The hardest thing of all is to find
a black cat in a dark room,
especially if there is no cat

Confucius

Are Gravitational Waves Directly Observable?

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Abstract

We take for granted that Gravitational Waves (GWs) exist, but examine critically the possibility for their *direct observation* with ground and space-based laser interferometers. It is argued that the detection of GWs can, at least theoretically, be achieved iff three requirements are met *en bloc*. Alternatively, a hypothetical case related to the so-called dark energy would render the task impossible in principle. The discussion is kept at conceptual level, to make it accessible to the general audience.

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1. Introduction

The failures to detect Gravitational Waves (GWs) have a long, and clearly symptomatic, history. Ever since the first unsuccessful effort by Joseph Weber in the late 1960s, the proponents of this (highly questionable, as we shall see later) enterprise have been suggesting new, improved techniques for 'noise reduction' and 'improved sensitivity', while the underlying presumptions about the very possibility for detecting 'the ripples of spacetime metric' have not been questioned. This peculiar pattern has not changed even after the second failure of LIGO to detect GWs [1], which hasn't been interpreted as a warning signal for

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possible fundamental flaws in the very idea of 'gravitational wave astronomy', but as a helpful estimate for the desired 'sensitivity level' for detecting GWs with the Advanced LIGO. The latter is expected to be operational by 2007, with more than a factor of 10 greater sensitivity than initial LIGO [2]. Even more alarming is what seems to be 'the Plan B' of GW astronomy: should LIGO fail for the third consecutive time, there is hope to detect GWs with three satellites, LISA (currently in its "Phase A", in NASA parlance), which are expected to be launched in 2013 or shortly thereafter.

Meanwhile, even more sophisticated and expensive projects have been proposed to NASA for consideration, such as the Big Bang Observer, the Advanced Laser Interferometer Antenna in Stereo (ALIAS), and the Laser Interferometer Space Antenna in Stereo (LISAS) [3].

There is certainly great enthusiasm among the proponents of 'gravitational wave astronomy'. Regrettably, it is also accompanied by systematic ignorance of numerous studies by leading gravitational physicists, who are very pessimistic and even sharply reject the possibility for detecting GWs [4].

Given the straight record of failures to detect GWs in the past forty years, perhaps the time has come to initiate a dialogue.

The most important question has not yet been answered: Are gravitational waves *directly observable*? Any decisive answer to this question requires elaborating on two possibilities, in the format: Yes, provided [A] holds, and No, provided [B] holds. After all, we aren't arguing over some aesthetical values of a painting or a song. Both the proponents and the opponents should be able to 'put their cards on the table' by explaining, in the clearest possible way, the conditions and circumstances under which the two alternative answers can be verified. Thus, we will obtain two sets of statements:

P: $\{(A_p \rightarrow \text{YES}), (B_p \rightarrow \text{NO})\}$, where P stands for 'proponents', and

O: $\{(A_o \rightarrow \text{YES}), (B_o \rightarrow \text{NO})\}$, where O stands for 'opponents'.

If we are doing science, we should be able to reach a full consensus, $A_p = A_o$, and $B_p = B_o$, after which the opponents and proponents of 'gravitational wave astronomy' will be able to engage in constructive and fruitful scientific discussion, with inevitable winners: all of us.

In the next two sections, we will take the stand of the opponents [4], usually referred to as 'early relativists', and will elaborate on the two possibilities above, by adhering to the format ($A_o \rightarrow$ YES) in Sec. 2, and ($B_o \rightarrow$ NO) in Sec. 3. We will also briefly examine the famous case of the binary pulsar B1913+16, and will argue that the relativistic status (to be explained in Sec. 3) of GWs resembles the so-called dark energy: it does exist but cannot be directly observable.

2. The benefit of the doubt

Let us grant LIGO Scientific Collaboration the benefit of the doubt, and suppose that there is indeed a black cat in the dark room, after Confucius.

All measurements and statements are relative; hence we must supply an answer to the question ‘with respect to what?’ The first off task will be to partition the ‘dark room’ into [dark room without the dark cat] and [dark cat occupying the rest of the dark room]. Thus, we introduce a *Schnitt* (cut) needed to observe GWs or ‘the dark cat’ [5] with respect to some [dark room without the dark cat] undisturbed by GWs. Following the explanation offered by Rainer Weiss [6], if LIGO were Manhattan, then the *Schnitt* (cut) separating the undisturbed Harlem from Manhattan will be Central Park North.

The first wave of problems follows immediately: how do we separate Harlem from Manhattan? They are simultaneously blasted by GWs, like kids dancing in a discotheque. Besides, if GWs carry real energy localized in *regions* (not at points), what would be the recoil of Harlem on these GWs? Aren’t we actually trying to log "online" on the bi-directional talk of matter and geometry, after John Wheeler [7]? Is it possible to detect a continual chain of states of LIGO’s arms, each one of them being the "end result" from this talk? Also, since GWs propagate ‘within themselves’, and (supposedly) with the speed of light, how can we record the talk of matter and geometry by real-time observations in the right-hand side of Einstein equation?

Perhaps it would be more productive if we choose one prominent and highly respected member of LIGO Scientific Collaboration (LSC), and follow her/his guiding insights, instead of asking questions ensuing from our viewpoint. Our choice will be Prof. Dr. Bernard F. Schutz, Director of the Astrophysical Relativity Division of Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Golm, Germany, and Chairman of the ESA Fundamental Physics Advisory Group.

In this section, we will list three quite conspicuous, in our opinion, problems exposed in the recent research of B. Schutz on GWs [8][9], and will formulate our statements in the format ($A_o \rightarrow$ YES).

2.1. Real-time observations of localized GW energy

B. Schutz writes [9, p. 317]:

> "Because the equivalence principle allows us to wipe out any gravitational field locally, even a gravitational wave, the energy of a wave is really only well-defined as an *average* over a region of space whose size is larger than the wavelength of the wave, and over a time longer than the period of the wave.”

