Sailing the Archipelago

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I made it to the forward deck
I blessed our remnant fleet –

Leonard Cohen

1. Introduction: Multiverse and the Archipelago

We live on a small island. We have not yet ventured much beyond our immediate locale on this small island; even our own inconspicuous location still holds great mysteries for us. It seems that we find ourselves near the mountain peak on our island, but even that is uncertain. Only recently we have discovered that there are other islands besides our home scattered in a vast (possibly infinite) ocean. And the ocean is dead. It is not just devoid of fishes, algae or anything similar – it is empty of any **conceivable** form of life, it epitomizes the absence of life itself. But recently we have made our first attempt at mapping our surroundings and, in particular, sketching the outline of the ocean shores. In this, some of us bear similarities to the great adventurers of the European Age of Exploration in XV and XVI centuries; only in this case the explorers are not sea-captains and conquistadors, but theoretical physicists, cosmologists and philosophers.

Before I explain the central metaphor of the **Archipelago of habitability**, I wish to emphasize how difficult and different from our modern experiences cartography once was (splendid recent histories of the subject can be found in Wilford [2001] and Ehrenberg [2005]). Imagine huge tasks facing the explorers of old: to map – for instance – a newly discovered South Seas archipelago with rather crude geographical and navigational means at their disposal. No *GoogleEarth* or aerial reconnaissance surveys or photography. Quite the contrary, the explorers of old had to rely on quite uncertain and imprecise navigational aids – including often very vague time-keeping. It is hardly a wonder that their maps were usually very wrong in detail, and at best imprecise and fanciful. This is a point to keep in mind when we discuss this much vaster and more abstract Archipelago.

Five physical science developments which have taken place in the last 10-20 years mark the intellectual convergence necessary for discussing the Archipelago:

(I) The emergence of the "new standard" cosmological model of the flat universe dominated by dark energy (after 1998; e.g., Perlmutter et al. 1999), connected with the predominance of the inflationary paradigm; especially chaotic inflation seen today as the generic form of the process (Linde 1986; 1990).

(II) Astrobiological "revolution" (1995-today), offering a new unified framework for the old set of questions about the place of life and intelligence in the cosmic context (for beautiful reviews see Des Marais and Walter 1999; Darling 2001; Grinspoon 2003).

(III) The rise of string theory as the best candidate for the "Theory of Everything" and realization of its huge number of low-energy sectors (or vacua) forming a "landscape" (Susskind 2003; Freivogel and Susskind 2004).

(IV) Elucidation of anthropic principle(s) as observation selection effects by Leslie (1998) and Bostrom (2002), leading to rejection of the old-fashioned teleological (mis)interpretations.

(V) The rise of an "information paradigm" in many sciences, from biology to fundamental physics to computer science (Lloyd 2000; Coffey 2002; Fredkin 2003; Chaitin 2006; Tegmark 2008).

All these developments have partly contributed to the tremendous increase in work on various theories of the **multiverse** – a term promoted (if not truly invented) in popular culture by the great British novelist Michael Moorcock.[1] In general (though the particulars may vary), multiverse is a set of large, causally connected cosmological domains – conventional universes. The multiplication – no pun intended – of multiverses has occured over a wide spectrum of disciplines, from cosmology and mathematics to quantum information theory to philosophy; see a review of Tegmark (2003) and popular books of Rees (1997) or Vilenkin (2006) on the subject. In the rest of this paper, we shall use the anthropic landscape of string theory as the prototype physical realization of the multiverse, while strongly emphasizing that it serves just a placeholder and no conclusion is crucially dependent on this choice.

The idea of the Archipelago of habitability has been introduced by Max Tegmark in his intriguing paper on the relationship between mathematical and physical worlds (Tegmark 1998). Conceptually:

> **The Archipelago of habitability**: a set of regions in the parameter space describing those parts of the multiverse which are hospitable to life and intelligent observers of any kind.

Physically, the Archipelago is a subset of the anthropic landscape of either string theory or any other overarching "Theory of Everything" with multiple low-energy solutions ("vacua"). Thus, the Archipelago is part of the abstract space defined by whatever physics determines the structure of the multiverse. It is both logically and physically contingent on the reality of the multiverse; but that is still not saying much, since as Tegmark (2003) emphasizes, simple variants of the multiverse are completely uncontroversial and legitimate consequences of our firmly established cosmological theories. Whether the multiverse is infinite, as in the currently popular cosmological theory of eternal inflation, or finite, as in some construals of the string theory landscape, reflects directly on the structure of the Archipelago as well.

