On a macroscopic traversable spacewarp in practice

Mohammad Mansouryar

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Abstract:

A design of a configuration for violation of the averaged null energy condition (ANEC) and consequently other classic energy conditions (CECs), is presented. The methods of producing effective exotic matter (EM) for a traversable wormhole (TW) are discussed. Also, the approaches of less necessity of TWs to EM are considered. The result is, TW and similar structures; i.e., warp drive (WD) and Krasnikov tube are not just theoretical subjects for teaching general relativity (GR) or objects only an advanced civilization would be able to manufacture anymore, but a quite reachable challenge for current technology. Besides, a new compound metric is introduced as a choice for testing in the lab.

1. Introduction:

It is clear that if a method of faster than light (FTL) travels would be discovered, its most natural consequences, such as contact to probable intelligent entities & colonizing the earth-like planets, could solve many problems of human race [1]. Even if within researching on FTL methods of communication, the related by-products could lead to rapid (not necessarily FTL) ways of transporting humans or things, that situation would be so profitable too [2].

Herein, TWs [3] are considered as the desired spacetime configurations that are able to satisfy the above requests. The main drawback of TWs hinges on their energy implications. In fact, if you want a TW, you need negative energy (NE) – energy less than vacuum energy of Minkowski 4D spacetime – with special conditions.

The stress-energy tensor of a TW metric violates both kinds of CECs [4]; pointwise & averaged. The "pointwise CECs" state, there cannot be local negative energy densities (NEDs) in physical spacetimes, while "averaged CECs" might permit violations of CECs in some points of spacetime but forbid negative values for energy measurements on the curves related to path of physical objects.

However this is not whole of the story; there are known violations of CECs, most famous of them – which would be base of present paper – is the experimentally observed Casimir effect (in parallel plate geometry with Dirichlet boundary conditions) [5].

In this paper, I have tried to review the literature, in the spirit of whether the TWs in practice are far reaching or constructible by present knowledge & technology. The conclusion is they are quite possible to manufacture provided a sufficient determination of investment on improving computation tools & necessary materials. The basic assumption is a generalization of a research done by Graham & Olum [6]. The calculations supporting my claims are too complicated, so the description will be mostly qualitative, but the principles are standard.

2. ANEC violation

If ANEC holds, topological censorship states: the observers that remain in the asymptotic flat region of a globally hyperbolic spacetime cannot have any experiment designed to actively detect the universe's nontrivial topology by sending & receiving causal signals (in the sense that all such signals will be homotopic [7]). With other words, it can be shown, under very general conditions, that a TW violates the ANEC in the region of the throat [8,9], by using the Raychaudhuri equation [4] together with the fact that a wormhole throat by definition defocuses light rays.

Indeed, ANEC is violated in curved spacetimes [10,11,12] – for null geodesics or non-geodesics curves – also, regarding ANEC violation, some authors [13,14] accept the existence of TWs but only in Planck scales. Further, there are other theoretical proposals [15,16,17,20], but the present approach is studying the relation between the Casimir energy – with interpretation of quantum vacuum [21] – & ANEC violation.

Qualitatively, I describe a model which can be considered as a promising generalization of the "plate with a hole" of [6].

The idea is as follows: if one considers one or several perforated pairs of mirrors (cavities), suitable for static Casimir system, in such a way that the holes are "not" symmetric, it can be expected some ANEC violation effects could leak from the extreme hole(s) of the collection. See Box **1**.

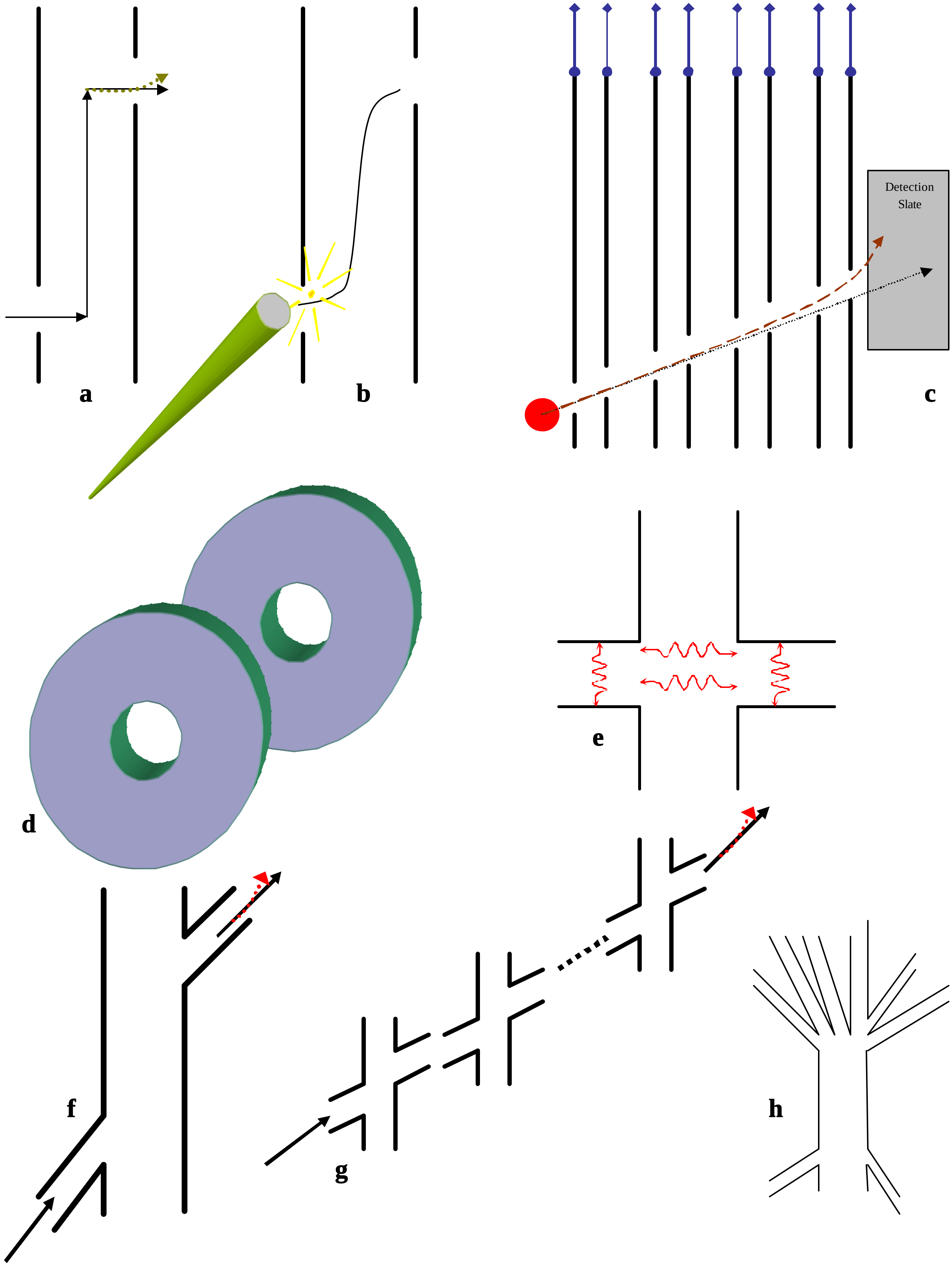
For two plates with a hole in their centers they derive [6]

$$\int dx V^l V^n T_{ln} \approx 2\Delta - \frac{p^2}{720\ell^3} \tag{1}$$

& declare: "above equation gives a positive result as long as $\ell > 1.6d$, which surely includes its entire range of applicability". But a modification might yield a different result. The modification is: The holes must not be (quite) face to face.