Thus, the first hurdle is to understand the limitations from the "finest spot" with which we can try to observe localized GW energy in Manhattan, with respect to Harlem: we *cannot* zoom on any region that is equal or smaller than the wavelength of the wave, and over a time shorter than the period of the wave. This is our ‘maximum resolution’. Another excerpt from B. Schutz:

> "To arrive at a conserved energy that can be exchanged between the detector and the wave, we have to treat the wave and detector together. This is not so easy in general relativity, because it is not easy to define the wave separately from the rest of the geometry. (...) Energy is only conserved in situations where external forces are independent of time. For weak waves, it is possible to define their energy with reference to the "background" or undisturbed geometry, which is there *before* the wave arrives and *after* it passes (emphasis added – D.C.)." [9, p. 317]

Any usage of temporal (‘before’ and ‘after’) and spatial notions to distinguish between GWs (Manhattan) and the "background" or undisturbed geometry (Harlem) is subject to the limit on the "finest spot" with which we can try to observe localized GW energy in Manhattan, with respect to Harlem.

> "But if the geometry is strongly distorted, the distinction between wave and background has little meaning. In such cases, physicists do not speak about waves. They only speak about the time-dependent geometry." [9, p. 317]

We shouldn’t obscure the issue of ‘maximum resolution’ with strong *vs.* weak waves. Again, the distinction between wave and background has meaning up to the "finest spot" with which we can try to observe GWs in Manhattan, with respect to Harlem (see above). These are *generic limitations* rooted on the equivalence principle, as stated by B. Schutz. They determine our maximum resolution in terms of temporal and spatial notions. Otherwise we simply cannot speak about ‘conserved energy of GWs’.

Moreover, recall that the Einstein field equations are intrinsically non-linear, which implies that, unlike light waves in Maxwell’s linear theory, GW energy acts as a source of gravity itself. This unique ‘self-acting’ feature of gravity makes all matter fields ‘self-interacting’ as well. Any classical field configuration will possess certain amount of energy, hence will curve the spacetime, coupling the field to itself.

Wouldn't this 'self-coupling' of the initial classical field lead to quantum effects? Bernard Schutz argues that we don't have to include Planck's constant **h** in the GW energy flux formula, because "that would have forced us to explain why defining energy in classical general relativity needs quantum theory." [9, p. 315] This statement leaves the impression that B. Schutz is aware of some definition of energy in classical GR, which is *not* plagued by the inconsistencies of the so-called pseudo-tensors, and has miraculously evaded all quantum fields as well. This seems highly unlikely, given his confession:

> "The biggest incompleteness in physics has to do with gravity. (...) So we could in principle measure the gravitational field far away with arbitrary precision (if it is a non-quantum field) and determine what the distribution of energy in the spacetime is with arbitrary precision, contradicting quantum theory." [9, p. 407]

The second problem is the crucially important, and still unconfirmed, *non-uniform* part of GWs, which "acts in such a way that one section of an apparatus is affected by gravity differently than another." [9, p. 310] All ground-based interferometers, as well as the future space-based ones, are supposed to interact with precisely this *component* of gravitational radiation.

But how do we separate the alleged *non-uniform* part of GWs from the uniform one? Hypothetically, the former would *not* interact with our reference object (Harlem), while the latter would be delivered to all parties, stretching 'n squeezing them like kids dancing in a discotheque. Maybe we have to somehow shield Harlem from the *non-uniform* part of GWs. Or make Manhattan (LIGO) filter out only the alleged *non-uniform* part of GWs. Or shall we do both, just in case something goes wrong?

Now we can formulate our first statement:

> $(A_o \rightarrow \text{YES})_1$: If Bernard Schutz or any other member of LSC can (i) explain the "smeared" nature of the energy of GWs within their maximum resolution in time and space, (ii) separate the alleged *non-uniform* part of GWs from the uniform part, and (iii) fix an undisturbed reference object (Harlem), then they would be able, at least theoretically, to perform real-time observations of GWs.

Philosophically speaking, we believe the energy of GWs is a *bona fide* case of the rule 'think globally, act locally': in order to calculate a global quantity (such as the putative non-uniform tidal forces of GWs) at a certain location, we need to know the state of ‘everything else’ at null-infinity. We inevitably use approximations; Mother Nature doesn’t. Hence we don’t know how to *calculate precisely* the local value of any global quantity. Its local value could be *zero*[1], being defined by the rule ‘think globally, act locally’.

To explain the conjecture on the global nature of non-tensorial quantities in Einstein’s GR, we shall refer to Roger Penrose:

> "The contributions of gravity to energy-momentum conservation should somehow enter *non-locally* as corrections to the calculation of total energy-momentum. (...) From this perspective, gravitational contributions to energy-momentum, in a sense, ‘slip in through the cracks’ that separate the *local* equation $\nabla^a T_{ab} = 0$ from an integral conservation law of *total* energy momentum." [10, p. 458]

Further, Roger Penrose writes:

> "It is an essential point of consistency, both in theory and observation, that the ripples of empty space that constitute the gravitational waves emitted by PSR 1913 + 16 and other such systems indeed carry actual energy away. The energy-momentum of empty space is zero, so the gravitational wave energy has to be measured in some other way that is *not* locally attributable to an energy ‘density’. Gravitational energy is a genuinely non-local quantity. (...) This conservation law (Bondi-Sachs mass/energy conservation law employing non-local quantities defined at null-infinity - D.C.) does not have the local character of that for non-gravitational fields, as manifested in the ‘conservation equation’ $\nabla^a T_{ab} = 0$, and it only applies in an exact way in the limit when the system becomes *completely spatially isolated from everything else* (emphasis added - D.C.). Yet, there is something a little ‘miraculous’ about how things all fit together, included certain ‘positivity’ mass theorems that were later proved, which tells us that the *total mass* of a system (including the ‘negative gravitational potential energy contributions’ discussed above) cannot be negative." [10, pp. 467-468]

To understand why R. Penrose emphasized on the *total mass* of a system, read John Stewart’s discussion of the apparent positivity of the Bondi mass [11, Ch. 3.12, p. 160] An excellent overview of energy (non)conservation in GR is also provided by Carl Hoefer. [12]

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[1]Not *exactly* zero, since it has to match the current value of the cosmological “constant”; see Sec. 3.

We will get back to these issues when discussing the so-called dark energy in Sec. 3; for now it suffices to quote again R. Penrose:

> "I believe that it is fair to say that we do not yet have a complete understanding of gravitational mass/energy ..." [10, p. 467]

Penrose's confession shouldn't be surprising, given the compelling evidence that 73 per cent of the universe is in the form of some perfectly smooth "dark" energy, as explained in numerous popular articles. This "dark" energy puzzle is incredibly difficult, and perhaps we should go back to the first years of Einstein's GR. Einstein couldn't accept Levi-Civita's conservation laws of energy-momentum tensor for gravitational system, including matter fields and gravitational fields [13]: these conservation laws, albeit exact, "do not exclude the possibility that a material system disappears completely, leaving no trace of its existence." [14] Perhaps we're facing exactly the same kind of "dark" stuff which, combined with the cold "dark" matter, builds up to 96 per cent of the universe (see Sec. 3).

