

KARDASHEV'S CLASSIFICATION AT 50+: A FINE VEHICLE WITH ROOM FOR IMPROVEMENT

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SUMMARY: We review the history and status of the famous classification of extraterrestrial civilizations given by the great Russian astrophysicist Nikolai Semenovich Kardashev, roughly half a century after it has been proposed. While Kardashev's classification (or Kardashev's scale) has often been seen as oversimplified, and multiple improvements, refinements, and alternatives to it have been suggested, it is still one of the major tools for serious theoretical investigation of SETI issues. During these 50+ years, several attempts at modifying or reforming the classification have been made; we review some of them here, together with presenting some of the scenarios which present difficulties to the standard version. Recent results in both theoretical and observational SETI studies, especially the \tilde{G} infrared survey (2014-2015), have persuasively shown that the emphasis on detectability inherent in Kardashev's classification obtains new significance and freshness. Several new movements and conceptual frameworks, such as the Dysonian SETI, tally extremely well with these developments. So, the apparent simplicity of the classification is highly deceptive: Kardashev's work offers a wealth of still insufficiently studied methodological and epistemological ramifications and it remains, in both letter and spirit, perhaps the worthiest legacy of the SETI "founding fathers".

Key words. astrobiology – extraterrestrial intelligence – history and philosophy of astronomy

1. INTRODUCTION: KARDASHEV'S LADDER

By their fruits ye shall know them.

Matthew, 7:16

*Once out of nature I shall never take
My bodily form from any natural thing...*

William Butler Yeats

One of the achievements of the early days of the Search for ExtraTerrestrial Intelligence (SETI), more than a half century ago now, was a practical way of thinking how to classify potential search targets by their impact on physical environment. The expression of this was the famous Kardashev's classification (or Kardashev's scale) of advanced extrater-

restrial societies, originally containing three types of civilizations detectable, at least in principle, through practical SETI activities:¹

[I]t will prove convenient to classify technologically developed civilizations in three types:

I – technological level close to the level presently attained on the earth, with energy consumption at $\approx 4 \times 10^{19}$ erg/sec.

II – a civilization capable of harnessing the energy radiated by its own star (for example, the stage of successful construction of a “Dyson sphere”...); energy consumption at $\approx 4 \times 10^{33}$ erg/sec.

III – a civilization in possession of energy on the scale of its own galaxy, with energy consumption at $\approx 4 \times 10^{44}$ erg/sec.

In other words, and in more conventional reading, we are dealing with the following basic types:²

Type 1: a civilization manipulating energy resources of its home planet.

Type 2: a civilization manipulating energy resources of its home star/planetary system.

Type 3: a civilization manipulating energy resources of its home galaxy.

Why is taxonomy important? Claude Lévi-Strauss famously argued that “Darwin would not have been possible if he had not been preceded by Linnaeus.” Historical experience in many other fields of science (chemistry, particle physics, extragalactic astronomy) strongly confirms this dictum. The underlying idea is that the very act of formulating explanatory hypotheses in any field is impossible to perform without an appropriate taxonomical framework. And the historical fact that Linnaeus held views about, say, biological species and their origination and persistence which were *diametrically opposed* to what we regard as basic tenets of the Darwinian revolution does not influence Lévi-Strauss’ conclusion in the least. Linnaeus’ personal beliefs about the origin of species and other taxons were unimportant; his taxonomy was the necessary, indeed magic, key to understanding. This could be immediately applied to the SETI research as well: without prejudicating anything about the outcome of the SETI searches or indeed our theoretical views on the emergence and frequency of extraterrestrial civilizations, we still need a taxonomical scheme indicative of *what*

we might expect to find. Our personal beliefs about the existence of SETI targets and the likelihood of success in the entire endeavor are unimportant; it is the taxonomy that matters. Since hypothetical targets of any particular SETI programme are likely to be wildly non-uniform – due to contingency of biological evolution, if nothing else (Gould 1989, Conway Morris 2003, 2011) – it is only reasonable that such taxonomic scheme is rather coarse-grained. In addition, it should take into account the realistic discrete distribution of matter – in essence, the fact that the distribution of matter (both baryonic and non-baryonic) in the universe is distinctly clumpy and that the emergent complex configurations of matter including living and intelligent and technological systems need to follow that same clumpiness. Kardashev’s Types thus correspond to the most important (from the point of view of any practical search) classes of objects we encounter in the universe, namely planets, stars (with their planetary systems) and galaxies. While minor deviations from the principle that life and intelligence follows the distribution of matter are possible – and indeed desirable – when considering advanced technological societies or taking into account the possibility of interstellar panspermia, these baseline celestial bodies remain the foci of any observational and theoretical search.

Practical *need for a taxonomy* in SETI studies and the *hierarchical distribution of matter* are two legs on which the significance of Kardashev’s scale rests; the other two are *Copernicanism* and *universality of evolution*. Copernicanism (often called the Principle of Mediocrity, the Principle of Typicality, etc.) in the narrow sense tells us that there is nothing special about the Earth or the Solar System or our Galaxy within large sets of similar objects throughout the universe. In somewhat broader sense, it indicates that there is nothing particularly special about us as observers: our temporal or spatial location, or our location in other abstract spaces of physical, chemical, biological, etc., parameters are typical or close to typical. Copernicanism did not only played an important role in the great scientific revolution which coined the moniker, but continues to play a vital part in debates surrounding both classical and quantum cosmology, and in particular attempts to apply various overarching theories of fundamental physics to an ensemble of universes, or the multiverse (e.g. Ellis et al. 2004, Page 2008, Linde and Vanchurin 2010). In the specific case of emerging SETI theory, we have been witnessing attempts to use Copernicanism in order to construct models of the set of habitable planets in the Galaxy (Franck et al. 2007, Vukotić and Čirković 2012, Hair and Hed-

¹Kardashev (1964), p. 219. I shall use Arabic numerals for Kardashev’s types throughout this study, although it is a historical fact that Kardashev, and indeed most subsequent authors, used Roman numerals. Apart from the latter being outdated in general, I have two justifications specific to the problem at hand: (i) Arabic numeration enables natural introduction of fractional subtypes, like Type 2.5 civilization, etc. which was already a problem for Carl Sagan in 1970s – see the quote below; and (ii) there is no Roman numeral for zero, while it seems logically natural to introduce Type 0 civilization (and its fractional successors) as the pre-technological state of any intelligent community. More on this in Section 2.