What is an island (cf. Houellebecq 2005)? It is a set of parameters describing habitable universes which are close in the parameter space; whether we can specify the meaning of "closeness" beyond simple intuition depends crucially on the structure of the multiverse itself. In other words, the multiverse imposes a natural or at least convenient metric upon the Archipelago. By definition, there is at least one island in the Archipelago – our home island. If the multiverse contains arbitrarily small variations in the constants of nature or cosmological parameters or even the mathematical shape of physical laws, than it is reasonable to conclude that the Archipelago is as dense as the remainder of the multiverse; for instance, it is clear that the change in the coupling constants of

[1] See Moorcock (1995), esp. the new introduction.

fundamental forces of 1 part in 10^{50} in comparison to those actually existing in our universe – not those actually measured! since we are unable to measure them to such precision yet – will not change anything in the habitable status of our universe. If such minuscule variations are actually realized within the multiverse, a universe otherwise described by identical laws and parameters to our also belongs to our habitable region = our home island. It is easy to see that various constants and parameters of the multiverse play the role of geographical coordinates in maps of terrestrial archipelagos. Thus, if we start on a land point in, say, Sumatra, and continuously (or in sufficiently small steps) change either longitude or latitude along any chosen direction, we are bound to end up in the ocean. Similarly, if we start with a universe like ours and continuously change some parameter – say the strengths of forces, or the baryon-to-photon ratio, or the cosmological constant – we shall inevitably end up in a universe lacking pre-requisites for life and observers. However, in the same manner as it is possible to start in Sumatra and by a non-continuous increase in longitude to end up in some other island, for example Borneo or New Guinea, it is possible that after a large interval of non-habitability, our parameter again enters an interval which (with appropriate changes in other parameters) enables the existence of life and observers. Thus, even if we did not know anything about possible different habitable universes (see §3), it would still be both rational and prudent to allow for existence of other islands beyond our home island in the Archipelago.

Copernicanism is inscribed in the Archipelago picture right from the start – we are dealing with the widest conceivable ensemble in which our universe can be embedded to avoid assigning it any special status. From the very beginning of the Copernican revolution, we have witnessed the loss of special status for wider and more encompassing environments. First we concluded that there is nothing special about Earth, then about Sun or the Solar System. In 1920s, we finally realized that even our Galaxy, the Milky Way is just one of the billions of galaxies spanning the distance to our cosmological horizon. Now, in the 21. century, we should not be surprised to learn that, in spite of the apparent fine-tuning, there is nothing special about the whole our cosmological domain – our universe – as well (cf. Ellis, Kirchner, and Stoeger 2004). Only in that manner will our universe's obvious property of being home to life and intelligent observers be adequately and naturalistically appreciated.

The exposition in the rest of this paper is as follows. After a brief survey of the role of astrobiology in defining the Archipelago (§2), I analyze recent discoveries of other habitable islands in some detail, with an emphasis on their philosophical significance, rather than technical issues and computational procedures (§3). This prepares the ground for putting recent resurgence of the anthropic arguments in cosmology into a new context, as well as for answering some of the common and/or fashionable criticisms of the anthropic reasoning (§4). Most of the latter are based upon the alleged teleology of the anthropic reasoning, a widespread and quite robust meme which infected large segments of both philosophical and scientific populations, but nevertheless misleading and wrong. Finally, some summarized points and prospects for further research are given in the concluding section (§5).

2. Astrobiology as Mapmaking

We are lucky enough to live in an epoch of great progress in the nascent discipline of astrobiology, which deals with three canonical questions: How does life begin and develop? Does life exist elsewhere in the universe? What is the future of life on Earth and in space? A host of important discoveries has been made during the last decade or so, the most important certainly being a discovery of a large number of extrasolar planets whose number increases on almost weekly basis; the existence of many extremophile organisms possibly comprising “deep hot biosphere” of Thomas Gold; the discovery of subsurface water on Mars and the huge ocean on Europa, and possibly also Ganymede and Callisto; the unequivocal discovery of amino-acids and other complex organic compounds in meteorites; modelling organic chemistry in the atmosphere of Saturn’s moon Titan; the quantitative treatment of the Galactic habitable zone; the development of a new generation of panspermia theories, spurred by experimental verification that even terrestrial microorganisms easily survive conditions of an asteroidal or a cometary impact; progress in methodology of the Search for ExtraTerrestrial Intelligence (SETI) studies, etc. However, the epistemological and methodological basis of astrobiology and SETI presents us with a hornet's nest of issues which have not been, with a few exceptions, tackled in the literature so far.

One such issue is the role of astrobiology in mapping the Archipelago of habitability which, it is worth repeating, is a continuous part of the general parameter landscape – with the sea level defined on the basis of our understanding of habitability. Even more, habitability determines the altitude profile of an island in the Archipelago: how high will it be, will it have steep or shallow slopes, great plains or even depressions inside it, etc. We all agree that our universe is hospitable to at least some forms of life and there is very strong empirical evidence that significant changes in values of some or all parameters will lead to an inhospitable universe (the subject matter of classical anthropic “fine-tuning” arguments, to be considered in the next section). Asking about the sea shores of the Archipelago is tantamount to asking the famous question “What is life?” (Schrödinger 1944).