2.2. Longitudinal and transverse quadrupole modes

B. Schutz writes:

> "Gravitational waves produce tidal accelerations only in directions *perpendicular* to the directions they are traveling in." [9, p. 311]

Let's pin down the notion of 'direction of GW propagation/scattering'. If we take this 'direction' to match the expansion of spacetime metric along the cosmological time arrow (driven with constant acceleration by the so-called dark energy), then B. Schutz himself has provided a simple explanation for the failures of LIGO to detect GWs – see the "rubber-band" model of the expansion of spacetime, Fig. 24.3 [9, p. 349], reproduced below. Obviously, tidal accelerations "across the band" are outside the scope of gravitational wave astronomy.

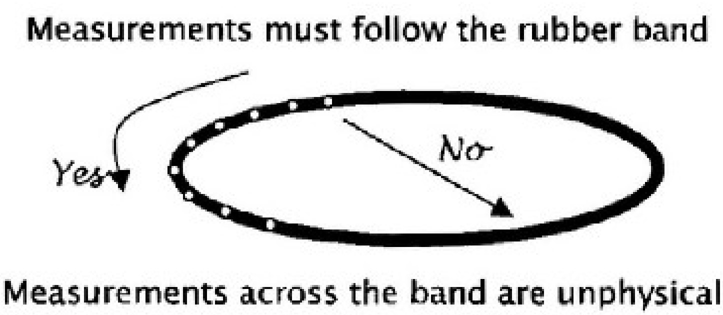

Fig. 1

B. Schutz explains:

> "Notice that the rubber-band universe really is homogeneous: no dot occupies a special position, there is no natural "central" dot on the band. (...) Because every dot is like every other one, all dots see the same Hubble law. Every observer attached to a dot sees the universe expanding away from the "home" dot. This is a good model for what our Universe looks like, except we have to extend the model to three dimensions." [9, p. 349]

It is hardly surprising that the viewpoint of B. Schutz and his LSC colleagues is different, since they have chosen a different interpretation of 'direction of GW propagation': in the 2-D 'elastic mesh' metaphor offered by Rainer Weiss, the *simultaneous* stretching and squeezing along X and Y originates from the transverse Z axis [7]. However, once we extend the space to three dimensions (from elastic mesh to elastic sponge, say), we introduce (in classical geometrodynamics) a gauge-dependent coordinate "time" parameter, and expect to make real-time measurements of GWs in this same coordinate "time" parameter, by 'stretching and squeezing' the 3-D space (sponge).

This is a whole new ball game, however, since we operate with *one entity*, called 4-D spacetime continuum. Some pretty obvious questions follow.

How can an axis transverse/perpendicular to the 3-D space accommodate the effects of gravity with GWs and without GWs? How can we sieve the "blueprints" from GWs? Let's look at the hypothetical *polarization* of GWs due to their hypothetical non-uniform component, as discussed in Sec. 2.1. The picture reproduced below is Fig. 22.1 from the latest book by B. Schutz. [9, p. 312] The same picture can be seen in B. Schutz' review article [8, Fig. 1], with the following caption:

> "Polarization of gravitational waves. The center line gives the wave as a function of time, with an amplitude of h = 0.2, and the top and bottom lines show to scale the distortions produced by two polarizations with this amplitude."

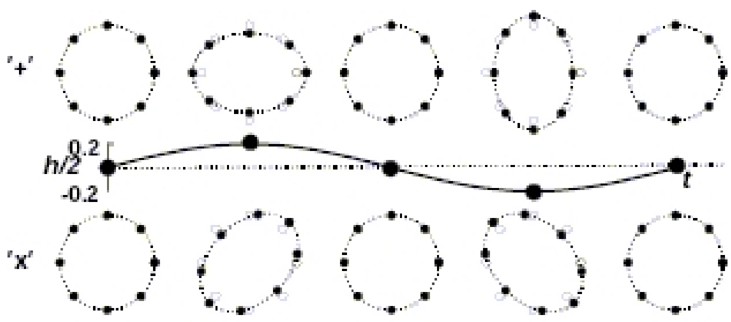

Fig. 2

The "vertical" line displays the GW amplitude, **h** , and one would naturally expect **h** to be a *parameter* of the time-dependent spatial curvature. [9, p. 310] But GW amplitude does not have any dimensionality whatsoever. The peculiar entity **h** is not a 'parameter'. It is just a *dimensionless number*. [9, p. 321; 8, Eq. 12]

It is hard to resist the temptation to place the GW amplitude **h** "across the band" in Fig. 1 above, and leave to Bernard Schutz and his LSC colleagues the burden of suggesting *any other interpretation* of their mysterious "dimensionless number" **h** .

The next problem is the *separation* of the time parameter, depicted with the horizontal center line in Fig. 2 above, from the time parameter of the *longitudinal* direction (not shown by B. Schutz), in which no GWs exist. B. Schutz argues that "the force of the Moon comes from the curvature of time" [9, p. 310], and "the deformation produced by the Moon is partly directed towards the Moon (the longitudinal direction), whereas gravitational waves are transverse." [9, p. 311]

Let's denote the time parameter of the non-uniform component of GWs, depicted with the horizontal center line of Fig. 2, with $t_{\mathbf{tqm}}$, and the time parameter of the action of gravity (no GWs) along the longitudinal direction (as in the case of the Moon) with $t_{\mathbf{lqm}}$, where indexes denote the transverse and longitudinal quadrupole modes respectively. Now we're ready to formulate our second statement:

> $(A_o \rightarrow \text{YES})_2$: If Bernard Schutz or any other member of LSC can separate $t_{\mathbf{tqm}}$ from $t_{\mathbf{lqm}}$, then they would be able, at least theoretically, to perform real-time observations of GWs.

Needless to say, the proponents of GW astronomy must avoid everything that could introduce some privileged status of either time parameters, as well as everything that could imply some *anisotropy* of the 3-D space common to these two time parameters.

