 2008, 2009, 2010; Watkins, Feldman & Hudson 2009; Feldman, Watkins & Hudson 2010; Lavaux et al. 2010; Abate & Feldman 2012) indicate large-scale peculiar velocities well in excess of those anticipated by the current cosmological paradigm. The work of Kashlinsky et al., in particular, suggests coherent bulk motions with roughly constant speed close to 1000 km s^{-1}, extending between 100 and 1000 Mpc (perhaps even farther out). These are the so-called *dark flows* (see Kashlinsky, Atrio-Barandela & Ebeling 2012, for a recent review). Although seemingly unconnected, the dark flow reports and the cosmological axis claims may be actually related.

Cosmological peculiar motions are measured with respect to the CMB frame, which defines the smooth Hubble flow. In all realistic cosmological models, typical galaxies move relative to the universal expansion. Our Local Group, for instance, 'drifts' at approximately 600 km s^{-1} (e.g. Padmanabhan 1993). The trademark signature of peculiar motions is an apparent, dipole-like anisotropy, due to the fact that the drift flow introduces a preferred direction in the observer's space. The CMB dipole, for example, is not treated as a sign of a real large-scale anisotropy, but as an apparent (Doppler-like) effect that results from our motion relative to the Hubble flow.

Peculiar motions change the local velocity field and can also modify the local expansion rate. In general, 'drifting' observers expand either faster or slower than the bulk of the universe. Similarly, the deceleration/acceleration rate of the local expansion is generally different from that of the background cosmos. One might then ask whether it is possible for an observer to experience locally accelerated expansion within a decelerating background universe. Although such an effect may be local, if the peculiar motions resemble the dark flows reported by Kashlinsky et al., the affected domain can be very large (of the order of 1000 Mpc). Then, to the unsuspecting observer, it might appear as though the whole universe has recently started to accelerate, which is the standard interpretation of the supernova observations (Riess et al. 1998; Perlmutter et al. 1999). Moreover, if peculiar motions are responsible for such an apparent cosmic acceleration, their trademark signature – some degree of dipolar anisotropy – should reside in the supernova data. Put another way, the Universe should appear to accelerate faster in one direction and equally slower in the opposite, more or less in the way indicated by Kolatt & Lahav (2001), Schwarz & Weinhorst (2007), Gupta et al. (2008); Antoniou & Perivolaropoulos (2010); Cooke & Lynden-Bell (2010); Colin et al. (2011); Cai & Tuo (2012)