There are many ways of surveying the Archipelago, just as in the terrestrial geography one can either do satellite imaging, or search for water, or look in the infrared, or do mineral prospecting, etc. It is impossible here to give more than a cartoonishly brief sketch of some of the directions currently being actively pursuited (although not always, or even not mainly, recognized as belonging to the astrobiological domain; but such is often historical pathway of young interdisciplinary fields). Research dealing with preconditions for life and observership as we know them in physical, chemical or geological sense is a part of the mapping endevoar; most of the research currently done and published, *inter alia*, in novel journals like *Astrobiology* or *International Journal of Astrobiology*, as well as in the older ones like *The Origin of Life and Evolution of the Biosphere*, belongs to this category.

On a more general level, the task of astrobiology obviously depends on our ability to recognize life even in its strangest (i.e., most removed from the terrestrial experience) forms. Contrary to arbitrary assertions of some critics, the tradition of speculative thinking about the alternative forms of life is as long as the astrobiological thinking itself (for a classical example, see Shapiro and Feinberg [1982], and for a modern one, Dyson [2003]). Speculations – now supplemented by computer simulations – whether life can be based of silicon, or fluor compounds or solid-state physics or even nuclear forces belong here and are likely to increase in number and quality in the future. The prevailing tendency even in the most conservative astrobiological circles has been to **increase** the robustness of life (e.g., in discoveries of various extremophiles), thus justifying heightening of our expectations for the possibility of life elsewhere in the multiverse.

A particular form of surveying is embodied in research on **artificial life** (Alife). From a rather eccentric game of computer scientists (though with august ancestry with von Neumann), it has become an important mainstream research discipline with wide-ranging influence and an increasing number of applications within fields such as evolutionary computation, cellular automata, genetic algorithms and even evolutionary art (see the review of Bedau 2003). It is often stated that the goal of Alife is **recreating** biological systems in a digital environment, but there are at least some distinguished researchers, such as ecologist and computer scientist Thomas Ray, who claim that such experiments are actually creating a new kind of life (Ray 2003). Clearly, if this strong Alife thesis turns out to be correct, this will have important epistemological implications for cosmology as well, since numerical experiments of Ray's type would make the sea shores of the Archipelago amenable to much more precise probing – something alike to the revolution of Gerardus Mercator and Abraham Ortelius in cartography in 1560s.

Finally and most pertinently to our goal, we can ask, with Tegmark (1998) what are minimal conditions for a physical environment containing intelligent observers. Tegmark lists three basic conditions, namely (1) complexity, (2) predictability, and (3) stability. (He imposes them on mathematical structures describing arbitrary physical laws, in accordance with his "Platonist" position on the relationship between mathematical and physical worlds; but the usage of these criteria does not really hinge on this philosophical viewpoint.[2]) The first necessary condition is almost self-evident: even the most ardent physicalists are unlikely to deny that excessively high level of complexity is the reason why, among other things, we have not yet managed to create living or intelligent beings in the laboratory. The other two criteria are meaningful if we consider the operation of measurement by which knowledge is received by observers, which requires both that the results do not fluctuate too much in the past or the future to preclude the use of inference for past experience and the existence of habitable conditions at least during measurements. Of course, these are necessary, but not sufficient criteria for habitability. The search for the sufficient criteria, and thus the outlines of the Archipelago, continues.

All this (and, arguably, much else) constitutes an "extended mandate" of astrobiology – and the one immediately answering all the conventional criticisms (e.g., Cohen and Stewart 2002): it, almost by definition, "looks outward to the general, rather than inward to the particular". It will, hopefully, give much more satisfactory answer to one of the perennial problems of science – Schrödinger's question – in the most general multiverse context.

3. Voyages of Discovery

Geography and cartography would be senseless without an appropriate metric; in the terrestrial case, the units of length (such as kilometers and nautical miles) combined with the angular coordinates (such as longitude and latitude), provide us with a hugely successful description of any explored piece of landmass or ocean. The extension of our analogy to the cartography of the Archipelago of habitability emphasizes the analogous role of changing various parameters of physics (including the very form of low-energy physical laws). Let us forget, for the purposes of this section, the issue of altitude of points on an island (i.e. the degree of habitability) and suppose that we are dealing with the single-contour map. Classical anthropic arguments from fine-tuning amassed significant empirical evidence that we cannot change **much** parameters describing our universe, at least as long as we keep other parameters constant (for compilation of the evidence up to

[2] Even more precisely, Tegmark uses the term "self-aware substructure" in order to pose the problem as mathematical, since on the Platonist viewpoint an observer is nothing else than a part of wider mathematical structure. But the same general reasoning about the criteria applies if we (i) regard observers as physical systems only approximated by mathematical descriptions, and (ii) have a particular physical mechanism of introducing variations (like the spontaneous symmetry breaking in the inflationary cosmologies).

mid-1980s see Barrow and Tipler 1986; somewhat updated is the review of Hogan 2000). For example, the initial low entropy of our Big Bang seems excessively fine-tuned (Penrose 1989; Ćirković 2003), as does the amplitude of the primordial density perturbations seen as anisotropies in the cosmic microwave background (Tegmark and Rees 1998). This would mean that our island is a rather small one, since even small changes in any single coordinate (with other coordinates kept constant) would lead us quickly to the ocean shore. In such a situation, it seems natural that early anthropic thinkers concluded that our island is the only one in existence. They were wrong, but not because of some ulterior and heinous agenda, as it is sometimes implied by the opponents of the anthropic reasoning; it was perfectly reasonable for them to think so, similar to the rationality of hypothetical ancient philosopher of Easter Island, pondering a huge ocean surrounding his home.