²See Shklovskii and Sagan (1966) as the “urtext” in this respect; Michaud (2007) or Bennett and Shostak (2011) for the prototypical “textbook” approach to the classification (and indeed most SETI issues).

man 2013) or to constrain the evolution of intelligent observers (Carter 2008, 2012, Gleiser 2010). Kardashev's classification relies on Copernicanism for the underlying assumption that both the increase in energy consumption and the overall resources in the astrophysical environment are in general typical for the universe at large; some advanced exceptions to this will be considered below.



Fig. 1. Academician Nikolay Semenovich Kardashev, the official photo. (Courtesy of the Russian Academy of Sciences.)

The *evolutionary character* of the classification was rather obvious at the time of its origin, amidst all the great excitement and enthusiasm for SETI in 1960s and 1970s. Kardashev and the rest of the “founding fathers” (Drake, Morrison, Bracewell, Oliver, Cocconi, Papagiannis, Shklovsky, and Sagan) clearly perceived SETI as a means for verifying the assumptions about biological *and* cultural evolution they deemed “natural” or “typical” or “default”. Hence came a rather violent reaction of some critics for perceived trampling on their hallowed turf of inquiry, either biological (e.g. G. G. Simpson, E. Mayr) or philosophical (e.g. N. Rescher, E. McMullin, A. Kukla).³ This reaction could not, however, turn the wheel of history backward: the role of mind and intelligence in the universe at large – what

was for a long time the province of a few bold speculative and mystical authors like Tsiolkovsky or H. G. Wells or Stapledon – has become part of the scientific discourse (for the historical accounts see Crow 1986, Dick 1996, Kragh 2004). In this context, the emergence of Kardashev's scale as a practical “rule of thumb” for quantifying this central issue – the impact of intelligence on the physical universe – could be regarded as somewhat symbolical for new directions in thinking which came before their time and are only now reaching fruition.

So, why is Kardashev's classification still of vital importance to us after more than 50 years of (so far unsuccessful) SETI efforts? Answers to this question are multifold. Since 1995, we are in the period which is more and more often referred to as “astrobiological revolution” (e.g. Des Marais and Walter 1999, Grinspoon 2003, Gilmour and Sephton 2004, Chyba and Hand 2005). Rapid increase of our knowledge about the cosmic context of abiogenesis and evolution, as well as realization that there are numerous potential habitats for life in the Galaxy, have been accompanied by the increase in both public interest and institutional framework, including new research departments, new peer-reviewed journals, etc. Entirely new key concepts, such as the *Galactic Habitable Zone* (henceforth GHZ, Lineweaver 2001, Gonzalez, Brownlee, and Ward 2001, Gonzalez 2005), have been introduced in this period, and the wider synergy between various fields of astronomical and life sciences has been achieved within this wide astrobiological front.

And yet, much older SETI research (starting with Project OZMA in 1960, or in late 1950s with the work of Cocconi and Morrison 1959) has not been entirely and happily integrated into the emerging astrobiological paradigm – for multiple reasons, some of which go way beyond the realm of science. On the purely cognitive level, the need for smooth integration is obvious, since it follows the physicalist and evolutionary foundations of all life sciences and technology. SETI studies cannot be anything but a particular research sector of the overall astrobiological effort; however, there have been unhealthy tensions on both sides, from the high level of philosophical approaches (best manifested in the rise of the “rare Earth” hypothesis) down to the overt funding issues and controversies (Darling 2001, Ward 2005). Therefore, it is of much current methodological *and practical* interest to seek those ideas and concepts which could facilitate this integration and enable stable and fruitful interaction of SETI with other sectors of the astrobiological enterprise; this pragmatic argument has been developed in more details in Ćirković (2012). It is even more important to emphasize such integrative concepts in an epoch in which SETI suffers from serious perception and image problems. One such novel and integrative concept has suggested in Bradbury et al. (2011):

³Simpson (1964), Rescher (1985), Mayr (1993), Kukla (2001). Simpson's strong-worded attack on SETI is the prototype of this sort of criticism. See, however, Ćirković (2014) for the possibility of more fruitful reinterpretation of Simpson's criticism with today's hindsight and in the contemporary astrobiological context.

Four strategies that characterize our supplemental approach, what we have dubbed Dysonian SETI (...):

1. The search for technological products, artefacts and signatures of advanced technological civilizations.
2. The study of postbiological and artificially superintelligent evolutionary trajectories, as well as other relevant fields of future studies.
3. The expansion of admissible SETI target spectrum.
4. The further development and study of astrobiology and the achievement of tighter interdisciplinary contact with related astrobio logical subfields, including magisteria like computer science, evolutionary biology, etc.

This leads to an entire new game. We are witnessing renaissance of the *extragalactic* SETI searches, most notably the \tilde{G} infrared search for Type 2.x/Type 3 civilizations (Wright et al. 2014a, b, Griffith et al. 2015) and the search for stellar-powered Type 3 civilizations by using the Tully-Fisher relation (pioneered by Annis 1999; for new attempts see Calissendorff 2013, Zackrisson et al. 2015). Both these original and dynamical approaches share the grounding directly inspired by Kardashev's classification and the Dysonian SETI. There is reason to believe, therefore, that the extent of SETI activities will increase and diversify in the near future, so the present topic will become more and more relevant in the years ahead.

While it was obvious at the time of its origin, subsequent use (and occasional misuse) of Kardashev's scale has obscured the key fact: it was meant to represent a practical guideline for what could be expected in the course of SETI searches, not a profound theoretical insight into the nature of extraterrestrial intelligence. In other words, a rule-of-thumb good mason need before starting work on any building. As Kardashev modestly put it:⁴

[W]e should like to note that the estimates arrived at here are unquestionably of no more than a tentative nature. But all of them bear witness to the fact that, if terrestrial civilization is not a unique phenomenon in the entire universe, then the possibility of establishing contacts with other civilizations by means of present-day radio physics capabilities is entirely realistic. At the same time, it is very difficult to accept the notion that, of all the 10^{11} stars present in our Galaxy, only near the sun has a civilization developed. It is still more difficult to extend this infer-

ence to the 10^{10} galaxies existing in the portion of the universe accessible to observation. In any case, the deciding word on this question is left to experimental verification.