Actually, asymmetric perforated mirrors model has some advantages: (1) If the separation between the plates ℓ is much smaller than the radius of the hole d, the two plates are not equivalent to a single plate; in contrast to [6]. (2) If a null geodesics or a non-geodesics curve can pass through both of the holes, the probability of defocusing that ray – equivalent to demonstration of ANEC violation – is more than [6]. (3) Another promising feature is, necessity of concentration to Eq. (2) instead a special type of it. It means as a different point of view in p. 11 of [6], if one calculates

$$T_{ln} V^l V^n = \dot{f}^2 + \sum_i (v_i \partial_i f)^2 \tag{2}$$



Box of figs 1: (**a**) The ideal path of a null ray. The ray tries to have minimum presence in the regions contained of positive contributions of the holes & positive divergences related to the walls. It quickly runs away from the entrance hole & quickly passes the region around the egress hole (i.e., along a straight line). Such a presence in the middle regions – to detect NED – is confirmed in real conditions too [23,24]. (**b**) A differentiable curve that – in contrast to situation of (**a**) but very similar – seems a natural candidate for geodesics or non-geodesic rays. However, it is reasonable there are so few of them in any group of light rays, but the scattering theory doesn't seem to forbid such a state completely. (**c**) A collection of cavities for detection of ANEC violating effects. Each plate can have more than one hole. Red circle denotes a light source which sends a ray (black arrow) to a detection slate; The blue tentacles are for engineering requirements & must not be conductive (to least interference effects). Their motions perturb the system but probably less than one already expects [27].

If ANEC violation effects occur, then there must be a defocusing of the ray (shown exaggeratedly by brown arrow, however based on AWEC violation [22], that occurs for timelike particles, at least at the end of each non-perforated cavity). In extreme conditions, it is probable the ray even doesn't arrive to the slate & impacts to a mirror; such a state can be achieved for a collection of numerous cavities. Now, some points should be noted: (*1*) More holes, more probability of detection of defocused rays, but also more positive contribution to the system, against the ANEC violation. (*2*) Less area (or radius) of the holes, less probability of detection of defocused rays, but also less positive contribution to the system in favor of ANEC violation. Therefore, an elaborate balance between the conditions (*1*) & (*2*) would be desired.

Also, there are other subtleties; if in a rather thick plate one has a circular hole (**d**), the Casimir energy would be positive there [30], that is given by (for perfect spherical boundaries):

$$E=\frac{1}{2i}\sum_{l=1}^{\infty}(2l+1)\int_{-\infty}^{\infty}\tfrac{dw}{2p}e^{-iwt}\int_{0}^{\infty}r^{2}dr\left(2k^{2}[\tilde{F}_{l}+\tilde{G}_{l}](r,r)+\frac{1}{r^{2}}\frac{d}{dr}r\left\{\frac{d}{dr'}r'[\tilde{F}_{l}(r,r')+\tilde{G}_{l}(r,r')]\right\}_{r'=r}\right) \qquad \text{(B1)}$$

However, another possibility (generally, in curved geometries), is giving negative contribution according to the curvature of spacetime (see [31, *ref 13 therein*], that's similar for the plates themselves; although, any shape manipulations – which would require heuristic calculations – must maintain previous efforts of extracting the EM). So, much precision is required for the holes (e.g., peculiar shapes or high stretchability to yield essential geometry may be needed [111]).

Next idea is fixing smaller plates on the holes. The vertical such plates have technical troubles, & low theoretical value (**e**), because of weakening the NE contributions by concluded imposition; while oriented attached cavities have interested results (**f**). Their effect causes the ray does not feel that has got rid of a cavity (by being present in the middle regions), & chains of cavities are expecting to give negative contributions, undertake the duty of their last colleagues, & 'knead' the ray in an CEC violating manner (**g**). Besides, instead of "*one* small continuing" cavity, branches of them are imaginable (**h**), to be an element of the chains or generally any tree-structural pattern as (**g**).

Additional remark: There are three factors interested to a NED detection; 1) finite plate, 2) a non-complete geodesic or non-geodesic ray, 3) {in relation to Eq. (3a)}, d be increased, no globally chance, so that should be increased locally, corresponding to perforated (& rather nonstationary) plates [27] (asymmetry & thoughtful dynamics are further auxiliary & definitive factors to that end). There are also similar – & probably weaker – ideas on m reduction (locally again). See next page.

because of being more general of "an asymmetric trajectory of a ray" rather than a ray passing in the perpendicular direction through two symmetric holes in one axis as in [6], the argument of failing the ANEC violation due to difference of a total derivative to the case of NEC contributions cannot be applied anymore & one should mention more complicated arguments for ANEC survival.

Calculations for proving that guess is too difficult, but there are facts which make us hopeful: Due to [22] for a perfectly reflecting boundary at $x = 0$, the positive energy density (PED) associated with the wall declines exponentially as $r_c(x) \sim \exp(-4|x|/a)$, while the NED associated with f declines only as a power law. For large enough x, the NE will dominate, & the total energy will approach the form of $r_f(x) = -1/(32p\, x^3)$. That is the same for realistic situations which CECs violation is more difficult to achieve than idealized models [23,24].

On the other hand, when the ray enters or exits, the hole gives a positive contribution in favor of ANEC, but in asymmetric model the ray has more time to be in the NED regions for compensation & decreases its absorbed positive contribution. Therefore the scenario can be like this: Set up a configuration of mirrors & holes which the rays can escape from the holes & the regions near the mirrors as fast as they can, & as much as possible; thus those would spend most of their time in the middle regions which NEDs are dominant [25].

As an encouraging instance, let us consider a situation for better intuition. Visser in his book (see [3], pp. 123,124), derives an inequality in a Casimir system as a necessary condition of the "formal" ANEC violation (i.e, for "every complete" [32] null geodesic, passing through cavity) in the case of two "infinite" metallic parallel plates:

$$a < d\left(\frac{p^2\hbar}{360\, mLc}\right)^{1/3} << d \qquad (3a)$$

where c is the speed of light, a, separation between the plates, m, atomic mass of the metal, L, thickness of the plate, & d, lattice spacing.