But the contemporary sailors of the Archipelago have been able to refute this prejucide. In the often-cited and almost as often poorly understood study, Aguirre (2001) finds a "cold" Big Bang model – a counterfactual one with low entropy-per-baryon in comparison to our actual Big Bang – which is habitable even according to the very high standards posed by the **terrestrial** kind of life. This type of universe is also capable of producing structure, such as galaxies and stars, as well as chemical building blocks of life; and there is a sufficient time for chemical and biological evolution in such, in other respects drastically different astrophysical environment. Some opponents of the anthropic reasoning hailed this result as a long-awaited refutation of the alleged "anthropocentrism" of such reasoning (Cohen and Stewart 2002; Smolin 2004). What Aguirre has in fact done is to discover another habitable region in the parameter space – another island of habitability!

While this is a seminal result, it is a far cry from the "disproval" of anthropic reasoning. In fact, the supporters of anthropic reasoning have stronger reasons to cheer for the Aguirre's bold exploratory voyage: it actually demonstrates that such exploration is meaningful, and that the questions of various measures of probabilities of observing various can, at least in principle, be answered quantitatively and operationally. The role of astrobiology sketched in §2 above finds some expression in the endnote of Aguirre's paper which states:

> I have assumed that the number of independent measurements in a subuniverse is proportional to the number of suitable stars, neglected such effects as, for example, high metallicity leading to more planets upon which multiple civilizations might arise in a single solar system. I have also neglected factors like extinction-causing impacts, radioactivity-induced plate tectonics, etc., which are possibly but not clearly necessary for the evolution of observers.

All these (and many other) factors clearly belong to the domain of astrobiological research. Thus, any elaboration of the classical anthropic arguments, no matter whether supportive or undermining them, straightforwardly necessitates use of astrobiological knowledge. And Aguirre shows that we need such knowledge from our universe (and our experience), even when dealing with other, disconnected parts of the Archipelago.

But Aguirre's is not the only island different from our home island discovered so far. In fact, the island discovered by Harnik, Kribs, and Perez (2006) is both larger (in both senses discussed above) and more remote from our home universe: they investigated nothing less than a set of conceivable universes without weak interaction ("weakless" universes). Before engaging in the analysis, they explain the methodology:

> We do not engage in discussion of the likelihood of doing simultaneous tunings of parameters nor the outcome of statistical ensembles of parameters. These questions are left up to the ultraviolet

> completion, such as the string landscape, which is outside of the scope of effective field theory. Instead, we are interested in ‘‘running the universe forward’’ from a time after inflation and baryogenesis through billions of years of evolution. We will exploit the knowledge of our Universe as far as possible, adjusting standard model and cosmological parameters so that the relevant micro- and macro-physical outcomes match as closely as possible. We emphasize that this is really a practical matter, not one of principle, since any significant relaxation of the ‘‘follow our Universe’’ program would be faced with horrendously complicated calculations. Put another way, there is probably a wide range of habitable universes with parameters and structures that look nothing like our Universe. For us, it is enough to find one habitable weakless universe about which we can make the most concrete statements, hence matching to our Universe as closely as possible.

This truly looks like a bold sailors' manifesto! The difficulties bound to be encountered by any stray explorer in the dangerous waters ("horrendously complicated calculations") are explained, and the independence of the basic approach on the form of the multiverse (i.e. string landscape or any other) explicated. This makes the results of the study still more impressive, since they find at least a single piece of rock above the water in the midst of the ocean – an apparently habitable universe missing so crucial an ingredient of our world as one of the four fundamental low-energy interactions. Whether this is just a rock protruding from the waters or a tip of much larger island is unclear at present; Harnik et al. honestly admit that much.

Why, then, these authors repeatedly perceive themselves as refuting or undermining anthropic arguments? The reasons are at least twofold. First, most anthropic arguments in the literature (like the one on setting of the electroweak scale, criticized by Harnik et al.) are narrowly or even badly formulated. They are based on narrow-minded calculation of the effects of small (one order of magnitude or so) changes in a small number of parameters, and not on a true insight in the underlying physics, which could point the way in which multiple parameters could be varied – at least in principle – to retain the habitability. A clear parallel here is with the misguided "rare Earth" (cf. Ward and Brownlee 2000) arguments in astrobiology of the form: "if there were no Jupiter in the Solar System, the Earth would have been catastrophically bombarded by large comets and complex life would have been impossible." Such arguments are clearly dead-wrong, since they contain internal contradiction: if there were no Jupiter, there wouldn't have been a Solar System as we know it at all! It is doubtful whether the Earth would exist at all in such a scenario, and everything else would have been different as well, so the comparison to the realistic case is pointless.[3] Instead, we need a more refined and detailed **physical insight** in the evolution of planetary systems. The same applies to habitability of universes in the anthropic landscape or any form of the multiverse.