2.3. The phase of the transverse quadrupole radiation

Regarding the *phase* of GWs in their "energy flux" formula, B. Schutz writes:

> "The key point about this formula is that the energy is proportional to the squares of the amplitude and of the frequency. Each of the two polarizations of the wave contributes its own energy, so this formula must be used separately for the "+" and the "x" amplitudes." [9, p. 316]

The explanation seems fairly simple:

> "As with **h** , the flux must be proportional to an even power of **f**, since frequencies, like amplitudes, can be negative[a]. Footnote: [a]If you are puzzled by the idea of a negative frequency, remember that frequency is the number of cycles of the wave per unit time (see our second statement above - D.C.). If we run time backwards, such as by making a film of the wave and running it backwards, then the number of cycles per unit time also goes backwards, and the wave has a negative frequency. But the backwards-running film shows a normal wave, one that you could have created in the forward direction of time with the right starting conditions, so it must also have a positive energy." [9, p. 315]

This reel film metaphor may look simple, but it isn't. First, it does not take into account the cosmological time arrow, driven by the "dark" energy: see Fig. 1 in Sec. 2.2 above. Secondly, it presumes that no quantum effects are present. Recall that in QFT there are negative energy densities corresponding to negative mass, but the latter is removed 'by hand' in present-day theory of gravity. [15]

There is no *dipole* gravitational radiation [5], as confirmed by LIGO so far [1], which implies that the "negative" sign of mass has been cancelled by the "positive" sign of mass, as hinted by the *even* power of **f** . Of course, we need quantum gravity to substantiate this speculation, and since we don't want to speculate on 'the unknown unknown', à la Donald Rumsfeld, let's take a closer look at something that belongs to 'things we know that we don't know': the very phase of GWs. It pertains to *transverse* waves only, like electromagnetic waves.

B. Schutz explains:

> "You can prove that light is a transverse wave by using Polaroid, the semi-transparent material that is used in some sunglasses. If you take two pieces of Polaroid and place them over one another, then if they are oriented correctly they will pass about half the light through that falls on them. But if you rotate one piece by 90^o, then the two pieces together will completely block all the light. (...) A further rotation by 90^o restores transmission. The kind of geometrical object that is turned into itself by an 180^o rotation is a line." [9, p. 311]

What geometrical object corresponds to the *cancellation* of the phase of GWs? Namely, what geometrical object is turned into itself by an 90^o rotation? The alleged "+" and the "x" amplitudes are shifted in 45^o, not 90^o. Such peculiar "phase" (if any) could be just an artifact from the quadrupole approximation.

All these ambiguities (to say the least) originate from the absence of any *unique* direction of GW propagation. Recall that a light beam propagates *in spacetime*, hence we can identify a *unique* 2-D plane transverse to the beam, then orient two Polaroid filters in this 2-D plane transverse to the direction of the light beam, and finally adjust the two Polaroid filters to completely cancel the phase of the light beam, thus proving that light is indeed a transverse wave. On the other hand, GWs are traveling *within themselves*, being some 'ripples of spacetime metric', hence there is no further *background* spacetime (nor "bulk" space) in which we can orient some Polaroid-like filter in some 3-D space "transverse" to the direction of GW propagation. Hence any direction in our 3-D space, in which we expect to detect GWs, is indistinguishable from, and interchangeable with, the *longitudinal* direction in which there are no GWs, as explained by B. Schutz in the example with the effect from the Moon cited above.

Let's formulate our third, and last, statement:

> $(A_o \rightarrow \text{YES})_3$: If Bernard Schutz or any other member of LSC can explain the geometrical object corresponding to the alleged phase of GWs, as well as suggest some Polaroid-like Gedanken-experiment demonstrating a two-step cancellation of GWs, then they would be able, at least theoretically, to perform real-time observations of GWs.

Needless to say, all three conditions of the type $(A_o \rightarrow \text{YES})$ need to be met *en bloc*. We will be happy to help, wholeheartedly.

3. Real-time observation of the "dark" energy of the universe?

What if we're actually trying to 'drill a hole' in the 'expanding balloon' (cf. Fig. 1 in Sec. 2.2) of the spacetime metric? Perhaps Mother Nature has imposed a strict ban on such *direct observations* of its "dark" energy. To explain this conjecture (which has far reaching implications, as we shall see later), let us elaborate on the meaning of 'direct observations', as we use it here.

All observations in astronomy are 'direct' and 'real-time', in the sense that the object being observed exists 'out there' as an objective reality. For example, if we look at the Sun, we will record a past state, which the Sun has had some 8 minutes prior to the instant of our observation: it takes a *finite* time interval for Sun's light to travel the distance to Earth. Taking into account the convention of simultaneity in the Special Relativity Theory (STR) [16], we can formulate three statements regarding the instant of observation, t_{obs} : (i) there exists a real state 'out there' of the Sun at t_{obs}, which (ii) *will* be observable after 8 min, and (iii) *was* the real state 'out there' of the Sun 8 min prior to t_{obs}. Thus, the relativistic status of ‘objective reality’ is elucidated with two equal and finite time intervals pertaining to the state of the observed object, both before and after t_{obs}. Relativistically speaking, dynamical effects (we observe the state of the Sun at t_{obs}) can only exist within forward light cones of their causes (the state of the Sun 8 min prior to t_{obs}).

If we apply the same line of reasoning to the substrate, call it X, of the “dark” energy, the following conundrum arises: we can reflect only on the state of X in the *past*, that is, what *was* the real state of ‘dark energy of X’ in the universe [17]. We cannot *determine* the state of X at t_{obs}, simultaneously [16] with our state at t_{obs}, because X is *not yet* real. Instead, it is somehow shifted into the *potential future* of all observers in the ‘rubber band’ universe, and “covers” all of the expanding ‘rubber’ points *simultaneously*, like some transcendental tachyon.

On the other hand, the ‘dark energy of X’ does not exist ‘outside’ the universe, and is not separated from it, like the Sun is separated in space from Earth. Again, although we always and inevitably observe a snapshot from the *history* of the world (e.g., the state of the Sun 8 min prior to t_{obs}), we do know that there exists ‘reality out there’, like the Sun. We don’t have this latter luxury with the substrate of the “dark” energy, and yet we have strong evidence that X must have evolved ‘in time’ (the coincidence problem; see [18]).