We shall try to show, however, that it is much more than that – and that, with some quite natural refinements and fine-tunings, it can reasonably hope to guide our activities in the SETI domain, *both practical and theoretical*, for quite some time to come (perhaps even to the centennial, if it is not too pretentious to speculate).

The rest of this review is organized as follows. In Section 2, I consider the relation of Kardashev's scale and the notions of detectability, observation-selection effects, and astrobio logical landscape, which can offer some new and provocative perspectives on the place and role of Kardashev Types in our overall astrobio logical research. While Section 3 is devoted to refinements such as fractional Types (notably Types 2.x, of relevance for practical SETI), Section 4 deals with extensions such as Type 4. The theme of linking Kardashev's scale with the future of the universe and the future of humanity is reiterated in Section 5, where I suggest some strategies for undermining the applicability of the scale to practical SETI searches, and on two scenarios demonstrate how we could obtain wrong inferences from naively sticking to the definition of individual Types. In the concluding section, the emphasis on detectability is reiterated in light of the preceding analysis, some orthogonal dimensions for quantifying advanced technological societies are suggested, and several directions for further research are outlined. Table 1 is of particular importance as it presents the maximal generalization of the scale obtained while retaining the organizing principle introduced by Kardashev.

2. DETECTABILITY, SELECTION EFFECTS, AND THE ASTROBIOLOGICAL LANDSCAPE

If you do not expect the unexpected, you will not find it; for it is hard to be sought out and difficult. The pronouncement of Heraclitus of Ephesus obtains a particular flavor in SETI studies, where proponents have often been labeled speculative fan-tasts or pseudoscientists. Kardashev's classification often risks similar fate – its targets are too often dismissed in a hand-waiving manner, without real understanding. And yet, for the reasons given above, the need for some taxonomical form has re-appeared time and again.

We may start with limited and modest attempts at better elucidation and/or modification of the Kardashev's scale, most notably by Carl Sagan, and recently by Robert Zubrin (Zubrin 1999). In 1973, Sagan wrote:⁵

⁴Kardashev (1964), p. 221.

⁵Sagan [1973] (2000), p. 234. The 2000 edition, produced by Jerome Agel, with contributions by Freeman Dyson, Ann Druyan, and David Morrison, as well as fine illustrations by Sagan's old friend and collaborator Jon Lomberg among other artists, is a very welcome testimony on the freshness and importance of Sagan's thought for the new millenium.

The energy gap between a Type I and a Type II civilization, or between a Type II and a Type III civilization is enormous—a factor of about ten billion in each instance. It seems useful, if the matter is to be considered seriously, to have a finer degree of discrimination. I would suggest Type 1.0 as a civilization using 10^{16} watts for interstellar communication; Type 1.1, 10^{17} watts; Type 1.2, 10^{18} watts, and so on. Our present civilization would be classed as something like Type 0.7.

The equivalent formula suggested by Sagan would be

$$n = 1 + \frac{1}{10} \log_{10} \left(\frac{E}{10^{16} \text{ W}} \right), \quad (1)$$

where n is the Kardashev type. It agrees within an order of magnitude with Kardashev's initial estimates, and Type 2.0 corresponds to a civilization managing total energy emitted by the Sun ($1 L_{\odot}$).

This immediately gives us a hint that the energy values in Kardashev's scale should not be taken literally. Solar luminosity is convenient for *us*, since we are accustomed to it in myriad ways, not only in our astronomy, where L_{\odot} is a natural unit for stellar luminosities. But majority of stars in the Milky Way are less luminous than our Sun, and the same holds for majority of stars with potentially habitable planets, even in properly conservative estimates which do not consider M-dwarf systems as habitable (e.g. Vukotić 2010). If we add M-dwarfs, according to recent rather liberal models of habitability (Heath et al. 1999, Tarter et al. 2007) and the conclusion that a large fraction of them possess Earth-like planets (Petigura et al. 2013), the difference between the median luminosity and L_{\odot} becomes profound. And recall that Kardashev's scale is justified *relative* to the each individual extraterrestrial civilization – in a sense, the *value* of a particular milestone is important only insofar it indicates the level of complexity and the magnitude of capacities achieved locally.

By Eq. (1), the humanity in 2012 was of Kardashev's type 0.72. Human energy resources are about 1.77×10^{13} W, roughly equal to the geothermal energy production in Earth's interior (Shimizu et al. 2011) and are still much smaller than the total energy reserves available on our planet, especially if nuclear energy of both fission and fusion is taken into account. It is still much smaller than the total Solar irradiance integrated over Earth's geometric cross-section at the upper atmosphere (about 1.74×10^{17} W). So, there is much more room for growth. On the other hand, the increase in power consumption of human civilization has been exponential, at least during the last two centuries, so any reasonable projection at timescales negligible in astrophysical terms will lead us very soon to the Type 1 and subsequently – barring a global catastrophe – to the 1.x status.

The key emphasis implied by Kardashev's scale – and the reason, I suspect, for its apparent longevity – is the focus on *detectability* of a tech-

nological civilization. Although it is often downplayed in the historical SETI discourse, detectability is clearly the most important parameter in *both* theoretical and practical SETI research (Tarter 2001, Duric and Field 2003) – and the one which is clearly very difficult to quantify in any detail. Kardashev's scale gives a very crude, but still quite functional, way of quantifying the *possible detectability* of a technological civilization. In other words, it gives us a benchmark for gauging and comparing entities in an entirely new and previously unknown context; benchmarks which are at least as useful as those in computer science or risk analysis.

This can be understood in the following manner. Morphology of any biosphere *not* including technological civilization is entirely product of biological evolution (presumably following upon prebiotic chemical evolution). Therefore, such morphologies are located within the huge parameter space of biological evolutionary processes – the “library of Mendel” in Dennett's (1995) famous metaphor. With the advent of intelligent observers and their culture, including technology for modifying physical and biotic environment, complexity increases tremendously and the corresponding parameter space expands. Evolutionary trajectories now lead to many more options and the number of corresponding morphologies exponentially increases in the course of the cultural evolution. Navigating this gigantic parameter space in search for something which could be detected by our meager SETI capabilities is completely hopeless *unless we find some simple way of coarse-graining it*; some crude way of interposing partitions and ordering this myriads of possibilities around a simple handle. This handle is power management/consumption and this task was fulfilled by Kardashev's scale.