Let us test Eq. (3a) in the case of plates made of "stable metallic hydrogen" [33]. Therefore $m = m_p = 1.67 \times 10^{-27}\, Kg$, $d = 2 \times (Bohr\ radius)$, $L = Nd$, which N is the number of layers [34]. Thus one has:

$$a < \frac{d^{2/3}}{\sqrt[3]{N}} 179\, nm << d \qquad (3b)$$

Based on Eq. (3a), the mirrors should be light & hollow, however because of the fraction $\left(d^2/m\right)^{1/3}$, hollowness is more effective, its physical reason is trivial: if you could produce a metallic composite with a lot of empty spaces inside, those regions are filled by the electronic sea, & less mass of the electrons rather than any other involved particle, is in favor of being affected of the plate's whole mass by attractive force of quantum vacuum; a demand that "averaged" CECs imply.

Along with searching for materials which are not heavy (metallic hydrogen is the best!) & dense neither, one may think of perforated mirrors as "locally" hollow systems (although, that's not a standard statement, but helps to a better intuition). In that direction, if in Eq. (3b), the mirrors were about 10^4 order of magnitudes closer (for $N = 1$, & ignoring realistic nature beneath the plasma wavelength), then ANEC would be violated. Such a result makes one expected to detect ANEC violation for asymmetric perforated systems as figs (**1c**, **1f**, **1g**, **1h**), however in the case of, e.g., maybe hundreds of cavities.

3. Post ANEC violation

Indeed, detection of the ANEC violation is the first milestone of generating any shortcut; thereafter we would still have a lot to do. There are papers where after assuming ANEC violation (explicitly or implicitly), discuss about minimizing the energy requirements of a TW (& sometimes wrong claims of removing the CEC violation). They can be classified into three groups: First of them consider CECs violations rounded in space [72,75,76,88], second group ones discuss about delaying those violations & round them in time [9,67,68], eventually the approaches of the third group are too far reaching [17,20,35,36,37], non-standard theories [39], or (mostly) mathematical [15,16].

As an intuitive affair, – something which calculations confirm too – it does not seem reasonable that a mere quantum effect (i.e, ANEC violation in arbitrarily small amounts [73]) could maintain a macroscopic TW for desired applications without any inconsistency [125]. Therefore, we should attack this problem from two fronts: (1) Enlarging the available potentials of producing various types of CECs violating effects. (2) Inventing the models of TWs with the best balances among minimizing energy requirements & other features of an applicative TW. The war in front (1) is "engineering" which its main demonstrating feature is increasing the equipments in the lab (Boxes **2** & **3**); but we have a lot to do in the second front, because "physical" manipulations of the parameters can have the deepest consequences in the model.

4. Extraction of NE

Obviously, without a standard theory describing the quantum properties of the fields relating to NE [40] in any manner (e.g., dark matter & energy, within dynamic spacetimes, ...) the theoretical frame of the model cannot be considered complete. Although, the most relevant researches to present purposes have been operated on quantum inequalities (QIs) [41,42,43,44,45].

In [44] Ford & Roman discuss about a "bound on the magnitude & duration of NEDs seen by a timelike geodesic observer in 4D Minkowski spacetime (without boundaries) for a minimally coupled, quantized, massless, scalar field in an arbitrary quantum state. That uncertainty principle-type inequality reads:

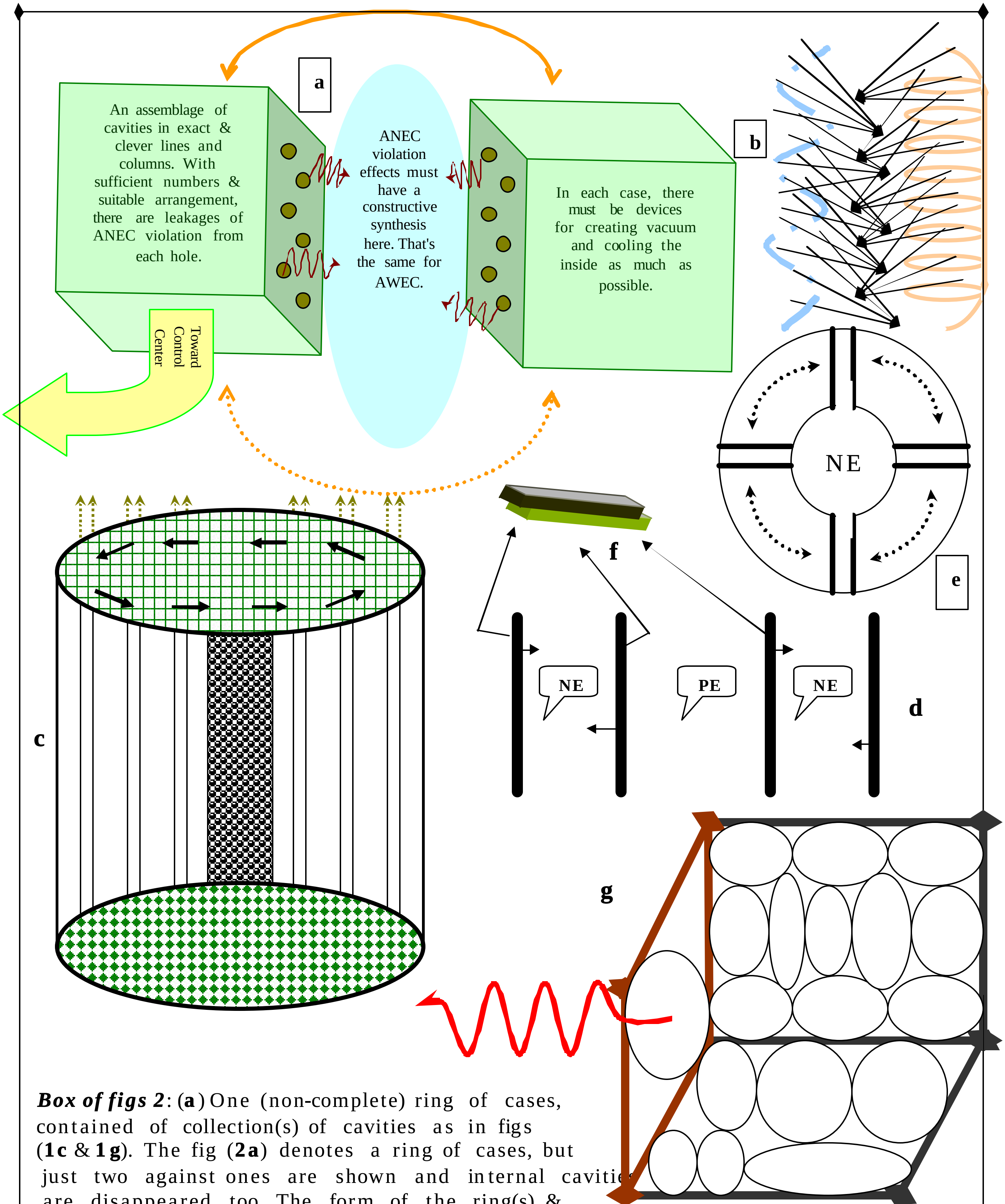
$$\frac{t_0}{p}\int_{-\infty}^{\infty}\frac{\langle T_{mn}u^m u^n\rangle dt}{t^2+t_0^2}\geq-\frac{3}{32p^2t_0^4} \qquad (4)$$

for all t_0, where t is the observer's proper time.