In what follows, we will try to argue that the ‘dark energy of X’ is a quantum-gravitational kind of reality: it is “dark” in the sense that it is a *potential* reality, being “attached” to every spacetime point from the ‘rubber band’ universe (cf. Fig. 1). We will introduce a new degree of freedom, called ‘global mode of spacetime’, to elaborate on the ‘attachment’ of the “dark” potential reality to the physical reality confined within 4-D spacetime of the ‘rubber band’ universe, or ‘local mode of spacetime’. In a nutshell, we will speculate that all observational devices in astronomy, laser interferometers included, can measure only the *dipole* radiation [1], since they inevitably perform *local* measurements (cf. Sec. 2.1) of ‘objective reality’ in classical physics, in the local mode of spacetime. From this perspective, GWs carry “dark” energy in the form of quadrupole radiation, which “propagate” in the putative global mode of spacetime, with amplitude $\mathbf{h}$ “across” the rubber band universe (cf. Fig. 1). We observe, in the local mode of spacetime, the localized “dark” GW energy *post factum* only [17], but the device that could measure it *directly* along the cosmological time arrow would have to be endowed with the faculty ‘think globally, act locally’, that is, to be able to interact with the “dark” quantum-gravitational *potential reality* originating from the global mode of spacetime. Another effect of this “dark” potential reality is the so-called cosmic equator, an anomalous alignment of the quadrupole and octopole moments observed in the WMAP data [19].

Notice that the “dark” potential reality is in a sense *atemporal*, as explained in John Cramer’s interpretation of quantum mechanics [20], which makes it a viable candidate for theories of canonical quantum gravity exploring the 'emergence' of time and space [21][22]. We will address this crucially important task in another paper, starting with the most "ordinary" thing: an elementary timelike displacement [23] in a fully non-linear theory of gravitational field [24]. We believe that the expression 'linearized gravity' is an oxymoron (see the two monographs by A. Loinger [4]), and will try to speculate on the elementary timelike displacement produced "after" the completion of quantum-gravitational 'handshake' [20] in the global mode of spacetime. In the *local* mode of spacetime, the "duration" of this non-local and non-linear 'handshake' is *strictly zero*, thus making the latter a *perfect* continuum, while the "discrete" steps of 'think globally' (cf. p. 6) are kept in the global mode of spacetime, being totally hidden in the local mode due to the so-called speed of light. To the best of our knowledge, this recipe for quantization of spacetime has not yet been explored (our approach was hinted in footnote 1, p. 6). On the other hand, the insurmountable problems of defining energy conservation in Einstein's GR [12][25][26][27][28], combined with the staggering challenge of the dynamic "dark" energy [17], suggest that we may not have any other choice.

Going back to the issue of "dark" energy, B. Schutz explains the amazing *local* properties of this perfectly smooth ubiquitous cosmological "fluid":

> "This fluid has *zero* inertial mass! It can be accelerated with no cost, no effort." [9, p. 255]

Just like the human thoughts! They too are completely "dark", they are indissolubly linked to the brain, and are *shifted* into the realm of *potentiality*; see the discussion of the relativistic status of the substrate of the so-called dark energy in the beginning of this section.

Suppose now, just for the sake of the argument, that GW energy is nothing but the "dark" energy. All measurements are inevitably local, but if we try to measure the *local* value of the current cosmological "constant" [18] with the current ground-based and future space-based GW detectors, we will inevitably end up empty-handed. (Perhaps the only device capable of detecting GWs along the cosmological time arrow is the human brain, which may have access to the realm of 'potential reality'.) Notice that the existence of GWs has been *inferred* from the observations of the famous binary pulsar B1913+16 [29], but no GWs have been observed so far [1]. A negative outcome could be a very important result as well, and we dare to suggest the possibility that there is a fundamental ban on detecting GWs, if they indeed originate from the "dark" energy. Our statement is as follows:

> ($B_o \rightarrow$ NO): If GW energy originates from the "dark" energy, then direct, real-time observations of the evolution of the latter

> along the cosmological time arrow will be impossible in principle, since such measurements will yield the *local zero value* of the current cosmological "constant".

We will deliberately bypass all alternative suggestions on the origin of the "dark" energy, and will assume that it is due to a cosmological constant.

Again, we do not dispute the existence of GWs, but suggest the possibility that their "dark" energy can 'smuggle' into the right-hand side of Einstein field equations "during" the non-linear bi-directional talk of matter and space [7], which 'takes place' in the putative global mode of spacetime. In the local mode of spacetime, the 'end result' [20] will be an indisputable contribution of GW energy to the *total* energy-momentum of the system, but if we try to detect the very dynamics of this contribution, we need to construct a device that can interact with the *potential* reality of the "dark" energy, in line with the rule 'think globally, act locally'.

From this perspective, we can understand the skepticism of Einstein and Eddington [30]: if confined exclusively in the local mode of spacetime, without the contribution from the global mode, GWs would be totally fictitious entities [4], which do not, and cannot convey any energy. With the global mode of spacetime, their energy becomes "dark", since it springs from the quantum-gravitational realm of 'potential reality'. It is not like observing the Sun, as we argued earlier. Recall also R. Penrose (cf. p. 6): "the gravitational wave energy has to be measured in some other way that is *not* locally attributable to an energy 'density'. Gravitational energy is a genuinely non-local quantity".

Perhaps a metaphor can help: imagine a shoal of fish swimming along a coral reef. Every fish is being guided by their common GW, and would anticipate the potential states of its neighbors from the shoal, hence would adjust its local Christoffel symbols 'online', one-point-at-a-time, thus creating a perfectly correlated geodesic in the local mode of spacetime. The local input on each fish, originating from the non-local "dark" GW covering the shoal of fish, cannot be observed with laser interferometers, unless the device can "see" the whole shoal of fish. In this context, Graham Nerlich writes (private communication): "I guess you know that the tensor as represented by a Christoffel symbol isn't straightforwardly like other tensors. If you don't, B. Schutz "A First Course in General Relativity" sec. 5.5 gives a clear account of it."

Perhaps there is a lot more to be unraveled in Einstein's GR.[31, p. 264] Perhaps there is no ban on *holistic* gravitational effects resembling those known in Quantum Field Theory, such as phonons and the Nambu-Goldstone boson. Perhaps Tullio Levi-Civita [13][14] was giving us a hint on how to include the "dark" potential reality into Einstein's GR: the total energy-momentum of a closed system would have to be "equal to zero" [32], in order to be transformed into a "dark" and perfectly smooth cosmological fluid with "*zero* inertial mass!" [9, p. 255] Perhaps the universe 'thinks' with its "dark" [33] quantum-gravitational potential reality: it is very smart indeed [34], and 'knows' how to adjust, with incredible precision, its initial parameters and fundamental "constants" right from the start, some 13.7 billion years ago.