⋆E-mail: tsagas@astro.auth.gr

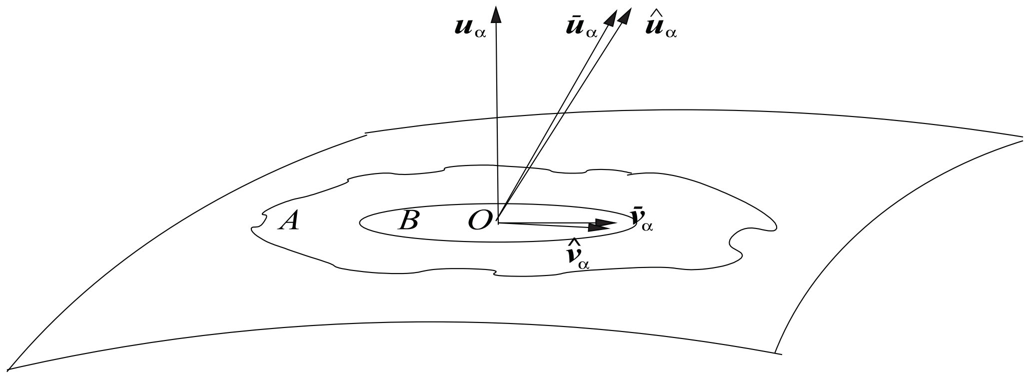

Figure 1. Region $\mathcal{A}$ represents a dark flow with mean bulk peculiar velocity $\bar{v}_\alpha$, relative to the Hubble expansion (see equation 1 in Section 2). Inside region $\mathcal{B}$, the right-hand side of equation (5) drops below zero and there the observer (O) measures a negative deceleration parameter (see Section 3). Individual observers in region $\mathcal{A}$ have velocities $\hat{v}_\alpha$, which are generally different from the mean (i.e. $\hat{v}_\alpha \neq \bar{v}_\alpha$). This difference, which for typical observers is small, leads to a weak dipolar anisotropy in the distribution of the deceleration parameter inside the dark flow domain (see equations 11a and 11b in Section 4).

and Mariano & Perivolaropoulos (2012). Then, by appealing to the dark flows, one might be able to address the recent accelerated expansion of the Universe without the need of dark energy, and at the same time answer the cosmological axis question as well. The aim of this Letter is to discuss the key features of such a scenario.

2 BULK PECULIAR KINEMATICS

Consider a large domain of the Universe moving relative to the Hubble flow with mean bulk peculiar velocity $\bar{v}_\alpha$ (see region $\mathcal{A}$ in Fig. 1). For simplicity, we will adopt a Newtonian approach and refer the reader to Tsagas (2010, 2011) for the relativistic treatment. Perturbing the Newtonian analogue of a dust-dominated Friedmann–Robertson–Walker (FRW) universe, the total mean velocity of an observer inside $\mathcal{A}$ is[1]

$$\bar{u}^\alpha = Hx^\alpha + \bar{v}^\alpha \,, \tag{1}$$

where $H = H(t)$ is the background Hubble parameter and x^a (with $\alpha = 1, 2, 3$) are the physical coordinates of the aforementioned observer (e.g. Padmanabhan 1993). Note that $u_\alpha = Hx_\alpha$ is the velocity of the background expansion and $\bar{v}_a$ is the perturbation due to the peculiar flow. The divergence of equation (1) leads to (e.g. Maartens 1998; Ellis & Tsagas 2002)

$$\bar{\Theta} = \Theta + \bar{\vartheta} \,, \tag{2}$$

with $\bar{\Theta} = \partial_\alpha \bar{u}^\alpha$, $\Theta = 3H$ and $\bar{\vartheta} = \partial_\alpha \bar{v}^\alpha$ by definition. These three scalars monitor the mean kinematics of region $\mathcal{A}$, namely the mean separation between neighbouring observers moving along with the cosmic fluid. Positive values for the aforementioned scalars imply that the average separation increases, which indicates expansion. In the opposite case, we have contraction. Hence, Θ is related to the Hubble expansion, $\bar{\vartheta}$ describes the average volume expansion/contraction of the peculiar flow and $\bar{\Theta}$ corresponds to the observer's total motion. Expression (2) shows how peculiar motions can change the local expansion. Unless the $\bar{v}_a$ field is exactly divergence-free, regions where $\bar{\vartheta}$ is positive will expand faster than the background universe, while those with negative $\bar{\vartheta}$ will expand slower (or even contract – when $\bar{\vartheta}/\Theta < -1$). Here, we will consider the $\bar{\vartheta} > 0$ case.

[1] Throughout this Letter 'barred' variables indicate mean bulk quantities inside domain $\mathcal{A}$ and 'hatted' ones correspond to typical individual observers living in that region (e.g. see Fig. 1, or equation (8) in Section 4).