Taking into account of state-independent geometrical & state-dependent part of $<T_{mn}>$ to be the source of EM is unnaturally & naively. That's the same for generalizing the Eq. (4) to other massless or massive fields. Other fields have trace anomalies with similar coefficients, i.e., with magnitude of the order of 10^{-4}. Thus these terms will give a very small contribution to a QI to a of the form of Eq. (4) when $t_0 << l$, where l is the characteristic radius of curvature. On the other hand, adding mass will not make it easier to have large NEDs, but one now has to overcome the positive rest mass energy. The effect of including interactions is the most difficult to assess. If an interacting theory were to allow regions of NE much more extensive than allowed in free theories, there would seem to be a danger of an instability where the system spontaneously makes a transition to configuration with large NED".

As an instance of constraints of that theory, consider [31], wherein Morris, Thorne & Yurtsever calculate $r_0 \approx 1\ A.U.$ for a plate separation of $s \approx 10^{-10} cm$, this wormhole satisfies FR bound. In that model, a typical infalling 3K photon in the CMB radiation, upon arriving at one of the plates, would get blueshifted to a temperature $T \approx 10^{23} K$. In order to traverse it one must go through the plates, that is extremely close to being a black hole, the plates would have to be constructed out of material capable of withstanding Planck energies or more, at last that's unstable. They conclude [44]: If some of the wormhole parameters change over very short length scales, then it would seem from the "tidal force constraints" that tidal accelerations might also change over very short length scales. As a result an observer traveling through the TW could encounter potentially wrenching tidal forces rather abruptly. None of these scenarios seem terribly convenient for TW engineering. Assuming that the stress-energy of the TW spacetime is a renormalized expectation value of the energy-momentum tensor operator in some quantum state, & ignore fluctuations in this expectation value [46], they argue the QIs place severe constraints upon TW geometries.

In the absurdly benign case, for a small "human sized" TW with $r_0 \approx 1m$, FR bound gives $a_0 \lesssim 10^{14} l_p \approx 10^{-21} m \approx 10^{-6}\ fermi$, or approximately a millionth of the proton radius. Those imply that generically the EM is confined to an extremely thin band, and/or that the TW geometry involves large redshifts (or blueshifts). Also, playing with QIs won't give interesting results. For example human sized values of length lead to very large magnitudes of $|\Phi|$ which positive values give undesirable redshits / blueshifts for a static observer & negative ones make the spacetime close to having a horizon.



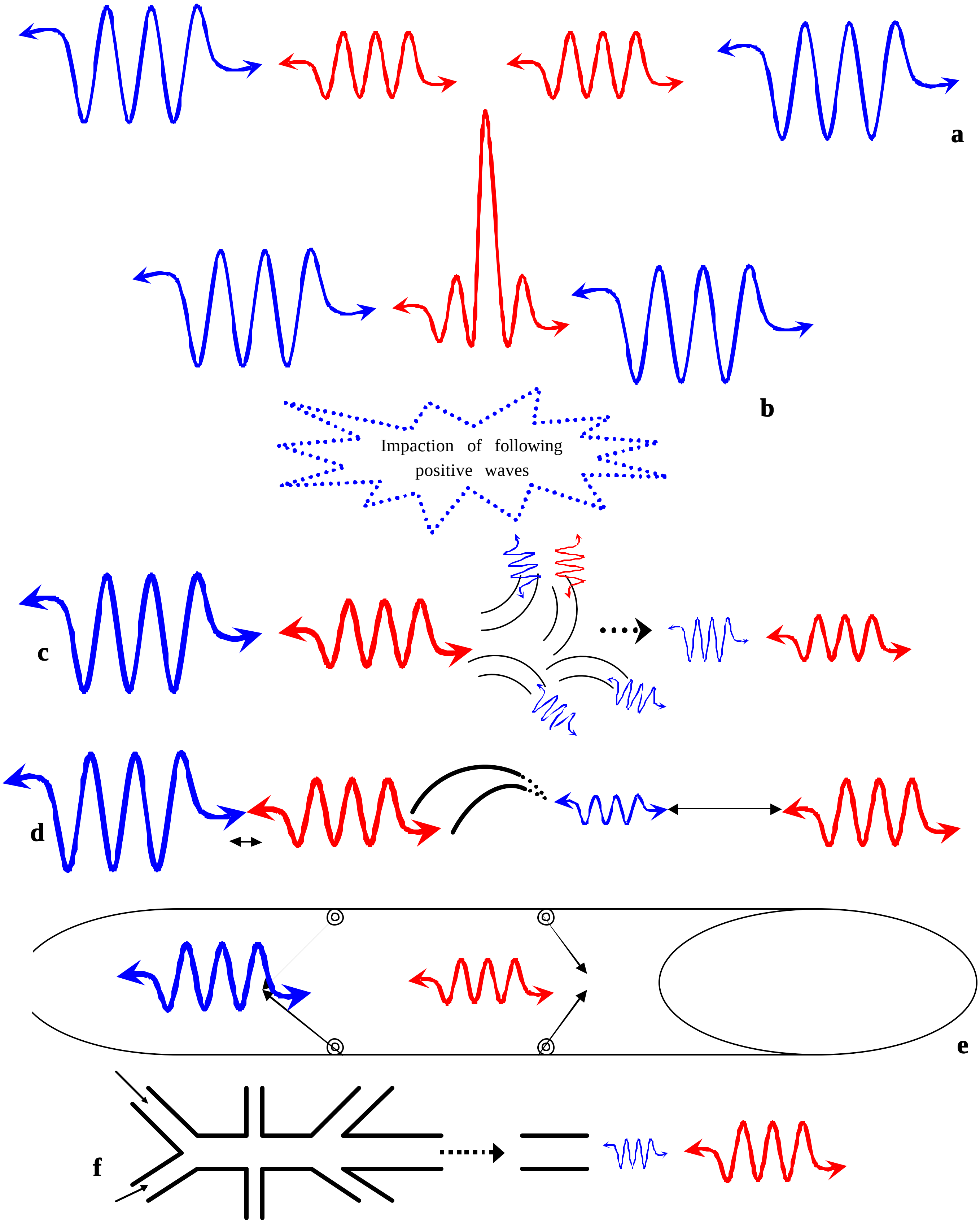
Box of figs 2: (**a**) One (non-complete) ring of cases, contained of collection(s) of cavities as in figs (**1c** & **1g**). The fig (**2a**) denotes a ring of cases, but just two against ones are shown and internal cavities are disappeared too. The form of the ring(s) & shape of cases are characterized by technical demands only for more profit. The surrounding inside them have to be as similar as possible to idealized systems (best vacuum, least temperature, flattest surfaces for least dispersive effects, ...). The tentacles are connected to a control division to be ordered in specific configurations.