"I want to know His thoughts; the rest are details", proclaimed Einstein, and grounded his General Relativity on the 'details': 3.6 per cent intergalactic gas and 0.4 per cent stars, etc. We should definitely make all efforts to reveal 'His thoughts' by November 2015, and complete his unfinished task [35]:

> "The right side (the matter part) is a formal condensation of all things whose comprehension in the sense of a field theory is still problematic. Not for a moment, of course, did I doubt that this formulation was merely a makeshift in order to give the general principle of relativity a preliminary closed expression. For it was essentially not anything more than a theory of the gravitational field, which was somewhat artificially isolated from a total field of as yet unknown structure."

Acknowledgments

I am very grateful to Angelo Loinger, who was very kind to send me his two monographs. Also, he has been answering, with amazing patience and clarity, all my stupid questions on the nature of gravity, in the past five years. I am also deeply grateful to Chris Isham for his time and efforts to satisfy my violent curiosity in canonical quantum gravity. Needless to say, I am solely responsible for all possible errors in the speculations outlined here. Last but not least, I would like to share my personal, and perhaps biased, opinion on the latest book by Bernard Schutz, "GRAVITY from the Ground Up": it is an excellent book. I greatly enjoyed reading it and communicating with the sharp mind of its author. Perhaps none of these prominent physicists, nor any established theoretical physicist would agree with my speculations, but, as Michel de Montaigne put it, "there is no conversation more boring than the one where everybody agrees."

References and excerpts

1. LIGO Scientific Collaboration, Upper limits on gravitational wave bursts in LIGO's second science run, gr-qc/0505029 v1.

LIGO Scientific Collaboration (395 scholars) wrote: "In this paper we report the results of a search for gravitational wave bursts using the LIGO S2 data. (...) The triple coincidence requirement is used to reduce the false alarm rate (background) to much less than one event over the course of the run, so that even a single event candidate would have high statistical significance. (...) Our analysis yielded a single candidate event which was subsequently determined to be terrestrial in origin and was vetoed retroactively. (...) No gravitational wave signals were detected in 9.98 days of analyzed data."
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Idem, Search for gravitational waves from galactic and extra-galactic binary neutron stars, gr-qc/0505041 v1.

"We have found no evidence of a gravitational wave event from binary neutron star inspiral. Without a detection, the 339 hours of non-playground data were used to place an upper limit on the rate of binary neutron star coalescence in the Universe."
--

Idem, Search for Gravitational Waves from Primordial Black Hole Binary Coalescences in the Galactic Halo, gr-qc/0505042 v1.

"Gravitational waves from binary inspiral are among the most promising sources for the first generation of gravitational wave interferometers. (...) No inspiral signals were found."

2. Advanced LIGO,
http://www.ligo.caltech.edu/advLIGO/

"Advanced LIGO will have more than a factor of 10 greater sensitivity than initial LIGO.

"It is anticipated that this new instrument will see gravitational wave sources possibly as often as daily, with excellent signal strengths, allowing details of the waveforms to be read off and compared with theories of neutron stars, black holes, and other highly relativistic objects. The improvement of sensitivity will allow the one-year planned observation time of initial LIGO to be equaled in roughly 3 hours.

"The proposed timescale is for a project start in 2005, first installation in 2007, and observations commencing in 2009."

3. J. Crowder and N. Cornish, Beyond LISA: Exploring Future Gravitational Wave Missions, gr-qc/0506015 v1.

4. A. Loinger, On the displacements of Einsteinian fields *et cetera*, physics/0506024 v2.; *Idem*, *On Black Holes and Gravitational Waves*, La Goliardica Pavese, Pavia, 2002, ISBN: 88-7830-371-2; *Idem, On BH's and GW's,* Vol. II, La Goliardica Pavese, Pavia, 2005, ISBN: 88-7830-427-1.

5. Jim Hough, Gravitational Waves -- Principles of detection and an Overview of Detectors,
http://www.physics.gla.ac.uk/~hough/PDFs/Sigravlectures2.pdf

Sec. 2.2, Generation and detection of gravitational waves, p. 5:

"Gravitational waves are produced when mass undergoes acceleration, and thus are analogous to the electromagnetic waves that are produced when electric charge is accelerated. However the existence of only one sign of mass, together with law of conservation of linear momentum, implies that there is no monopole or dipole gravitational radiation."

6. Waiting for Gravity at LIGO, American Museum of Natural History,
http://sciencebulletins.amnh.org/astro/f/gravity.20041101/essays/45_1.php

"Gravitational waves are energetic ripples of space traveling from massive objects in the cosmos. To measure one, do these things:

"1. Get $365 million from the National Science Foundation.

...

"LIGO's main attraction is its two 4 km long arms, labeled X and Y. Like the axes of a graph, the X arm is perpendicular to the Y arm. This orientation corresponds to the two directions in which a gravitational wave affects space. As a wave travels toward Earth (perpendicular to the arms, long the third dimension of a Z axis), it will *shrink* space along the X axis. For LIGO this means the space that is the X arm (and all the matter in it) will shorten a fraction. The space of the Y arm will, at the same moment, *stretch* in response to a gravitational wave. Then vice versa, again and again, many times per second.

"Imagine LIGO were Manhattan, suggests Weiss: "Squeeze Manhattan from uptown to downtown, and expand it east to west. Bang-boom!" In a flash, a gravitational wave extends the distance from the East River to the Hudson. Traveling from river to river would take more time (I wonder if Bernard Schutz would agree with Rainer Weiss - D.C.). It's not that the landmarks themselves are moving. It's that the distance between the landmarks is expanding. (...)

"So Have They Found Anything at All?

"Nope. LIGO started making preliminary runs in 2002, but it still hasn't noticed its first gravitational wave. (...) Expect the observatory to turn on for real in 2005."

7. C. Misner, K.S. Thorne, and J.A. Wheeler, *Gravitation*, W. H. Freeman & Co., New York, 1973, p. 5: "Space acts on matter, telling it how to move. In turn, matter acts back on space, telling it how to curve."

8. Bernard F. Schutz, Gravitational Radiation, AEI-2000-020, gr-qc/0003069 v1; Accepted by *Encycopedia of Astronomy and Astrophysics*, 2000.

9. Bernard Schutz, *GRAVITY from the Ground Up: An Introductory Guide to Gravity and General Relativity,* Cambridge University Press, Cambridge, 2003, ISBN: 0521455065 (hardback).