If the expansion rate of domain $\mathcal{A}$ is different from that of the Hubble flow, their corresponding deceleration/acceleration rates will differ as well. To demonstrate that, let us take the convective derivative of equation (2). Keeping up to linear-order terms, we immediately obtain

$$\dot{\bar{\Theta}} = \Theta' + \dot{\bar{\vartheta}} \,, \tag{3}$$

where $\dot{\bar{\Theta}} = \partial_t \bar{\Theta} + \bar{u}^\alpha \partial_\alpha \bar{\Theta}$ and $\dot{\bar{\vartheta}} = \partial_t \bar{\vartheta} + \bar{u}^\alpha \partial_\alpha \bar{\vartheta}$ are (by definition) the convective derivatives along the total flow, while $\Theta' = \partial_t \Theta + u^\alpha \partial_\alpha \Theta = \mathrm{d}\Theta/\mathrm{d}t$ [since $\Theta = \Theta(t)$] is the one relative to the Hubble frame. Following equation (3), the quantities $\dot{\bar{\Theta}}$ and Θ' are generally different. This means that the associated deceleration parameters ($\bar{q}$ and q, respectively) will also differ. One may then ask whether it is theoretically possible for these two parameters to take different signs. More specifically, whether we can have $\bar{q} < 0$ and $q > 0$ simultaneously. If so, observers living inside region $\mathcal{A}$ will experience (locally) accelerated expansion within a globally decelerating background universe.

3 ACCELERATED DARK FLOWS

It is essential to investigate this possibility on a decelerating FRW background and when the effect of the peculiar motion is relatively weak. We ensure the former by imposing the conditions $\Theta' < 0$ and $q > 0$, while for the latter we demand that $|\bar{\vartheta}/\Theta| < 1$ and $|\dot{\bar{\vartheta}}/\Theta'| < 1$ at all times. Physically, this means that the overall kinematics are still dominated by the background expansion (see equations 2 and 3) and guarantees the linear (almost-FRW) nature of our analysis. To begin with, we first recall that the deceleration parameters in the 'barred' and the Hubble frames are $\bar{q} = -[1 + 3(\dot{\bar{\Theta}}/\bar{\Theta}^2)]$ and $q = -[1 + 3(\Theta'/\Theta^2)]$, respectively. Solving these relations for $\dot{\bar{\Theta}}$ and Θ', and substituting the results into the linear relation (3) gives

$$1 + \bar{q} = (1 + q)\left(1 + \frac{\bar{\vartheta}}{\Theta}\right)^{-2}\left(1 + \frac{\dot{\bar{\vartheta}}}{\Theta'}\right) , \tag{4}$$

to first order (Tsagas 2010). This is the deceleration parameter measured by observers inside $\mathcal{A}$, in terms of background and perturbed ('barred') variables. When the right-hand side of equation (4) drops below unity, these observers will assign negative values to the deceleration parameter. This is possible even when q is positive, in which case our observers will experience accelerated expansion in a decelerating background universe.[2] Such an effect can only have a local range of course. Next, we will outline the basic features of a scenario that does exactly that.

Suppose that region $\mathcal{A}$ (see Fig. 1) is a nearly uniform region of a universe that contains nothing else but conventional pressure-free matter. Also, assume that region $\mathcal{A}$ has a bulk peculiar velocity with $\bar{\vartheta} > 0$, such that it expands faster than the background universe. Following equation (4), the deceleration parameter measured inside region $\mathcal{A}$ is given by the linear expression (Tsagas 2010)

$$\bar{q} = \left(1 + \frac{1}{2}\,\Omega\right)\left(1 + \frac{\bar{\vartheta}}{\Theta}\right)^{-2}\left(1 + \frac{\dot{\bar{\vartheta}}}{\Theta'}\right) - 1\,, \tag{5}$$

since $q = \Omega/2$ to zero order. The latter can be seen as the effective density parameter of the matter in region $\mathcal{A}$, rather than that of the whole universe. When the right-hand side of equation (5) drops below zero, around every observer there will be a smaller and essentially spherically symmetric patch $\mathcal{B}$ where the expansion is accelerated (see Fig. 1). The chances of this happening, and the size of the affected area (i.e. that of domain $\mathcal{B}$), increase when $\mathcal{A}$ is a low-density region with a relatively large bulk outflow. The sign of $\dot{\bar{\vartheta}}/\Theta'$ is also important, with negative values strengthening the local acceleration effect (favourable case) and positive ones doing the opposite (unfavourable case). Here, we will consider the favourable case and set $-\dot{\bar{\vartheta}}/\Theta' \simeq \bar{\vartheta}/\Theta < 1$, referring the reader to Tsagas (2010) for the rest. Then, a simple Taylor expansion reduces expression (5) to[3]

$$\bar{q} \simeq \left(1 + \frac{1}{2}\,\Omega\right)\left(1 - 3\,\frac{\bar{\vartheta}}{\Theta}\right) - 1\,. \tag{6}$$