The cardinal virtue of Kardashev's particular scheme – and one which has not been entirely appreciated within the framework of the orthodox SETI so far, remaining an active challenge – is that it exactly speaks in the *language of detectability*. It sets the limits to what is achievable, within the known laws of physics, and it is exactly those limits which need to be probed, especially in light of the fact that we now know that some of the Earth-like planets are multiple Gyr older than the Earth. According to the results of Lineweaver (2001), as well as Lineweaver et al. (2004), the median age of the Earth-like planets is:

$$\tau_{\text{med}} = (6.4 \pm 0.9) \times 10^9 \text{ yrs}, \quad (2)$$

which strongly suggests that Copernicanism is correct, at least regarding the ages of potential biospheres in the Galaxy (Lineweaver and Davis 2002, Čirković 2009, 2012). In the same time, the question why we do not (yet) perceive any traces, manifestations, or other sorts of evidence of Gyr-older civilizations becomes particularly pertinent, since naive Copernicanism would suggest that the median age of *technological civilizations* is correspondingly larger than the case on Earth. And, as usually shown in discussions of Fermi's paradox, the difference between timescale in Eq. (2) and the age of our Earth and

the Solar System is more than enough not only to colonize the Galaxy, but presumably also to create a Type 3 civilization.

Obviously, *there is no Type 3 civilization in the Milky Way at present*. This basic empirical fact is worth emphasizing for several reasons, notably because it is one way of formulating the familiar Fermi’s paradox (we would naively expect one to form on known temporal and spatial scales, or at least to witness some of the manifestations of its emerging).⁶ In addition, we have good reasons to assume that there has been no Type 3 civilization *in the past* of our Galaxy. We cannot be entirely certain on this, but considering the fact that we see no traces of Solar System being ever colonized by the galaxy-spanning large civilization, nor any artifacts or traces of such a civilization, we can exclude this possibility with reasonably high degree of confidence. This hinges crucially on the definition of Type 3 civilizations. Smaller civilizations (of what I shall call Type 2.x, see Section 3 below) could certainly exist in Milky Way’s past – whether any exist at present is an interesting problem in SETI studies.

But by both original Kardashev’s and the modified Zubrin’s understanding, there is simply no possibility to reconcile the existence of the local (= Milky Way-based in the further text) Type 3 civilization with the astronomical data.⁷ So, this is another way of formulating Fermi’s paradox or the “Great Silence” problem (Brin 1983, Čirković 2009, Webb 2015). “Being stealthy” is at best in tension with the ascent along Kardashev’s ladder; Type 3 civilizations could arguably be detected over huge distances, and only by making things extremely contrived could one conceive of a “stealthy” Type 3 civilization. The same persistence applies to a vanished Type 3 civilization as well, or even more: since staying stealthy with so large energy consumption would require much intentional effort, it might well be the case that untended artifacts or traces of activity of a galaxy-spanning civilization would be detectable for a long (cosmological) time after the civilization itself goes extinct.⁸ The complete absence of such artefacts or activities discovered by astronomers in

the Milky Way thus far offer support to our working conclusion that there was no Type 3 civilization at any point in our Galaxy’s history. We shall see later how this conclusion can be generalized and to what important constraints in the parameter space it points.

Whether there are Type 3 civilizations in some of the other galaxies within our cosmological horizon remains unknown, but some preliminary indication is that they are at best rare (Annis 1999). There is a large field for possible empirical studies there, in searching for possible outliers in the regularity of “natural” properties of external galaxies, like the Tully-Fisher relation. However, this type of empirical work needs to be based on the further theoretical insight and possible numerical modeling of what we can reasonably expect Type 3 civilizations to look like. This has not been done so far, for reasons probably having to do more with conservatism and bad public image of SETI studies in the scientific community than with modesty.

I shall argue below that even if there is a law-like regularity preventing the emergence of Type 3 civilizations in our past light cone, the concept itself is still quite fruitful. In particular it is due to the circumstance that such items in the classification obtain truly universal value in the cosmological context, where timescales for propagation of signals are comparable to both astrophysical and biological evolutionary timescales. This circumstance links large-scale properties of our universe – especially homogeneity as understood by the classical cosmological principle of Eddington, Milne and other early cosmologists – with the concept of astrobiological evolution. And, of course, in astrobiology we wish to obtain as universal (and “timeless”) perspective as possible: if humanity is, in due course, to become a pangalactic civilization on the timescale estimated by Fermi, Hart, or Tipler in connection with Fermi’s paradox, it is useful to have such a scenario encompassed in a natural way into our classification. It is exactly the concern for *future* astrobiological evolution which prompts a generalization of the classification to include possible Type 4 civilizations, as described in Section 3 below.

⁶Of course, there are some weird possibilities which should be mentioned for the sake of completeness. For instance, one of the hypotheses suggested by Olum (2004) to account for some strange consequences of the anthropic reasoning is that we are actually part of a larger galactic civilization or a “lost colony”, without being aware of the fact.

⁷If somebody still doubts that, let us mention in passing just a handful out of literally hundreds of pieces of empirical evidence for that: the star-formation rate in the Milky Way is similar to that in other normal large spiral galaxies and to our theoretical understanding of the process (Mutch et al. 2011); stellar population colors (Strateva et al. 2001) or dynamical characteristics of its disk are completely in accordance with the models suggested for spiral galaxies *per se* (Kannappan et al. 2002). Even those wildly speculative suggestions about possible explanations of *some* astronomical anomalies by astroengineering (e.g. Beech 1990) are squarely local; it would not be an overstatement to claim that the (present-day) existence of Type 3 civilization in the Milky Way is at variance with the entire edifice of contemporary stellar and galactic astronomy. This same evidence weights, somewhat less conclusively, but still overwhelmingly, against the existence of a *past* Type 3 civilization as well. The latter hypothesis compounds the problem by postulating *extinction* of a galactic-size civilization.

⁸Completely neglecting a very germane problem of what could be a conceivable reason for extinction of a galaxy-wide species (while retaining local habitability, as testified by our existence). Such literally cosmological agency seems to be beyond our current imagination; see, however, Egan (1997), Reynolds (2008).