There are arbitrarily numbers of lines and columns, each composed of a collection of perforated asymmetric cavities. The holes depicted can have arbitrary numbers, shapes and locations up to being in favor of mentioned purposes. In the absence of a standard theory of NED, the region of best constructive synthesis (denoted by light turquoise oval region in **2a**) should be specified experimentally (as a good news, the system controlled by fuzzy logic [54], can identify such a region after several experiences [55]). Besides, as a nontrivial result, ordering the pointwise CECs (i.e., DEC, WEC, NEC) violations would be more difficult, because one has to sift the positive contributions of the averaged effects (so, a knowledge of microscopic properties of the averaged integrals seems necessary). One could set up structures of various generalizations of the rings; e.g, different shells, layers, & any ingredient which have such rings. More explicitly, NE of a Casimir system considered as a possible support of spacewarps, happens in a restricted region between the plates. Hence, one needs a more extensive region of distribution of NE for traversability conditions of the metric. In the interacting model of [6,22], we can imagine the interaction at inside region could have induced effects penetrated to outside. Indeed, if prediction of bending the light ray at coming out of an asymmetric perforated system of cavities, would be observed, one can provide a plan for better distribution of NE than before. The plan is as follows: Existence of NED is equalivalent to its gravitational manifestations, i.e., defocusing of photons (ANEC violation) and slower particles (other CECs violations), so as soon as detection of a region having such properties, we must strengthen it by placing the similar regions caused by other collections near together. Various configurations can stretch the NED region, permitting it to be extended without the technical limitations of a simple Casimir setup, hence (longer range of interactions in the fields as a more seminal approach, not being limited to study NED merely at inside regions), the objections of FR [44] to MTY model [31] are modified. Two examples are (gradual) "opening" of plate-like systems (**2a**), and spiral arrangement of systems to pursue an initial detected NED area (point) (**2b**). Indeed, one aim is: "not" overwhelming & vanishing of NEDs by (diverging) positive contributions in free space. Also, we should search for stress-energy tensors more general than

$$T_{mn} = (r + p)\, u_m u_n + p h_{mn} + \Pi_{mn} \qquad \text{(B2)}$$

(discussed in [58]) to have a more pleasant and more reachable physics. That is, providing the least restrictions to l.h.s. of (A1) dependent to every appropriate application.

Figs (**2c** & **2e**) show two sides of a NE producer tube – definitely, AWEC violating effects – as [22]. The strategies for effective accumulation of NE are used in this case either with more confidence. In (**2e**), the cavity yields NE from two end sides (or one side NE, the other PE). The motion of the plates would be confined to a globally (probably non-complete) circular path (in which the plates in figs (**2c** or **2e**) might be ordered so that after any coming near, find the proper initial configuration *again*) and there are shutters to stop any lossy effects. Also, parallel lines in (**2e**) (might) denote resultant of the assemblies of (**1c**) or (**1g**). If two plates have attractive force on each other representing NE, two adjacent plates might find repulsive effects causing PE somewhere else (**2d**); As a cure for suppress such effects (except of shutters), one may attach an insulator surface to outer side facing to next cavity (**2f**). Fig (**2g**), shows a case contained of tubes as (**2c** & **2e**), they are placed in different orientations in order to give powerful constructive synthesis of interacting fields; i.e., a great flow of NE [124].



Box of figs 3: Engineering scenarios for obtaining more NE. (Blue waves represent NE effects while Red ones represent positive energy (PE) effects);

In Fig (**3a**) two N/P pairs close to each other, negative ones find constructive synthesis and are induced (guided) to another –a deviated– course (e.g., by a gravitationally repulsive mouth of a TW [see **§** below]), while positive ones are not so (**3b**). This scenario is imaginable for oriented (not-directed) impacts too [60].
In Fig (**3c**), a NE front is adjusted so that lots of tiny TWs are created which disperse following PE. The conclusion is a NE front with a weaker following PE.
In Fig (**3d**), NE makes a dynamic TW so that passes though it and outruns PE (by not allowing positive wave to pass through the TW or have a perfect passage). Of course, the arisen distortions are immediately flattened by PE (up to Planck scales, so a statistical analysis is needed), but any decrease of destructive effects of PE has a great value. In enormous scales, i.e., if one does repeat the tests (**3c, 3d, 3e**) for many times, the probability of more separations between N/P waves, would be increased and even small additional separations can have desired effects.
In Fig (**3e**), the course is decorated by some up and down hooks. The hooks must be lightest stringy structures; e.g., one column of stable metallic hydrogen molecules. The NE effects repel the hooks and continue the path with a weaker strength lost for that work, but during traversing PE, the hooks turn out to be obstructive tools. As a good news, if one designs the end points in an appropriate style (e.g., **S** shaped in which leads to a tight junction), it is expected the PE effects be extremely diminished or even completely blocked.
Fig (**3f**) shows a maze-like collection where at a first glance makes the magnitudes of N/P waves equal through absorbing additional PE by the walls and warming them because of slim course (or increase of velocity?), also by disturbance effects (like sudden twists, etc; mostly for PE), combinations of above tricks in its circuit, and *local* influences like temporary mechanical changing of some parts, gives an output of more NE. Such engineering give contributions to the program of making (B2) more complicated. A strategy which was also followed in Box **2**. (Dependent on extraction of suitable amounts of NE)

§: As [44,61], let $U^m = dx^m/dt = (U^t,0,0,0) = (e^{-\Phi(r)},0,0,0)$ be the four-velocity of an observer who is at rest with respect to the r,q,f coordinate system. The observer's four acceleration is

$$a^m = \frac{DU^m}{Dt} = U^m{}_{;n}U^n = \left(U^m{}_{,n} + \Gamma^m_{bn}U^b\right)U^n \qquad \text{(B3)}$$

For the MT metric [62] we have

$$a^t = 0, \quad a^r = \Gamma^r_{tt}\left(\frac{dt}{dt}\right)^2 = \Phi'(1-b/r), \quad \Phi' = d\Phi/dr \qquad \text{(B4)}$$

From the geodesic equation, a radially moving test particle which is initially at rest has the equation of motion $\frac{d^2r}{dt^2} = -\Gamma^r_{tt}\left(\frac{dt}{dt}\right)^2 = -a^r$. A TW will be called "attractive" if $a^r > 0$ (observers must maintain an outward-directed radial acceleration to keep from being pulled into the TW), and "repulsive" if $a^r < 0$. For $a^r = 0$ the TW is neither attractive nor repulsive.
In that spirit, one can visualize that, up to creation of last entrance mouth to start of being used by passengers, all mouths are repulsive, and in the last stage, they lose repulsion just proportional to the mass of ingoing passengers, – in a certain time – & then the situation converts well.

However, this is not all of the story. There are circumstances in which QIs are violated.