10. Roger Penrose, *The Road to Reality*, Jonathan Cape, London, 2004.

11. John Stewart, *Advanced General Relativity*, Cambridge University Press, Cambridge, 1993.

12. Carl Hoefer, Energy Conservation in GTR, *Stud. Hist. Phil. Mod. Phys.* 31(2), 187 (2000).

13. Tullio Levi-Civita, On the analytic expression that must be given to the gravitational tensor in Einstein's theory, *Rendiconti della Reale Accademia dei Lincei*, vol. 26, 381 (1917); English translation in physics/9906004 v1.

14. Carlo Cattani and M. De Maria, Conservation Laws and Gravitational Waves in General Relativity (1915-1918), in: M. Jansen, J. Earman and J.D. Norton, editors, *The Attraction of Gravitation: New Studies in the History of General Rela-*

tivity, Vol. 5, Birkhäuser Verlag, Boston, 1993, pp. 63-87.

15. Thomas A. Roman, Some Thoughts on Energy Conditions and Wormholes, gr-qc/0409090 v1.

"Energy conditions tell us what are "physically reasonable" distributions of mass-energy, which in turn tell us what are physically reasonable spacetime geometries. They are also crucial in proving many theorems using global techniques in general relativity, such as singularity theorems and the topological censorship theorem [15]. However, the energy conditions are not derivable from GR."

16. A. Einstein, On the Electrodynamics of Moving Bodies, *Annalen der Physik* 17, 891 (1905).

"We have to take into account that all our judgments in which time plays a part are always judgments of simultaneous events. If for instance I say, 'that train arrived here at seven o'clock', I mean something like this: 'the pointing of the small hand of my watch to seven and the arrival of the train are simultaneous events'".

17. Eric V. Linder, Cosmic Growth History and Expansion History, astro-ph/0507263 v1.

“Acceleration of the cosmic expansion reveals fundamentally new physics missing from our picture of the universe, yet key for the understanding of the recent and present history and the fate of the universe. Furthermore, this new physics tells us that our standard models of gravitation and particle physics may be woefully incomplete. The acceleration may lead us to insights about new high energy physics and the nature of the quantum vacuum, or about gravitation beyond Einstein’s general relativity. Perhaps most exciting would be a signal that both are involved, providing clues to a theory of quantum gravity. (...) We can say that searching for the nature of the accelerating expansion is seeking to answer one or the other question: "Does nothing weigh something?" or "Is nowhere somewhere?"
...
“With clear measurements of the cosmic expansion history and the cosmic growth history together we can learn if nothing weighs something, if nowhere is somewhere, or even more unexpected insights.”

18. N. Straumann, The history of the cosmological constant problem, gr-qc/0208027 v1.

“Furthermore, the energy density is determined by what is called the effective potential, and this is dynamically determined. Nobody can see any reason why the vacuum of the Standard Model we ended up as the Universe cooled, has -- for particle physics standards -- an almost vanishing energy density.”

19. J. W. Moffat, Cosmic Microwave Background, Accelerating Universe and Inhomogeneous Cosmology, astro-ph/0502110 v4.

"The dipole, quadrupole and octopole contributions are produced by gradients of the gravitational potential associated with the large scale perturbation enhancement. The dipole contribution is small and undetected in the WMAP data, while the quadrupole and octopole contributions have been found to be planar and the planes are aligned to a statistically anomalous degree [40, 43, 44].
...
"The possible statistically significant alignment of the quadrupole and octopole moments in the WMAP data can be explained, in our large scale inhomogeneous model, by an off-center observer seeing an axisymmetric alignment of the quadrupole and octopole moments as the observer receives light rays from the center of the large scale perturbation enhancement."

20. John G. Cramer, The Plane of the Present and the New Transactional Paradigm of Time, in: *Time & the Instant*, ed. by Robin Drurie, Clinamen Press Ltd, Manchester, 2001, Ch. 9; quant-ph/0507089 v1.

“Since the advanced-retarded-wave handshake used by the transactional interpretation operates in both time directions, it is in a sense atemporal, in that no elapsed time at the space-time site of the emitter is required between the beginning of a quantum event as an offer wave and its conclusion as a completed transaction (or ‘collapsed wave function’, in the terminology of the Copenhagen interpretation). Similarly, at the space-time site of the absorber (the future end of a transaction), there is no elapsed time between responding with a confirmation wave and the completion of the transaction. The transactional interpretation asserts that at the quantum level time is a two-way street, in which at some level the future determines the past as well as the past determining the future.”

21. C.J. Isham, *Prima Facie* Questions in Quantum Gravity, gr-qc/9310031 v1.

"IV. Both general relativity and standard quantum theory appear only in certain limiting situations in the context of a theory that starts from radically new perspectives. Very little is known about potential schemes of this type or, indeed, if it is necessary to adopt such an iconoclastic position in order to solve the problem of quantum gravity. However, the recurring interest in such a possibility is based on the frequently espoused view that the basic ideas behind general relativity and quantum theory are fundamentally incompatible and that any complete reconciliation will necessitate a total rethinking of the central categories of space, time and matter."

22. C.J. Isham, J. Butterfield, On the Emergence of Time in Quantum Gravity, gr-qc/9901024 v1.

"The usual tools of mathematical physics depend so strongly on the real-number continuum, and its generalizations (from elementary calculus 'upwards' to manifolds and beyond), that it is probably even harder to guess what non-continuum structure is needed by such radical approaches, than to guess what novel structures of dimension, metric etc. are needed by the more conservative approaches that retain manifolds. Indeed, there is a more general point: space and time are such crucial categories for thinking about, and describing, the empirical world, that it is bound to be ferociously difficult to understand their emerging, or even some aspects of them emerging, from 'something else'."

23. Ted A. Jacobson (September 2, 2004), A Spacetime Primer, http://www.glue.umd.edu/~tajac/spacetimeprimer.pdf

"The existence of an intrinsic time interval associated to any timelike displacement is another deep mystery. The fact is that, in Nature, there are systems that can serve as clocks. It seems to be the case that fundamental systems all march to the beat of the same drummer, in the following sense: there is a large class of physical systems that mark time in a commensurate fashion."

24. Domenico Giulini, Norbert Straumann, Einstein's Impact on the Physics of the Twentieth Century, physics/0507107 v1.

"One of the most prominent features of Einstein's equations lies in their nonlinearity. This means that solutions evolving from regular initial data may develop singularities in finite time. Hence not much is known about global (in time) existence of solutions."