Recently, we have proposed a concept of *astrobiological landscape* as a useful way of thinking about biological evolution in the most general cosmological context (Ćirković 2012, Ćirković and Vukotić 2013; for a similar concept see also Ashworth 2014). This can be imagined as a (hyper)surface consisting of all evolutionary trajectories starting with the “dead space” taking up most of the universe’s volume (e.g. the intergalactic space) and the epochs before any abiogenesis took place anywhere. Subsequent emergence and evolution of life, as well as the appearance of intelligence (noogenesis) represented a particular manifestations of the increase in complexity as functions of the spatio-temporal coordinates and probably other, yet poorly understood, physical, chemical, etc., parameters which drive the changes in complexity. Only a part of this vast set of possible evolutionary trajectories will be realized within our cosmological horizon, in analogy with the fact that only a small subset of all evolutionary possible forms will be realized in the actual course of the biological evolution on Earth. But in each case, we do not have reason to suspect the existence of the vast overarching set of consistent possibilities (astrobiological landscape or the morphological space of evolutionary biology).

It is exactly within the landscape framework that Kardashev’s scale can be usefully interpreted as a set of attractors of evolutionary trajectories in the high-complexity (“intelligent”) part of the overall astrobiological landscape. Therefore, a task for the true SETI theory, which will undoubtedly emerge at some future point, would be to explain the dynamics of evolving different Kardashev Type civilizations, presumably as a function of the age of a galaxy and the domicile planetary systems and its other astrophysical properties, in addition to a number of chemical/biological/cognitive variables. While this might seem a tall order at this juncture, it is not that much different from the programme of explaining the distribution of algae in terms of marine chemical patterns and water temperature histories (e.g. Van den Hoek 2008), to give just one “mundane” example.

3. REFINING: TYPES 2.x

While Kardashev’s study was pioneering in linking the abstract and vague concept of the “level of development” of a civilization with something as specific and quantifiable as the energy consumption and management, it does have some limitations which could be overcome by simple refinements. One part of the limitations comes from the very nature of the distribution of (baryonic) matter in the universe. While it seems clear that at least a fraction of baryonic matter is used in building an advanced civilization, it is not obvious that non-baryonic matter is entirely unusable in this respect. In contrast, there are some indications that annihilation of CDM particles and antiparticles could become a viable source of energy in physical-eschatological future (Adams and Laughlin 1997). If advanced technological civilizations are capable of utilizing vast amounts of non-

baryonic dark matter distributed through the halo of the Milky Way – and other large luminous galaxies – as either energy source or other industrial purposes, this would not only allow much larger and more complete control of physical environment, but also would lead to civilizational trajectories not bound to stars and their distribution. In other words, there could be 2.x-level civilizations not located (primarily) near luminous stars. Only advances in fundamental physics and successful detection of CDM particles (for a review, see Cheung et al. 2012) will throw some further light on this part of the overall design space.

Why put an emphasis on 2.x types and not, for example, on 0.x or 1.x which are equally legitimate as fractional Kardashev’s Types? The answer is twofold. One aspect is purely practical: we might wish to concentrate on what is most likely to be detected and yet be viable. Suppose that we are planning a practical SETI project and that, counterfactually, we start in the *tabula rasa* state, without any empirical information about the real universe and, especially, the real Milky Way. What would be the best possible target civilization, the one easiest to detect? Clearly, that would be the Type 3 Milky Way civilization. But, clearly, such thing does not exist at present on empirical grounds. In the other extreme, Type 0.x civilizations are clearly empirically allowed at our present level of knowledge and in large quantities; indeed, it is still not possible to decisively reject the possibility of technologically very primitive civilizations of this sort even around the closest stars. So, there is a see-saw situation between detectability and empirical constraints, well-known to the more original SETI thinkers: what would be easiest to detect is the least empirically viable, and more empirically viable targets are proportionally harder to detect. Such a situation implies the existence of an optimum position for meaningful targets, the one which is easiest to detect *when all empirical constraints are taken into account*. It is my conjecture here that this optimum lies in the Type 2.x domain, presumably toward the lower part of the scale.

One admittedly extreme, but still instructive way of thinking about the constraints of detectability is imposed by the Dyson-sphere model for Kardashev’s Type 2 civilizations. Following pioneer suggestion by Dyson (1960), we could expect that sufficiently advanced civilizations will tend to use more and more of the “naturally available” nuclear fusion energy released by its parent star. This would, to an outside observer, look like bigger and bigger part of the stellar short-wavelength UV and optical flux being converted into high-entropy infrared radiation corresponding to low working temperature of the supposed alien technology. Therefore, anomalous infrared sources are excellent targets for the Dysonian SETI attempts and some searches have been made in the Solar neighborhood (e.g. Jugaku et al. 1995, Jugaku and Nishimura 2003, Timofeev et al. 2000, Carrigan 2009); continuation of this tendency consists in already mentioned extragalactic searches, along the lines set by Annis (1999).

The other side of the problem deals with the measure of detectability at each particular step (or tier) of the scale. Whatever the best estimator of