The second reason why the studies such as Aguirre's or Harnik et al.'s are often misconstrued is that such conclusions are based on the misconstrual of the anthropic reasoning itself (e.g. Cohen and Stewart 2002). The widespread perception of anthropic principle(s) as teleological naturally leads to the erroneous conclusion that habitability is if not identical (such an extremist position is relegated to ID proponents and other religious circles), than at least **centred** on the criteria for evolution of the *homo sapiens*. Along this way of thinking, it is enough to show that the change of some parameter for a factor of a few or an order of magnitude is incompatible with some prerequisite for life as we know it (read: *homo sapiens*) to argue that this parameter must be anthropically selected. In the language of our central metaphor, it is enough is you could walk a hundred steps in a particular (single!) direction and get your feet wet to prove that you live on an island. This logic is anthropocentric and flawed; it has nothing to do with the real meaning of anthropic reasoning. It may as well be true that we are indeed living on an island (after all,

[3] I thank Chris Chyba for pleasant discussion of this point.

even Eurasia can be regarded as a large enough island!), but the justification for it is wrong. And yet, it is appealing for the same extrascientific reasons we shall return briefly to in the next section: rear-guard actions of both positivists and teleologians leading to a widely accepted anthropocentric “noble lie”.

In a more general sense, studies such as the one of Chavanis (2007) on white dwarf stars in an arbitrary number of dimensions, or Adams (2008) on stellar evolution with unconventional parameters, are part of the research helping us elucidate the Archipelago. We do not perceive any direct connection between us and white dwarfs at present, but the elegance and simplicity of the problem of such physical objects in *D* dimensions gives us a feel of the approaches and ways of thinking necessary for performing the sketched cartographical task. Obviously, the interest for this sort of research has increased significantly in the last couple of years – we might be on the verge of true multiverse Age of Exploration!

4. The Anthropic Selection and Detraction

Steven Weinberg claimed to have predicted the existence of a small positive cosmological constant in the anthropic manner more than a decade before its actual observational discovery (Weinberg 1987). This theoretical success opened the way for dramatic expansion of the anthropic arguments in cosmology. In the current cottage-industry of multiverse predictions in theoretical physics, the special role is reserved for the equation giving a probability that some observer anywhere in the multiverse measures a feature *X* (e.g., Carroll 2006):

$$p(X) = \frac{\sum_n \sigma_n(X) V_n \rho_n^{\mathrm{obs}}}{\sum_n V_n \rho_n^{\mathrm{obs}}}, \quad (1)$$

where the index *n* labels all possible vacuum states (all different low-energy “*physicses*” or different universes); in current versions of string theory there is a finite number of such states, although it is huge (10^{500} or so; see Susskind 2003), but in principle it could be infinite. The latter case could pose some interesting problems in the theory of probability (cf. Hamkins and Montero 2000; Tegmark 2008), but in general will not preclude the usage of Eq. (1) with appropriate weightings. V_n is the spacetime volume belonging to the universe *n*, ρ_n^{obs} is the density of observers in the same universe, and

$$\sigma_n = \begin{cases} 1, & \text{if universe } n \text{ has property } X \\ 0, & \text{otherwise} \end{cases}. \quad (2)$$

In principle, V_n is calculable from our understanding of cosmological physics, although in weird enough universes it might be impossible to calculate in practice (or at least in finite time available to human cosmologists!); it is also likely to be infinite in some or most of the universes, so some appropriate weighting procedure is certainly necessary. But, of course, the biggest uncertainty comes from the quantity ρ_n^{obs}, the density of intelligent observers. It is usually assumed to be proportional to the density of galaxies, being the main features of the structure of our own universe. But this is at best uncertain, and at worst fantastically wrong for islands outside of our own home island. Obviously, more sophisticated astrobiology is needed here.

How can the concept of the Archipelago of habitability help us elucidate Eq. (1)? Even very cursory thinking points toward the way, which I shall dub "altitude weighting". Obviously, even islands of identical shape on the map can have vastly different habitabilities – the universes in two groups could have vastly different density of observers. We have thus far discussed only surface coordinates of islands in the Archipelago; but their essential property (which makes them islands) is their altitude profile. Very high points (analogues of the volcano peaks of the Hawaii islands) represent sets of parameters describing extremely bio-friendly universes, in contrast with bare rocks protruding from the waters, where lifeforms are possible but unlikely or very rare. The same pertains to intelligent observers: regions of high altitude will contain the predominant fraction of the entire set of observers in the multiverse. This corresponds to high values of ρ_n^{obs} in such regions of the parameter space.