In [47], Hayward states: "Wormhole horizons are two-way traversable, while black-hole & white-hole horizons are only one-way traversable. It follows from the Einstein equations that the NEC is violated everywhere on a generic wormhole horizon. It is suggested that QIs constraining NE break down at such horizons. However, when Pfenning & Ford [48] generalized this method to static spacetimes, the inequalities for static observers were found to depend singularly on the norm of the static Killing vector, which physically encodes the gravitational redshift. For instance, for a Schwarzschild black hole, the inequalities break down at the horizons [48,49]. Thus it may be conjectured that QIs generally break down at trapping horizons. For instance, in spherical symmetry one may take the Kodama vector [50] as the choice of time determining the preferred vacuum state. The Kodama vector has vanishing norm at trapping horizons, becoming zero or null for static wormholes & black holes respectively." (Box **6**)

In addition, there are significant criticisms & counterexamples mainly for applicability of QIs in constructing artificial TWs [51,52,53].

Also, in the model of interacting quantum fields used before [22], it was shown QIs are violated. Further, interaction of matter & spacetime in different polarizations & squeezed states might yield other violations of QIs. (Box **5**)

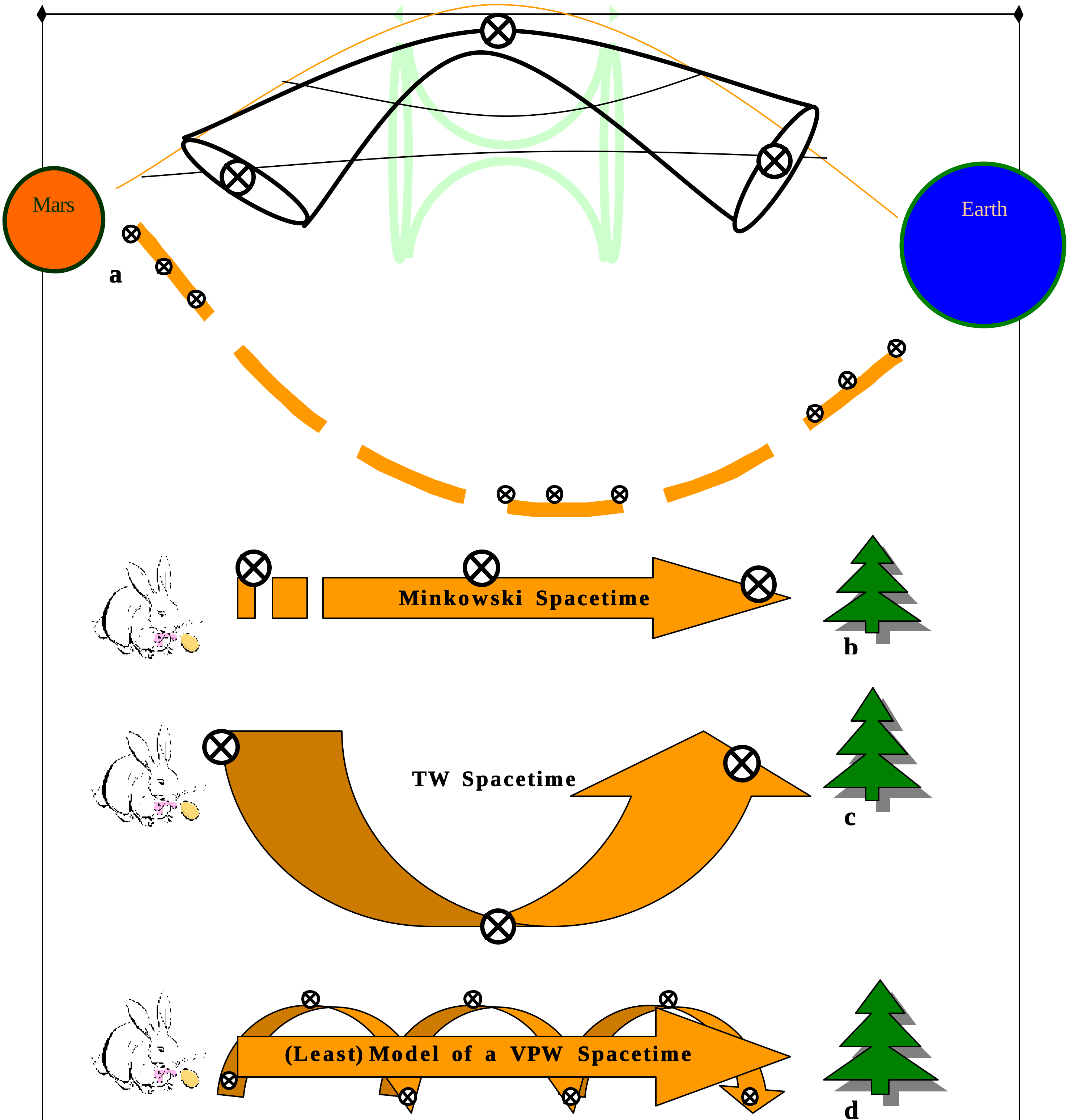
At last, if one accepts the nature enforces severe constraints on producing macroscopic amounts of NE due to QIs, there is still possibility of adopting a program which physical manipulations in addition of *engineering* tricks can change the situation. See Box **3**.

5. Stability

It is possible to arrange the spacetime – by a simple flare-out condition – in which various CECs (mostly NEC) be on the verge of being violated [8,63,64], but since the TW has to be stable, NE is unavoidably necessary for any kind of usage; there are more conditions too [37]. Actually, all features of increasing the NE (except of untractable divergent behaviors; e.g., interaction of traveler's body to huge amounts of EM) are in favor of a TW.

For example, in [65] Poisson & Visser consider linearized radial (spherically symmetric) perturbations around some assumed static thin-shell TWs solution of the Einstein field equations. This permits them to relate stability issues to the (linearized) equation of state of the EM which is located at the TW. One important case in their paper is the energy conservation relation containing the surface energy density s, surface pressure p, & the radius of the throat (which is a function of time $a \mapsto a(t)$):

$$\frac{d}{dt} s\mathrm{A} + p\frac{d}{dt}\mathrm{A} = 0 \qquad (5)$$



Box of figs 4: (**a**) It seems reasonable, "finite" amounts of NE, could cause a TW connecting a "finite" set of points of spacetime (both *mathematically* and physically). In other words, in studying intra-universe TWs, the 'universe' under consideration should be quite in the usual scales & not of cosmic dimensions (or connecting two points *arbitrarily*). Therefore, the concept of limitedness of effective range of operation of a TW modifies the asymptotic flatness (via reconsideration of the definitions of the flaring-out conditions [see (A3) & (A4)]) for the practical applications, dynamics of metric, ANEC violation with finite interval of integration, i.e., different from $(-\infty,\infty)$, etc. So the strategy is: Go to large distances by 'partial' effecting on spacetime *not* "an overall distortion".