25. M. Sharif, Tasnim Fatima, Energy-Momentum Distribution: A Crucial Problem in General Relativity, gr-qc/0410004 v1.

"In GR, many energy-momentum expressions (reference frame dependent pseudo-tensors) have been proposed. There is no consensus as to which is the best. Hamiltonian's principle helps to solve this enigma. Each expression has a geometrically and physically clear significance associated with the boundary conditions."

26. Katarzyna Grabowska and Jerzy Kijowski, Canonical gravity and gravitational energy, in: *Differential Geometry and Its Applications*, Proc. Conf., Opava (Czech Republic), August 27-31, 2001, Silesian University, Opava, 2001, pp. 261-274.

"There is a lot of ambiguities in the definition of gravitational energy. A textbook version of the Legendre transformation, which is often used to derive Hamiltonian formalism from the Lagrangian field theory, leads to a somewhat paradoxical result: gravitational energy vanishes modulo boundary terms. The same textbook version of the Canonical Field Theory (used, e.g., as a starting point for second quantization of Electrodynamics) is only "volume sensitive" but not boundary sensitive". This means that boundary phenomena are simply neglected. But here, in Gravity Theory, neglecting boundary terms means neglecting everything. Some authors improve this version of Canonical Gravity by imposing extra requirements on the energy functional in the asymptotically flat case (see, e.g., A. Ashtekar, *Lectures on Non-Perturbative Canonical Gravity*, World Scientific, Singapore, 1991).

"In this way gravitational Hamiltonian is defined as "zero + boundary corrections". These corrections are, however, often obtained not by a universal procedure, well defined for any field theory (e.g., electrodynamics), but via *ad hoc* improvements, which make no sense outside of Gravity Theory."

27. Christopher Eling, Energy in the Einstein-Aether Theory, gr-qc/0507059 v1.

"Energy in a field theory is defined as the value of the Hamiltonian, which acts as the generator of time translations. Although in diffeomorphism invariant theories there is generally no preferred notion of time (and thus energy), in asymptotically flat spacetimes one can naturally define the ADM and Bondi energies associated with asymptotic time translations at spatial and null infinity respectively. The ADM and Bondi definitions for GR have also been shown to satisfy positive energy theorems [8].

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[8] see, for example, E. Witten, A New Proof of the Positive Energy Theorem, *Comm. Math. Phys*. 9, 861 (1981); R. Schoen and S.-T. Yau, Proof That the Bondi Mass is Positive, *Phys. Rev. Lett*. 48, 369 (1982).

...

"Thus, unlike ordinary fields, the aether will contribute to the energy expression directly. (...) However, the positive energy theorem for GR [8] requires a stress-

tensor that satisfies the dominant energy condition. The aether stress-tensor (8) does not appear to generally satisfy this condition, so proof of total positive energy remains elusive. For some speculative thoughts on modifying the positive energy theorem, see [6].
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[6] C. Eling, T. Jacobson, D. Mattingly, Einstein-Aether theory, gr-qc/0410001.
...

"However, other special cases of the coupling constants yield negative energy solutions even when the linearized theory has positive energy. A complete answer to the question of positivity of energy in the non-linear theory is not yet in hand."

28. Michael Weiss and John Baez, Is Energy Conserved in General Relativity? http://www.math.ucr.edu/home/baez/physics/Relativity/GR/energy_gr.html

"Indeed, the issue of energy in general relativity has a lot to do with the notorious "problem of time" in quantum gravity... but that's another can of worms."

29. J.M. Weisberg and J.H. Taylor, Relativistic Binary Pulsar B1913+16: Thirty Years of Observations and Analysis, astro-ph/0407149 v1.

30. A. S. Eddington, The propagation of gravitational waves, *Proc. R. Soc. London*, Series A, 102, 268 (1922).

"Einstein had also become suspicious of these waves (in so far as they occur in his special co-ordinate system) for another reason, because he found that they convey no energy. They are not objective, and (like absolute velocity) are not detectable by any conceivable experiment. They are merely sinuosities in the co-ordinate system, and the only speed of propagation relevant to them is "the speed of thought."

31. Graham Nerlich, *The shape of space*, Cambridge University Press, Cambridge, 1994.

"(W)ithout the affine structure there is nothing to determine how the [free] particle trajectory should lie. It has no antennae to tell it where other objects are, even if there were other objects (...). It *is because space-time has a certain shape that world lines lie as they do*."

32. Angelo Loinger, Non-existence of gravitational waves. The stages of the theoretical discovery (1917-2003), physics/0312149 v3.

"This result has an unquestionable logical soundness, as it was finally admitted by Einstein himself. Of course, it implies the rejection of the various pseudo (false) energy tensors of the gravitational field proposed by Einstein and by other authors: a false tensor cannot have a true physical meaning!

"Einstein objected that in such a way the total energy-momentum of a closed system would always be equal to zero -- and this fact would not imply the further existence of the system under whatever form. However, from the standpoint of the coherence of the formalism, Levi-Civita -- and Lorentz [1] -- were undoubtedly right."

33. Tony Reichhardt, Cosmologists look forward to clearer picture, *Nature* 421, 777 (20 February 2003).

"The new data imply an age for the Universe of 13.7 billion years, and a distribution of mass and energy in which 4% of the Universe is normal matter (atoms), 23% is dark matter, and 73% is dark energy."

34. Philip D. Mannheim, Alternatives to Dark Matter and Dark Energy, astro-ph/0505266 v1.

"Dark matter thus seems to know where, and in what amount, it is to be needed, and to know when it is not in fact needed (dark matter has to avoid being abundant in the solar system in order to not impair the success of standard gravity in accounting for solar system observations using visible sources alone); and moreover, in the cases where it is needed, what it is actually made of (astrophysical sources (Machos) or new elementary particles (Wimps)) is as yet totally unknown and elusive.

"Disturbing as the dark matter problem is, the dark energy problem is even more severe, and not simply because its composition and nature is as mysterious as that of dark matter. Rather, for dark energy there actually is a very good, quite clear-cut candidate, viz. a cosmological constant, and the problem here is that the value for the cosmological constant as anticipated from fundamental theory is orders of magnitude larger than the data can possibly permit. With dark matter then, we see that luminous sources alone underaccount for the data, while for dark energy, a cosmological constant overaccounts for the data."

35. *Albert Einstein: Philosopher-Scientist*, Ed. by P. A. Schlipp, Open Court Publishing Company - The Library of Living Philosophers, Vol. VII, La Salle, 1970.