Thus, in order to make anthropic arguments cogent against the background of the Archipelago, we need to weight universes by their "altitude", i.e. the measure of habitability. Clearly, this is a task for astrobiology in the widest sense: as discussed above, the very definition of the Archipelago is contingent upon the resolving the issue of criteria for life to arise in a naturalistic manner. But in order to get the altitude profile, we need much more further effort – we need at least some hold on the emergence and dynamics of intelligent observers, traditionally in the province of SETI studies (and the recreational discourse of SF books and movies). On the other hand, there is no discontinuity here: by studying already "traditional" astrobiological themes, like the Galactic Habitable Zone (Gonzalez, Brownlee, and Ward 2001; Lineweaver, Fenner, and Gibson 2004) we expect to survey viable SETI targets and assess the density of extraterrestrial civilizations, even if some specific modifications are made when we consider intelligent observers rather than just complex lifeforms (e.g., Duric and Field 2003; Ćirković and Bradbury 2006). Obviously, much further research needs to be done in that direction. But the encouraging news is that there are several approaches developed recently which encapsulate elements of the future whole picture, notably the counting of observer-moments discussed by Bostrom (2002) in philosophical, and the counting of the number of possible observations in a particular universe devised by Starkman and Trotta (2006) in physical domain. There seems to be an epistemological similarity between this proposal of weighting by the astrobiological description ("altitude" in terms of my central metaphor) and the suggestion of Trotta (2007; Trotta and Starkman 2006) that a "fully Bayesian approach" could resolve the difficulties with anthropic arguments, especially the lack of universal weight criterion for ρ_n^{obs}.

In practice, this task is enormous; perhaps generations of astrobiologists will pass before we get close to a quantitative precision. But the enormity of the task should not detract us from the fact that it is a well-defined problem from the start. If anything, it should demonstrate how utterly wrongheaded is the classical criticism that the anthropic reasoning is "lazy man's approach to science" (Pagels 1998).

In the remainder of this section, I shall explore some of the more conventional criticisms of the anthropic reasoning and how the metaphor of the Archipelago may help us refute or undermine them.[4]

[4] I am skipping more bizarre anti-anthropic "arguments" occassionally surfacing in the literature, an example being the charge that "anthropic principle" is a misnomer (Mosterin 2004, after many others). Being, in principle, sympathetic to a programme of excising misnomers from the scientific discourse, may I humbly

4.1. Betrayal of the Enlightenment?

There is a rather strange tendency in some scientific and philosophical circles to regard anthropic reasoning as a sort of "betrayal" of the allegedly sacred traditions of scientific explanation dating from the times of Galileo and Newton. Although this form of criticism has never been clearly and unambiguously formulated, it haunts many recent discussions (e.g., Smolin [1997, 2004, 2006], Pagels [1998] or Mosterín [2000, 2004]). Roughly, it alleges that we should rationally explore nature as seen from a completely neutral and immobile "Archimedean" point, not as real, physical beings evolved through various processes of physical, chemical and biological evolution, but as disembodied abstract observers. Only the latter viewpoint, suggest these researchers, yields true causal explanations and satisfy the overall goals of science. Anthropic reasoning does not conform to this model and, consequently, "has no place in physics or cosmology" (Pagels 1998). In my view, this is entirely wrong on several counts, including some purely epistemological ones, dealing with the nature of explanation of contingent facts, though I cannot enter this complex topic here.

Instead, I would like to point out that such rear-guard positivist attitude is in itself bound to end in either contradiction or mysticism. Are observers natural? It is somewhat surprising to see that the same critics of anthropic reasoning tend to believe in physicalist explanations of mental phenomena, including the observership itself. This makes the criticism of the anthropic reasoning somewhat close to hypocrisy: if observers are part of the nature to be studied, how can one justify ignoring their properties? Should not they be regarded as parts of the wholeness of reality to be rationally and logically explained? Quite the contrary to assertions of the detractors, the anthropic program of elaboration of observation selection effects – and outlining the properties of the Archipelago of habitability in terms of our metaphor – is the continuation of the Copernican revolutionary spirit in overcoming apparent specialness of not only the Earth and life on it, including humans, but of the very physical laws, associated mathematical structures, and our universe in general.

What is really betrayed here – and with good reason – are relics of the Cartesian dualism which underlined the mechanicist philosophy of classical physics for centuries, as well as positivist attitudes in the last century; that is, until the modern science progressed sufficiently to tackle the most general questions on the origin of universe, life and intelligence. To approach the problems dealing implicitly or explicitly with the properties of observers (e.g., problems in quantum physics or cosmology or astrobiology) in the same manner as, for instance, classical physicists studied motion of a pendulum or the planet Uranus is not just epistemologically naive, it is plain wrong.

4.2. How Cozy Is Our Universe?

A charge occassionally brought against anthropic reasoning (especially in older, pre-Weinberg literature) is that its proponents blithely assume that our universe is at the peak of habitability, i.e. "the best of all worlds" regarding life and intelligence, although it is clear that one could conceive a universe significantly friendlier for life than our own (echoes of this position can be found in, e.g., Maynard-Smith and Szathmáry 1996). While such panglossianism might indeed have been true for the now discarded teleological

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ask that the interested philosophers start with concepts such as "Hubble's constant", "planetary nebulae", "forbidden spectral lines", or even "quark colors" and "flavors"?

construals of the anthropic principle(s), there is no reason to retain such misperception any more.