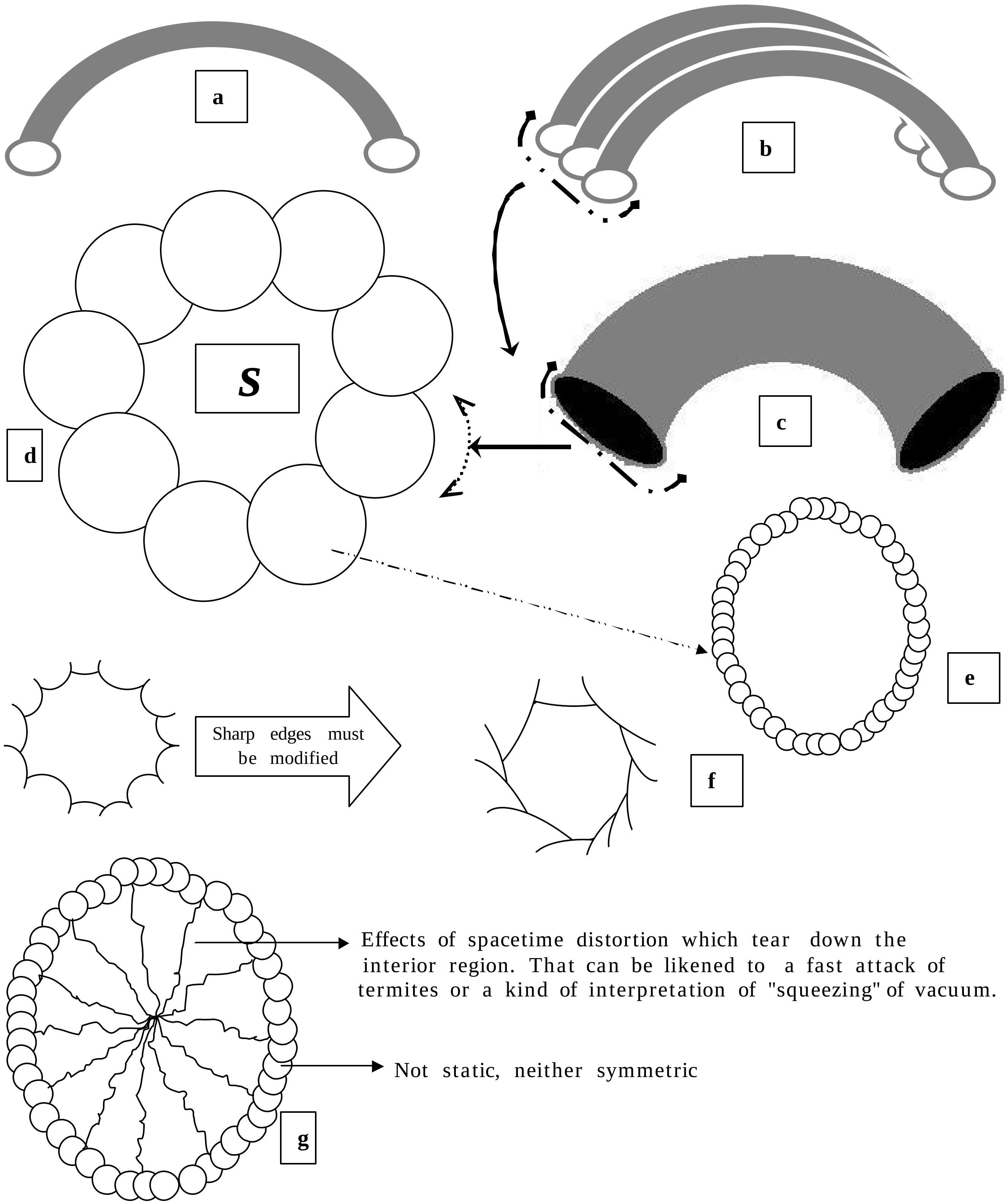
Other three figs show approaches for faster achievement to a destination. First rabbit increases her velocity in a Minkowski spacetime to reach to tree (**b**). Second rabbit passes through a general (somehow static) TW system. Indeed, a kind of shortcut is used in arriving to tree (**c**). Nevertheless, the way third rabbit chooses cannot be called a shortcut model (in traditional manner). Instead, she does some *leaps* to avoid of both high curvatures (and consequently severe energy requirements) and slow flare-out (as is [73,89,90, and almost 82]).

By means of a balance among dynamics of every jump, its geometry and topology, suitable choices of shape and redshift functions, and auxiliary back-reactions, one may expect third rabbit leaves the first one behind in a racing by temporary modifications in spacetime, equivalent to sudden peaks in her velocity; similar to a doper racer.

As a matter of fact, more studies need to be done on probable time confusion in (**d**), but "as a conjecture", a combination of Novikov consistency conjecture plus Hawking chronology protection conjecture [3] might act against conversion of a VPW to a closed timelike curve.

Therefore it seems reasonable by intelligent chains of (TW+WD) systems, presenting essential energy requirements and spacetime configurations, a transition by spacetime shortcut can occur at least for non-dreamy distances; sending humans or goods to earth-like planets in the solar system, like Mars, Europa, etc.

Remark : To circumvent "the fact that at 300 times FTL impacts with asteroids comets supernovas or Black Holes also photons of background radiation Doppler blueshifted to energies of the radiation synchrotron impacting the Warp Bubble would disrupt the Warp Field as for TWs", one can focus to identifying some front points (denoted by tiny crossed circles) along with adjusting secure margins to avoid damaging the VPW. That must be done by the common detection equipments of a spacecraft using the VPW for its propulsion; similar to an intelligent guided missile which avoids of hitting to mountains, anti-missiles, etc. Besides, because of different situation of the throat(s) in *dynamic* and static TWs [63], "in order to use a TW from a realistic point of view to travel from Earth to Andromeda Galaxy for example you must have one of the mouths here and the other mouth in Andromeda Galaxy of course ... and who creates the other mouth in the first place?", locating the other mouth *during the operation* and convincing to lower scales such as Earth-Mars (instead of Earth - Andromeda !) can be an answer to that problem, at least for the first generation of VPWs. At last, the drawback of "having an event horizon (Penrose diagrams, Kruskal-Szekers or Boyer-Lundquist coordinates) and lack of directing the creation of a mouth in a desired place distant from Earth", seems to be removed by choosing an element of VPW as the *subluminal* WDs & exact locatings like military missiles, recent discoveries on Mars, etc [126].



Box of figs 5: First, there is a TW (**a**); If we arrange e.g., three of them near to each other (**b**), it seems to be able to gain one with bigger size in mouth and throat (**c**).

Now, the question is: What would happen if we extend that settlement to a complete ring (or any closed curve) of mouths which none of them are completely distinct (i.e., have common regions)? (**d**)

Definitely, what would be the destiny of the middle region (***S***)? Is it possible in principle to create a large TW, by the mentioned arrangement of numerous tiny ones (**e**)?

Can it improve the energy requirements? and what difference is between the static and dynamic TWs in such configuration?

Without an explicit interpretation of (island–like) PED regions, (however those probably cause instability effects to a required shortcut), one can think to cleaning them by a 'vacuum cleaner'–like device (temporarily). The NE-issuing tube (Box **2**) *cleans* those *dirty* regions of PED.

If resonance of the effects of smaller TWs and converting the system to a bigger resultant, be possible, that can yield a great result; i.e., the creation of regions causing squeezing of vacuum and NE.