Let us now assume that region $\mathcal{A}$ is a dark flow with roughly constant bulk peculiar velocity, close to 1000 km s^{-1}, like that reported in Kashlinsky et al. (2008, 2009, 2010). In that case, we have $\bar{\vartheta}/\Theta \simeq \bar{v}/Hr$, where $\bar{v}$ is the magnitude of the mean peculiar velocity and r is the size of the region. Then, recalling that $H \simeq 70$ km s^{-1} Mpc^{-1} today, we may set $\bar{\vartheta}/\Theta \simeq 1/7$ around the 100 Mpc threshold, $\bar{\vartheta}/\Theta \simeq 1/35$ close to 500 Mpc, $\bar{\vartheta}/\Theta \simeq 1/70$ at the 1000 Mpc mark and $\bar{\vartheta}/\Theta \simeq 1/140$ as far out as 2000 Mpc. Also, when region $\mathcal{A}$ is a low-density domain, with, say, $\Omega \simeq 1/25$, equation (6) gives

$$\bar{q} \simeq -0.417, \quad \bar{q} \simeq -0.067 \tag{7a}$$

and

$$\bar{q} \simeq -0.023, \quad \bar{q} \simeq -0.002 \tag{7b}$$

on scales near 100, 500, 1000 and 2000 Mpc, respectively. The above numerical results should be seen as indicative, rather than typical, since lower values for $\bar{q}$ are possible. For example, setting $\dot{\bar{\vartheta}}/\Theta' \simeq -1/2$ close to 500 Mpc and keeping $\bar{\vartheta}/\Theta$ and Ω as before gives $\bar{q} \simeq -0.5$ there. Similarly, setting $\dot{\bar{\vartheta}}/\Theta' \simeq -1/10$ at 1000 Mpc will lead to $\bar{q} \simeq -0.1$ on that scale. In fact, $\bar{q}$ can take all the values within the $(-1, 0)$ interval without violating the (linear) conditions $|\bar{\vartheta}/\Theta| < 1$ and $|\dot{\bar{\vartheta}}/\Theta'| < 1$. The characteristic feature is that the effect of the peculiar motion fades away as we move on to larger lengths. This means that the deceleration parameter will eventually become positive. So, in this scenario, the accelerated expansion is not a global effect, but a local one. The affected scales, however, can be large enough ($\gtrsim$1000 Mpc) to create the false impression that the whole universe recently started to accelerate. Recall that the supernova data set the threshold from decelerated to accelerated expansion at approximately $z \simeq 0.5$, which corresponds to a scale of a couple of thousand Mpc. Therefore, one could in principle confront the observations without the need of dark energy, or of any new physics. Living inside a dark flow may be just enough.

4 THE COSMOLOGICAL AXIS

To this point, we have argued that peculiar motions could provide a conventional explanation to the accelerated expansion of the Universe, which does not require dark energy. Since the supernova data became public, various alternative scenarios have appeared in the literature. One could therefore ask whether there is a particular feature that can distinguish the dark flow paradigm from the rest of the alternatives and whether there are any observational data supporting that feature. As we will explain below, it seems that the answer to this question may be positive.