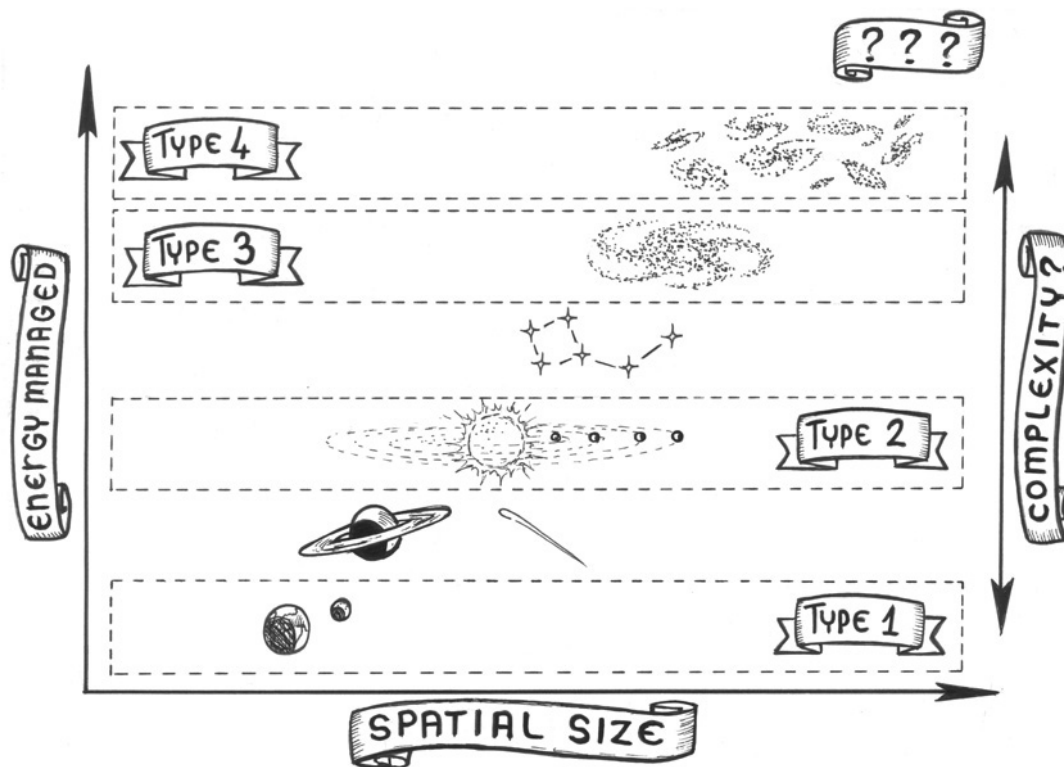


Fig. 2. A schematic representation of Kardashev's types in an extended framework. While the energy management is largely determined by the fraction of cosmic resources at the disposal of a civilization, the scale of increasing complexity is far less certain to establish since smaller structures could, in principle, be more complex than the large ones. Type 4 pertains to the entire universe within our horizon – anything above it is necessary non-empirical and at best dependent on extremely speculative theories. (Courtesy of Slobodan Popović Baġi.)

detectability is – and we do not have a clear view of this in the general case, although of course each particular SETI activity by definition has some estimator built in it – we may reasonably argue that it must be *superadditive*. Namely, if d_m is our adopted measure of detectability of a civilization managing the set of resources m (including the spatial volume controlled), we may argue that it holds that, on the average:

$$d_{m+n} \geq d_m + d_n. \quad (3)$$

So, for example, a civilization managing 5 planetary systems is more detectable than either 5 civilizations managing a single planetary system, or two civilizations, one managing 3 and the other 2 planetary systems. Obviously, communications and transport between the managed systems are “extra” potentially detectable processes. In the worst case, those could be undetectable, so that we would have equality in Eq. (3) above; but in realistic case we expect inequality, even very strong one. Quantity does not make up for quality – or a lack of it.

Note that this conclusion does not imply that the *complexity* measure is superadditive as well. In contrast to most of our everyday experience, smaller structures could, from the physical point of view, be more complex than the large ones. In fact, the ubiquitous process of spontaneous symmetry breaking may cause the total complexity of the whole universe to be quite small (Tegmark 1996)! While this is admittedly an extreme view, it still remains uncertain whether realistic civilizations, human or extraterrestrial, possess a well-defined complexity measure and whether such measure behaves superadditively.

It is clear what this means for practical SETI: specific searches should make a compromise between the volume and duration surveyed on one hand, and detectability measures on the other. Obsession with large number of civilizations, including primitive ones similar to humanity, evolving in parallel (large values of N in the Drake equation) should be toned down, and traces and manifestations of interstellar colonization and appropriate energy consumption should be given higher priority. The spectrum of possible targets should be increased by novel, original and creative theoretical work, conservative hand-waiving notwithstanding.

4. EXTENSIONS AND MODIFICATION

While the galaxy-size civilization managing resources of several times 10^{11} or more stellar objects and possibly even the CDM content may seem as a crown of achievement of any intelligent community, this is not necessarily so. Already Olaf Stapledon, in *Star Maker* envisioned an even greater control over physical and cosmological environment as a possible next stage in the universal evolution of complexity.⁹ Stapledon's narrator has a vision in which he travels through space visiting alien civilizations from the past and the future, before finally encountering the eponymous Star Maker, an "eternal and absolute spirit" who has created all these worlds in a succession of experiments. Each experiment is a universe, and each serves designing the next one a little better. While creation of "basement universes" is a possible activity of advanced civilizations which has already been discussed a bit by humans (e.g. Sato et al. 1982, Farhi and Guth 1987, Holt 2004), one should keep in mind that this of itself does not guarantee further ascent on the Kardashev's scale. Depending on the energy requirements for such feat – if possible within the framework of the correct theory of quantum gravity – it is perhaps not necessary for a civilization to be particularly high on Kardashev's ladder to create a "basement universe". Again, as in the case of possible utilizing of CDM for industrial purposes, only further advances in fundamental physics will be able to judge to what extent these possibilities are realistic; up to that moment, we include them here in an extended classification (Table 1 below) as logically possible.

In the overall context of rather limited *research* interest for SETI issues, it is not surprising that the alternatives sometime proposed have not really become comparable in popularity in spite of being potentially more realistic and useful. For instance, Kecskes (1998, 2009) proposes a complex level-based hierarchy of civilizations ordered in terms of transport, communications, material, and energy resources. It contains four basic types ("planet dwellers, asteroid dwellers, interstellar travellers, interstellar space dwellers"), to which six additional types have been subsequently added. The motivation is to avoid some of the pitfalls and weaknesses of Kardashev's scale, notably, what Kecskes and many others have perceived as "bigger is better" error. While the motivation is sound (and can be illustrated by examples of defeating scenarios; see Section 5 below), the resulting scheme is too complicated to gain wide acceptance any time soon. The discussion of what Kecskes calls measure of "advancedness" clearly shows, however, that much multidisciplinary research, including that in social sciences and economy, is necessary to achieve anything more realistic and fine-grained than what Kardashev's crude scheme offers.

Galántai (2004) suggests adopting designation Type 4 for the natural extension of previous Karda-

shev's types, but presents strong philosophical arguments why we should not hope to detect it at all, even if it exists; some of those were prefigured in a superb story-essay of Stanislaw Lem entitled "New Cosmogony" (Lem 1993; the original was written in 1971). Note that Lem's conclusion is more optimistic in this respect, since he speculates that it is exactly the influence of universe-wide civilizations *on effective local laws of physics* which could give evidence of their existence, while the "classical" scenario of detection or communication is, of course, excluded. In a subsequent work, Galántai (2007) rejects Kardashev's classification entirely and argues that a taxonomy more appropriate for both SETI and future studies would be one based on robustness toward various catastrophic risks. So, from level I where a puny local disaster can destroy civilization, to level V where potentially immortal civilizations, immune to all kinds of threats, could be found, we have a wide spectrum of possibilities. Galántai's scheme is open to criticism that robustness of this kind is rather unlikely to be detected from afar; in addition, the author is forced to admit that higher levels of robustness are connected to wider spatial range, i.e. to the same process of interstellar colonization and resource utilization on which Kardashev's scale is based. In a sense, this is an unavoidable compromise Galántai – together with other Kecskes, Zubrin, and other authors – is forced to make with Kardashev, if the proposed taxonomy is to retain a degree of relevance for practical SETI projects.