On the contrary, it is clear from the idea of "altitude weighting" sketched above how easily the Archipelago view can resolve our difficulties. There is no *a priori* reason for us to believe that we are at the top mountain peak of our own island, not to mention the entire Archipelago. One may sympathize with Tegmark's (1998) view that the requirement that "[o]ur observations are the most generic ones that are consistent with our existence" is a useful prediction in the multiverse, but its meaning depends on the qualification of "our" type of observer (human? human-like? planetary? carbon-based? evolved?, etc.). We cannot say in advance whether our home-island is mostly flat or very rugged. Our real altitude and the height profile of our vicinity is a matter for rational investigation; we should conduct many numerical experiments and calculate how far in various directions we are from both the peak(s) and the shores of our home island. Suppose, for the sake of simplicity, that there is just a single peak, corresponding to the most habitable universe in our region. Our distance from the peak is equivalent to answering the question how much various parameters can be simultaneously changed in order for the number of predicted observers to increase. Our distance from the sea level is equivalent to answering the question how much various parameters can be simultaneously changed in order for the universe to cease to be habitable. We may have different intuitions as to the answers to these questions, but the bottom line is that this is a problem to be answered by quantitative astrobiological modelling.

4.3. Imprecisely Defined Shores?

Klee (2002) laments the fact that the anthropic arguments are numerically imprecise, often for an order of magnitude or more, and stretch the meanings of terms "of the same order of magnitude" or "of similar order of magnitude". He calls it "mathematical sharp practice" and concludes that it is usually motivated by the extrascientific, namely theistic, reasons. Apart from the old moral about taking up the sword and perishing by it (see Walker and Ćirković [2006] for Klee's own numerical mistakes, as well as for conflating of mathematical and physical fine-tunings), this criticism sounds like a whiggish charge that Pedro Álvares Cabral or Fernando de Magallanes did not use precise maps; their errors in navigation were often an order of magnitude or more larger than what we in the GPS age know about the **correct** geography. Are their discoveries less appreciated for that undeniable fact? Do we mock them – or, in contrast, celebrate their achievements, while emphasizing simple means at their disposal? Understanding that we are at the very beginning – an overstatement, if anything – of the exploration of the Archipelago of habitability leads naturally to expectation of large errors in positioning its shores – how can it be otherwise?

4.4. The Problem of Swarming Advanced Observers

In a thought-provoking paper, Olum (2004) argues that "a straightforward application of anthropic reasoning and reasonable assumptions about the capabilities of other civilizations predicts that we should be part of a large civilization spanning our galaxy." This has been quoted by Carroll (2006) and others as an instance of anthropic reasoning giving unacceptable results even within a single universe. Starting from the assumption of an infinite universe (following from the inflationary paradigm), Olum conjectures that there are civilizations much larger than ours (consisting of about 10^{10} observers). Spatial extent and amount of resources at disposal of such large civilizations would lead, in principle, to much larger number of observers (for example, 10^{19} observers). Now, even if 90% of all existing civilizations are small ones similar to our own, anthropic reasoning suggests that the overwhelming probabilistic prediction is that we live in a large civilization. Since this prediction is spectacularly unsuccessful on empirical grounds, with a probability of such failure being about 10^{-8}, something seems clearly wrong here.

There are several ways out of Olum's problem, as he points out himself. For instance, we may conceive the redefinition of the concept of an observer in the future (e.g., in the "hive-mind" scenarios popular in the SF discourse), which would skew the Bayesian factor and resolve the paradox. But even if we restrict ourselves to our universe, there are less strong medicines at our disposal. It can be shown that the knowledge of the particular present epoch, together with some rather uncontroversial astrophysical assumptions, is sufficient to undermine – or, more precisely, to **postpone** – the applicability of Olum's argument (Ćirković 2006). However, this way out may not be open when we generalize to the entire spacetime of the Archipelago – in that case we should ask the question: "Why we don't find ourselves in a universe where almost all observers belong to large civilizations?" Although this question has not been addressed this far, a possible approach could be that such universes are strongly suppressed for some at present unclear reason (say the observer-moment count peaks strongly before a typical large civilization anywhere can develop). Obviously, this remains a problem for the generalized anthropic reasoning.