The typical, trademark, signature of peculiar motions is an apparent dipolar anisotropy, triggered by the fact that the flow introduces a preferred direction into the observer's space. The dipole seen in the CMB spectrum, for example, has been traditionally interpreted as such an apparent Doppler-like effect (e.g. Padmanabhan 1993). If the accelerated expansion of the Universe is a side-effect of our large-scale peculiar motion, as described above, there should be a similar dipole-like signature into the supernova data as well. Put another way, the Universe should appear to accelerate faster in one direction and equally slower in the opposite. To analyse and estimate such an apparent effect, we first need to discuss the kinematics of anisotropic peculiar motions.

For our purposes, it suffices to consider irrotational flows and include only shear. Then, inside region $\mathcal{A}$, the expansion tensor of the overall motion reads (e.g. Ellis & Tsagas 2002)

$$\hat{\Theta}_{\alpha\beta} = \frac{1}{3}\,\Theta\delta_{\alpha\beta} + \hat{\vartheta}_{\alpha\beta} = \frac{1}{3}\left(\Theta + \hat{\vartheta}\right)\delta_{\alpha\beta} + \hat{\sigma}_{\alpha\beta}\,, \tag{8}$$

with $\hat{\Theta}_{\alpha\beta} = \partial_{(\beta}\hat{u}_{\alpha)}$ and $\hat{\vartheta}_{\alpha\beta} = \partial_{(\beta}\hat{v}_{\alpha)} = (\hat{\vartheta}/3)\delta_{\alpha\beta} + \hat{\sigma}_{\alpha\beta}$. The latter is the expansion tensor of the peculiar flow, where $\hat{\vartheta} = \partial^a\hat{v}_a$ and $\hat{\sigma}_{\alpha\beta} = \partial_{(\beta}\hat{v}_{\alpha)} - (\hat{\vartheta}/3)\delta_{\alpha\beta}$ is the peculiar shear (with $\hat{\sigma}^\alpha{}_\alpha = 0$). Since the shear matrix is diagonalizable, we may ignore the off-diagonal components of equation (8) and use a single index for the diagonal components. Then, written along the three principal shear (eigen)directions, expression (8) simplifies to

$$\hat{\Theta}_\alpha = \frac{1}{3}\,\Theta + \hat{\vartheta}_\alpha = \frac{1}{3}\left(\Theta + \hat{\vartheta}\right) + \hat{\sigma}_\alpha\,, \tag{9}$$

where $\sum_{\alpha=1}^{3}\hat{\sigma}_\alpha = 0$. For zero shear, the above equation reduces to equation (2). In general, however, there are three scalefactors and three deceleration parameters. The former are defined by $\dot{a}_\alpha/a_\alpha = \Theta_\alpha$ and the latter by $q_\alpha = -\ddot{a}_\alpha a_\alpha/\dot{a}_\alpha^2$. Then, the time derivative of

[2] There are two types of universal acceleration, based on the value of the deceleration parameter. The first has $-1 < q < 0$ and may be termed 'weakly accelerated' expansion. The second has $q < -1$ and corresponds to 'strong acceleration' (see Tsagas 2010, 2011, for more details). Observers in a perturbed, almost-FRW, universe can only experience weak acceleration. Strong acceleration means $\dot{\bar{\Theta}} > 0$, which requires $\dot{\bar{\vartheta}}/\Theta' < -1$ (see equation 3). The latter is not allowed at the linear level, where $|\dot{\bar{\vartheta}}/\Theta'| < 1$. Note that the supernova data suggest that $\bar{q} \simeq -0.5$ and therefore indicate weak acceleration for our universe (Turner & Riess 2002; Riess et al. 2004).