We should also consider those aspects of cultural evolution leading to the inward bounds. British astrophysicist John D. Barrow suggests adding a number of civilization types based on the level of control of the *microworld*:¹⁰

Type I-minus is capable of manipulating objects over the scale of themselves: building structures, mining, joining and breaking solids;

Type II-minus is capable of manipulating genes and altering the development of living things, transplanting or replacing parts of themselves, reading and engineering their genetic code;

Type III-minus is capable of manipulating molecules and molecular bonds, creating new materials;

Type IV-minus is capable of manipulating individual atoms, creating nanotechnologies on the atomic scale and creating complex forms of artificial life;

Type V-minus is capable of manipulating the atomic nucleus and engineering the nucleons that compose it;

Type VI-minus is capable of manipulating the most elementary particles of matter (quarks and leptons) to create organized complexity among populations of elementary particles;

⁹Stapledon (1937), esp. chapters 9–11.

¹⁰Barrow (1999), p. 133.

culminating in:

Type Ω -minus is capable of manipulating the basic structure of space and time.

On this scale, the present-day humanity is about Type II-minus, with some aspirations toward Type III-minus in fields like graphene or nanotube research. Obviously, levels of Barrow’s scale are not entirely decoupled from Kardashev’s Types since, for example, it is only reasonable to assume that Barrow’s Type V-minus civilizations could achieve nuclear fusion in more efficient way than just to utilize natural stellar fusion via Dyson-shell-type constructions. Possible or likely interrelations between the two scales present a fascinating topic for exploratory engineering (Inoue and Yokoo 2011, Vidal 2014), which lies beyond the scope of the present review.

5. SOME DEFEATER SCENARIOS: INTRODUS AND THE KRELL MACHINE

In order to facilitate further discussion of limitations of the Kardashev scale, I find it useful to consider possible scenarios of systematically erroneous perception of an advanced technological civilization, escaping the clauses of the taxonomy. Those defearer or outlier scenarios might be of immense interest, since their study could, at least in principle, provide deeper, “low-level” explanations for the regularities underlying Kardashev’s scale. As is usual in science, we arrive to satisfactory insight into law-like regularities by investigating counterfactual cases and exceptions from the rule. The fact that inspiration for these is found in pop-cultural references should not be cause for any greater hesitation in considering them compared to the case of conceiving them as pure thought experiments. On the contrary, examples from literary or cinematographic fiction are advantageous over the pure thought experiments, since often develop significant details (thus guarding us from the coherence gap problem, see Havel 1999). It is also likelier that they will provoke a serious debate on the structure of the problem and possible resolutions.

I have labeled these scenarios *defeating scenarios* (or defeaters), since they represent cases of dissonance between the real states of affairs and our practical prospects of detection in SETI projects, while led by Kardashev’s scale. In the sense emphasized in the introductory section Kardashev’s scale is regarded as a practical tool for thinking and searching; if the reality is dramatically different from any cases included in an anyway flexible and wide framework, then the framework is essentially defeated from the practical point of view (while it might retain some theoretical relevance). While necessarily subjective, these two scenarios – or two bunches of scenarios – encapsulate major points which need further elaboration in more detailed, quantitative models.

Introdus: An advanced technological civilization might consist of individuals uploaded into virtual reality supported by extremely miniaturized

and energy-efficient pieces of hardware containing a finite number of individuals sharing, at the basic level, the same virtual reality (“polises”). Such pieces of hardware are very small – in comparison to astronomical and even geological length scales – and might be undetectable directly over interstellar distances even if no stealth is desired or implemented. In terms closer to the spirit of Kardashev’s scale, their efficiency might be so high that no significant amount of waste heat and other products could be detectable above the natural background. Since a particular ideal of “perfection” has been achieved, no significant interaction with the physical surrounding is necessary – and it might even be regarded as culturally or morally undesirable.

Of course, the Introdus scenario is inspired by Greg Egan’s polises in his imaginative and intriguing 1997 novel *Diaspora*. It is also related to concepts such as John Smart’s “transcension” (Smart 2012) or Kurzweil’s “singularity” (Kurzweil 2005, Chalmers 2010), although these concepts possess other important elements which are irrelevant from the point of view of SETI. The Introdus is characterized by extremely low detectability of a civilization – or an assembly of civilizations – which nevertheless possesses advanced scientific knowledge and *capacity* to perform large feats of astro-engineering if so desired. That capacity remains, as far as Egan’s *fictional* example is concerned, undeployed since there is no impulse, or imperative to do so; even in the face of external catastrophe which prompts the eponymous exodus or “diaspora”, posthuman polises remain stealthy and undetectable. Their cross-section for any actual or even conceivable detection and/or communication technology are extremely low – in dramatic contrast to their *actual level* of civilizational advancement. This could be generalized to a wider class of evolutionary trajectories in which optimization of research, technology and daily life becomes the stable end-value (Čirković and Bradbury 2006).

The Krell Machine: A complementary scenario is the one in which large physical power is actually deployed but for some reason is hidden or remains undetected. In the classical science-fiction movie *Forbidden Planet* (Wilcox 1956), humans become aware of the extinct race of advanced beings of the planet Altair IV, only known as the “Krell”. The Krell had reached a stage of technological and scientific development so advanced that they were able to construct a vast underground machine – about 33,000 km³ of operational volume – with virtually unlimited power; a machine that could turn thoughts into reality and project that reality anywhere on the planet. The energy resources of the Krell machine make them safely in the Type 1.x if not Type 2 domain. (In the same time, the Krell perfected cognitive enhancement to the level that their devices, one of which is shown in the movie, were able to increase intelligence and impart knowledge to any sentient being in a – relatively – non-invasive manner.) But they have vanished, a rather modest interval of 200,000 years ago, leaving only the artefacts and some terrible secrets, upon which reckless human protagonists unwittingly stumble. As a likely a nod to Plato’s

tale of Atlantis, all above-ground evidence of their civilization has been obliterated. By its particular form and location, the Krell machine in the movie is undetectable from afar – but this might not be, and indeed is not expected to be, the essential trait of such mega-engineering feats.