4.5. The Problem of Freak Observers

One of the recently discovered difficulties facing application of the anthropic reasoning to the multiverse are so-called freak observers, also called Boltzmann's brains. Although prefigured by Price (1996), Rees (1997), Bostrom (2002) and some other thinkers, it was explicitly posed in the "disturbing" study of Dyson, Kleban, and Susskind (2002), as a consequence of the new standard cosmology dominated by constant vacuum energy (positive cosmological constant). Such a cosmology leads asymptotically to a future-eternal de Sitter spacetime. This is equivalent (in the eschatological limit of future eternity) to a thermal state with a characteristic temperature $\sim 10^{-29}$ K. On a first glance, such low temperature coupled with the extreme dilution of matter at such late epochs is unlikely to yield anything interesting, but in fact like any thermal system, such late vacuum will fluctuate at a nonzero rate per unit spacetime volume. And out of such fluctuations, in the large eschatological time spans, complicated systems, e.g., intelligent observers can arise, again at non-zero rate. Since de Sitter spacetime is eternal, such "freak observers" will be infinite in number (in fact, exponentially increasing) and thus completely overwhelm "normal" observers, like us, emerged through physical, chemical, and biological evolution. Why, then, are we not freak observers?

Several recent publications show that the threat has been taken seriously. In particular, Page (2006) argues that the simplest answer to the puzzle is that the future is finite and that our universe will vanish before Boltzmann brains start to dominate the total observers' census. On a more optimistic (at least from the point of view of non-freak observers) side, Carlip (2007) shows that the time variation of fundamental constants can lead to a small measure of freak observers, and Vilenkin (2007) demonstrates that the same effect is achieved by the bubble nucleation in de Sitter vacuum under some fairly reasonable assumptions.

From the present point of view, the problem of freak observers is easily generalized to a multiverse, since de Sitter spacetime is usually regarded as the source of inflationary self-reproducing fractal. Rather uncontroversial aspect of anthropic reasoning is that we need to suppress the measure of freak observers in the entire Archipelago (and, clearly, Page's recipe will not work for a multitude of universes) in order to explain our evolution and our ordered observations. Although this problem will require further work, good news is that there are ways out, such as shown by studies of Carlip and Vilenkin.

5. Prospects for an Age of Exploration?

In this essay, I have argued that the bridge between cosmology and particle physics on one side and astrobiology (and some further "mundane" disciplines, like artificial life, evolutionary theory, etc.) can be achieved through exploration of the cosmological parameter space. The Archipelago of habitability – the set of habitable domains in the multiverse – seems to be a useful metaphor which puts our efforts on elucidation the relationship of astrobiology and cosmology in a wider perspective. It offers directions for tight interdisciplinary collaboration between scientists interested in properties of life and those interested in a grand-scale structure of physical reality. It also offers great opportunities for philosophers – notably to generalize the classical anthropic reasoning to the entire Archipelago, where all teleological and other unnecessary baggage is explicitly discarded. The relationship between the Archipelago and other multiverses containing intelligent observers considered in both philosophical (e.g., Lewis 1986) and scientific literature remains to be elaborated.

I have also attempted to argue that we may expect a true Age of Exploration of this Archipelago. Is this taking a metaphor too far? Not necessarily, even beyond Borges' idealistic statement – following Chesterton – that a really good metaphor cannot be taken too far; considering how dramatically has the informatic revolution changed our thinking about the "simulated" vs. "real" worlds, it would be premature to claim that the theoretical research on the other habitable universes is any more intrinsically speculative than the very concepts of "computer virus" or "genetic algorithm" or even "quantum computer" were a quarter of century ago. Not only studies on the observable consequences of the existence of other universes (e.g., Aguirre, Johnson, and Shomer 2007), but also intriguing arguments on simulating entire universes (Bostrom 2003) are pieces of the same dynamical and tightly entangled and intertwined – as "natural" and "artificial" in Magritte's painting – research activities at the dawn of the new millenium. Further elucidation of this perennial dichotomy could be a bonus philosophical benefit.

At the end, I have used the concept of the observer here in purely passive sense, in accordance with the only valid interpretation of anthropic reasoning as observational selection. But what about the vast future times for intentional action accorded to us (and other intelligent observers in the multiverse) by physical eschatology? Could, at least in principle and in the fullness of time, the rules be changed and parts of the landscape modified by intentional influence, like the build-up of artificial islands in today's world (Figure 4)? Fortunately, at least two visionary pioneers strode with giant steps in that direction; we should keep silent in the huge shadows of Olaf Stapledon (1937) and Stanislaw Lem (1999, this volume).

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FIGURE CAPTIONS!

Figure 1. A prototypical archipelago (according to LeGuin 2004).

Figure 2. *Colorful Ensemble*, the 1938. canvas of Wassily Kandinsky (Musée National d'Art Moderne, Centre Georges Pompidou, Paris) can be regarded a symbolic representation of the multiverse: no colour is special as long as it is embedded in a wider ensemble.

Figure 3. René Magritte's *The Beyond* (1938). The juxtaposition of an artifact and an apparently inhospitable planetary surface (remarkably prescient of our contemporary photographic images of the Martian surface) poses the age-old problem of the distinction between "natural" and "artificial" in the general context.

Figure 4. The Pearl-Qatar: man-made island in the Persian Gulf, covering 400 hectares of reclaimed land. A metaphorical glimpse of Lem's "new cosmogony". (Courtesy of the Middle East Dredging Company; http://www.medcodredging.com/index.html.)