[3] For simplicity, we have used Taylor expansions and kept up to ϑ/Θ-order terms only (see equation 5 above and also equations 11a and 11b given below). This has slightly compromised our numerical accuracy on scales close to 100 Mpc, but has no practical effect on larger lengths. More accurate numerical estimates can be found in Tsagas (2010, 2011).

equation (9) leads to (see Tsagas 2011 for details)

$$\hat{q}_\alpha = \left(1+\frac{1}{2}\,\Omega\right)\left[1+\frac{\hat{\vartheta}}{\Theta}\left(1+3\,\frac{\hat{\sigma}_\alpha}{\hat{\vartheta}}\right)\right]^{-2} \times \left[1+\frac{\dot{\hat{\vartheta}}}{\Theta'}\left(1+3\,\frac{\dot{\hat{\sigma}}_\alpha}{\dot{\hat{\vartheta}}}\right)\right]-1\,, \tag{10}$$

along the three main directions of motion. Note that Ω is the effective density parameter of region $\mathcal{A}$. Also, in the absence of shear anisotropy, $\hat{\vartheta} \to \bar{\vartheta}$ and the above equation reduces to equation (6).

In the case of real anisotropy, the shear takes three different values along the corresponding axes (eigendirections). When the anisotropy is apparent, induced by the observer's peculiar motion, there is only one shear axis in the direction of the motion (as in the CMB case). Let us go back to the dark flow domain $\mathcal{A}$. An observer that happens to move with the mean bulk velocity of the patch exactly will measure an isotropically distributed deceleration parameter. To this observer, the universe will accelerate equally fast in all directions. Typical observers in region $\mathcal{A}$, however, have peculiar velocities close but not equal to the bulk velocity (see Fig. 1). This difference should lead to an apparent dipole in the distribution of the deceleration parameter, as measured by these observers.

To estimate the magnitude of the aforementioned apparent anisotropy, assume that our observer moves along the first of the shear axes and assign a positive value to the apparent shear ($\hat{\sigma}_1^+$) along that direction. Then, in the opposite way, the corresponding shear will be $\hat{\sigma}_1^- = -\hat{\sigma}_1^+$. For typical observers, with $\hat{v}_a \simeq \bar{v}_a$, the associated (apparent) anisotropy should be small, which implies that $|\hat{\sigma}_1^\pm/\hat{\vartheta}| \ll 1$. Let us assume, mainly for illustration purposes, that $\hat{\sigma}_1^+/\hat{\vartheta} = 1/15 = -\hat{\sigma}_1^-/\hat{\vartheta}$ and $\dot{\hat{\sigma}}_1^+/\dot{\hat{\vartheta}} = 1/15 = -\dot{\hat{\sigma}}_1^-/\dot{\hat{\vartheta}}$ (any small value for these ratios will do). When $-\dot{\hat{\vartheta}}/\Theta' \simeq \hat{\vartheta}/\Theta$ (i.e. in the favourable case – see equations 5 and 6) expression (10) gives

$$\hat{q}_1^+ \simeq \left(1+\frac{1}{2}\,\Omega\right)\left(1-\frac{18}{5}\,\frac{\hat{\vartheta}}{\Theta}\right)-1 \tag{11a}$$

and

$$\hat{q}_1^- \simeq \left(1+\frac{1}{2}\,\Omega\right)\left(1-\frac{12}{5}\,\frac{\hat{\vartheta}}{\Theta}\right)-1\,, \tag{11b}$$

along the direction of motion and in the opposite way, respectively. Applying the above to a region of 100 Mpc, where $\hat{\vartheta}/\Theta \simeq 1/7$, and setting $\Omega \simeq 1/25$ there, we find

$$\hat{q}_1^+ \simeq -0.504 \qquad \text{and} \qquad \hat{q}_1^- \simeq -0.330\,, \tag{12}$$

which should be compared to the average value of $\bar{q} \simeq -0.417$ (see equation 7a). According to equation (12), there is a small dipole anisotropy in the spatial distribution of $\hat{q}$ along the direction of the peculiar flow. The universe seems to accelerate faster in that direction and equally slower in the opposite (relative to the average). This pattern is maintained on larger scales, where the effects of the peculiar motions weaken. Close to 500 Mpc, for example, equations (11a) and (11b) give

$$\hat{q}_1^+ \simeq -0.084 \qquad \text{and} \qquad \hat{q}_1^- \simeq -0.050\,, \tag{13}$$

instead of the average $\bar{q} = -0.067$ (see equation 7a). Again, a small dipole appears in the $\hat{q}$ distribution.