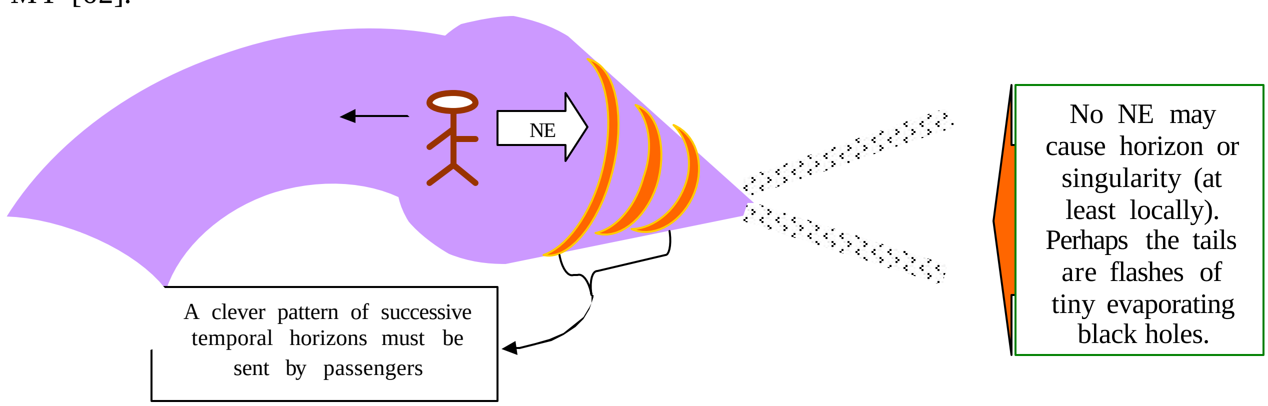
Notes : Breakthrough in the behavior of tiny TWs with oriented squeezing and polarization of vacuum as (**5g**), would give major contributions to any influence on spacetime which cause macroscopic demonstration (and as a good news, there would be less necessity to artificial pumping of EM). That would be done through a special imposition of thoughtful regions of NED (created by the very curvature of spacetime see [16,91,97]) & constructing (not necessarily self-maintained) TWs. As a suggestion, during a surgery the system applying the fuzzy control, would find the best order after some repeats.

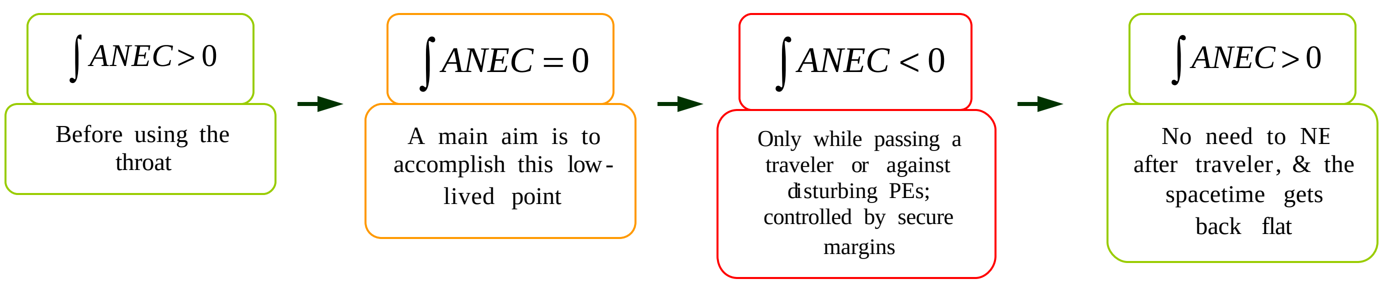
However embedding diagrams for dynamic TWs are misleading, but above figures are for better intuition. Also electromagnetic scanning [56] may clarify the shape of process. That's similar for the Boxes **7**, **8**.

Box 6: Some remarks on a desired geometry:

If one can construct a TW, nothing would be more vital than the comfort of the passengers. Therefore, there always must be a confident secure margin. That finds more importance when one does a "balance game" in a time-dependent geometry by the boundary of, having or not having the essential conditions which define a TW. (Maybe, on (in)equalities of geometrical properties, one can perform a "balance game" and uses the advantages placed on the borders; that's the case for previous discussions too.)

Indeed, the concept of the horizon has a great potential to the energy improvement. This is based on two facts; breaking QIs on the horizons, and providing suitable conditions for "volume integral" theorem of total amount of EM proposed by Visser, Kar & Dadhich [72,92]. One may consider it as a generalization of cut-off imposed versions of TWs energy discussions, started by 'absurdly benign' solution of MT [62].





If one assumes the two-way horizons of TWs, by breaking QIs on the horizons either [98], dynamic TWs would then encounter to an alternating cleaning the ergoregions, (for more insight to interconvertiblity or bifurcation of such (double) trapping horizons, see figures, e.g., at [93]), one might deduce the concept of event horizon is totally dependent to presence of EM. Therefore, that seems an appropriate idea, which by creation / annihilation of numerous horizons in the lifetime of a dynamic TW [99], one could gain a dominant control on less constraints of NE [100]. That is more interested to subtle experiments when you meet 'small' needed amounts of NE. Note in huge amounts, there are two destinies for a dynamic TW; converting to a black hole or an inflating universe! [47,93,94,95].

However, due to [64], temporary suspension of the violation of the NEC at a time-dependent throat also leads to a simultaneous obliteration of the flare-out property of the throat itself [63]. So, we must pick up a formalism containing limiting behavior to that problem; thus, note Eq (B5) represents the arbitrarily small total amount of EM, provided $e^{g(r_0)} \to 0$, where is the throat of the TW. The limit actually refers to a sequence of TWs.

But in an asymmetric version, up to a flare-out corresponding to be on the verge of violating the NEC – ideal condition equals to zero energy density, more values require faster return to normal situation – any conduction of perturbing effects e.g., diverging fluctuations at particle horizons for the case of WD with $v_s > 1$ [101], away from passengers to elsewhere of spacetime would be useful.

Now the second fact: The skeleton of the metric is of Kuhfittig [82], subjected by an imposition of VKD [72]. It means when one considers

$$\int [r + p_r]\ dV = 2\int_{r_0}^{\infty} [r + p_r] 4p\ r^2 dr \qquad \text{(B5)}$$

as a suitable measure of the 'amount of EM' required to maintain a TW, the spatial slices must be the same as of Eq (7). Therefore the 'proper volume' of the region of EM in the Kuhfittig III model [73] accepts further reduction (see p. 23 of [80]), and "an extensive region of NEC-violation" up to a cut-off to both satisfy QIs & *radial* tidal constraints necessary for human traversal [102] meets a new dynamical diminution.

As a matter of fact, there seems a deep inconsistency between a real TW & severe restrictions of QIs (in all models, e.g., MTY [31], Kuhfittig III [73,125], cut-off imposed versions, etc). Regarding continuity implications (to functions & derivatives), the above scheme tries to circumvent the problems such as, unsafely being close to a Schwarzschild wormhole, causality violating discrepancy between the traveler's clock & of an other observer in the external universe (i.e., an appropriate traversal time), and enormous blue/red-shifts. Therefore, any theoretical framework more relaxed than QIs would give new promising consequences.