If both the $\hat{q}$ dipole and its CMB counterpart are apparent (Doppler-like) effects, triggered by the observer's peculiar flow, it is plausible to argue that they should not lie far apart from each other. We should not expect these two axes to coincide either, however, because their corresponding reference frames are different. In the CMB case, the rest frame is that of the smooth Hubble expansion, while here the rest frame is that of the average velocity of the dark flow. Recently, an increasing number of surveys claim that a small dipolar anisotropy, which is more or less aligned with the CMB dipole and is occasionally referred to as the 'cosmological axis', may actually exist in the supernova data (Kolatt & Lahav 2001; Schwarz & Weinhorst 2007; Gupta et al. 2008; Antoniou & Perivolaropoulos 2010; Cooke & Lynden-Bell 2010; Colin et al. 2011; Cai & Tuo 2012; Mariano & Perivolaropoulos 2012).

5 DISCUSSION

The course of modern cosmology changed at the turn of the millennium as a result of the supernova observations. The subsequent development of the Λ cold dark matter (ΛCDM) paradigm and its agreement with key observations, like the angular anisotropy of the CMB and the large-scale galactic correlations, has led most cosmologists to embrace the idea of an accelerated Universe driven by dark energy. There are still scepticism and open issues, however, both theoretical and observational. The theoretical questions stem mainly (though not entirely) from the mysterious nature of dark energy, which remains an essentially free parameter fine-tuned by the observations (see Sarkar 2008 for an overall discussion). From the observational perspective too, there are a number of puzzling data that seem to disagree with the ΛCDM predictions at a noticeable level (2σ or higher – see Perivolaropoulos 2008, 2011). One of these puzzles is the recently reported large-scale peculiar motions, especially the dark flows; another is the apparent existence of the cosmological axis.

Peculiar motions are believed to result from structure formation and their domain of influence reflects the inhomogeneity scale of the Universe. The latter is typically set around the 100 Mpc mark, beyond which our cosmos is expected to resemble an FRW model to a high degree of accuracy. This picture has been challenged by recent observations, suggesting faster than expected peculiar motions on very large scales. The dark flows are probably the best known example. We have argued that observers living inside a dark flow can experience accelerated expansion within a decelerating, almost-FRW universe that contains conventional dust. Such an acceleration is local and not universal. Nevertheless, the affected regions can be large enough (of the order of a few thousand Mpc), to make the unsuspecting observer believe that the whole Universe has recently entered a phase of accelerated expansion. One might therefore be able to address the supernova observations without appealing to dark energy, introducing new physics, or abandoning the FRW models. Living inside a fast dark flow, like that reported by Kashlinsky et al., may be just enough.

If the accelerated expansion of the Universe is a local effect, caused by our participation to a large-scale dark flow, the supernova data should also contain the trademark signature of peculiar motions. This should appear as a dipolar anisotropy in the related data, which will not be real but apparent. In other words, observers within the dark flow domain should see the Universe accelerating faster in one direction and equally slower in the opposite. For typical observers, the aforementioned anisotropy should be weak and the axis of the supernova dipole should lie close to its CMB counterpart. Thus, the presence of a weak dipolar anisotropy in the distribution of the deceleration parameter is a generic feature (a 'prediction') of the dark flow scenario, which distinguishes it from the rest of the known dark energy alternatives. Interestingly, an increasing number of reports claim that such a small dipolar anisotropy may actually reside in the supernova data. So far, the close alignment of the so-called cosmological axis with the CMB dipole has been largely treated as coincidental. In our dark flow paradigm, however, the proximity of the two axes is a physical consequence rather than a mere coincidence. Put another way, the supernova data seem to contain the trademark signature of a large-scale peculiar motion.

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