These defeaters are very different in details, but share two key common properties: (i) their detection cross-section is low; and (ii) they can simulate – poorly, perhaps – multiple Kardashev's types at once. From the point of practical searches, they are likely to lead to confusion, since they are both hard to detect at interstellar distances, and even if detected, are likely to be *misclassified*. (In Wilcox's movie, such misinterpretation is one of the generators – pun intended! – of the dramatic plot.)

The concept of *galactic/interstellar archaeology* (Campbell 2006, Carrigan 2012, Davies 2012) is another important idea following not only from Kardashev's classification, but also from the entire unconventional, Dysonian thinking about detecting traces and manifestations. Just as terrestrial archaeology uses artefacts of ancient civilizations to uncover their existence and properties, so interstellar archaeology hopes to do the same for artefacts of extraterrestrial civilizations. It's a “parallel track for SETI” in words of Paul Gilster,¹¹ clearly affirming the relevance of Kardashev's thought.

6. DISCUSSION: DETECTABILITY, RATHER THAN DETECTION

In spite of all limitations and criticisms in the last 50 years, Kardashev's scale remains the most popular and cited tool for thinking about advanced extraterrestrial civilizations. Its one-parameter nature has been regarded, seemingly paradoxically, as both its strength and weakness. The analysis given above and summarized in both Tables 1 and 2, strongly suggests that one-parameter scale is still very much sufficient to both (i) delineate vast domains of our ignorance, and (ii) help formulate research programs and explanatory hypotheses aimed at diminishing that ignorance. Exceptional cases – i.e. evolutionary trajectories of advanced civilizations leading them off the Kardashev scale – are still too rare, bizarre, and seemingly of small practical import; those exceptions are, of course, fully deserving of further study, especially through numerical models and simulations. Coupled with a convenient scale describing the dominion over microscopic physics (chemistry, biology), such as the Barrow scale mentioned above, Kardashev's scale remains the best taxonomical tool for both astrobiology/SETI and future studies.

Thus, in stark contrast to most of the other hot topics of early SETI days (like the Drake equation), Kardashev's classification aged surprisingly well. There is not that many concepts in astron-

omy and related sciences which are still active and used after more than half a century – and in the case of Kardashev's scale the usage seems to be more frequent in recent years. For instance, even cursory search at the NASA ADS database shows that more than a half of publications mentioning Kardashev's scale in the title or the abstract have been published since the beginning of this century.

Near the very end of his original paper, Kardashev offered the following assessment: “The discovery of even the very simplest organisms, on Mars for instance, would greatly increase the probability that many Type II civilizations exist in the Galaxy.” This shows a rather far-reaching awareness of the issues which will much later become part of the “rare Earth hypothesis” of Ward and Brownlee (2000), as well as most of the mainstream astrobiological thinking of today (Chyba and Hand 2005). Universality of evolution, with many peaks of complexity in the astrobiological landscape, leads hierarchically to different fruits in different locales, all having place within the same huge morphological space. The most complex parts of the astrobiological landscape, corresponding to advanced technological civilizations, will open quite new design spaces. In practical terms, reasoning upon which Kardashev's conclusion is based serves as a prescient introduction into the *exploratory engineering* (cf. Armstrong and Sandberg 2013) – we could:

- ask ourselves what kind of technologies is required for each step on the scale;
- construct a research program to outline the necessary resources and skills for each particular item; and
- determine the optimal method of detection and estimate the magnitude of detectability, relative to the natural “noise”.

These steps show how the discussion about SETI is deeply connected with both considerations of engineering and cultural evolution on one hand, and observational astronomy (detectability) on the other. We can even go some steps further and consider epistemological and even ethical consequences following from the discovery of possible extraterrestrial intelligent artefacts, with all implications of a long-term planning, stable society. Recent controversy over the lack of flux from KIC 8462852 (Boyajian et al. 2015, Marengo et al. 2015, Wright et al. 2015) is just one instance of the possible formulation of explanatory hypotheses directly motivated by Kardashev's scale and its ramifications. It is the prediction following from the overall framework of detectability, Dysonian SETI and the logic of Kardashev's scale that the number of such hard cases in which purely “natural” (i.e. non-intentional) explanations are progressively harder and harder to find will increase with the number and sensitivity of our

¹¹<http://www.centauri-dreams.org/?p=11237>.

detectors, in both intragalactic and extragalactic domain.¹²

A proposed generalization of Kardashev’s classification may be schematically presented in the Table 1. While rather conservative in comparison to the overhauls suggested by Kecskes, Vidal, or Galántai, it still formalizes the expansion of thinking prompted by the astrobiological revolution and the Dysonian SETI. While one could criticize the emphasis on power consumption and “bigger is better” thinking inherent in it, it is still more amazing how few exceptions or defeaters have actually been conceived in the literature (both discursive and fictional) so far. Some of them are summarized in Table 2.

The emphasis on *detectability* is, as justified above, a particularly salient feature of Kardashev’s and Kardashev-inspired schemes and the one which still needs to be tirelessly repeated, more than a half century later. Namely, it goes against the grain of the orthodox SETI with its blind insistence on large values of N in the Drake equation as a good pre-

dictor of the success of practical search activities. But the value of N is, to a large extent, a red herring. It does not require a sophisticated analysis to conclude that a *single* ($N = 1$) Type 3 civilization is a better SETI target than a hundred or a thousand or perhaps a million of humanity-level Type < 1 civilizations. “Better” here means easier to detect signal and easier to recognize its artificial nature. This simple insight has in the meantime been observationally operationalized and used in very real SETI surveys of external galaxies (Annis 1999, Wright et al. 2014a,b). Taking into account superadditivity, as discussed above, leads to similarly obvious conclusions when civilizations of the 2.x and even 1.x Types are concerned. Since the amount of resources, like the energy whose fraction is directly or indirectly used for emitting those signals potentially detectable by other observers, is huge but definitely finite, Kardashev’s ladder also tells us simple, but important truth that the naive idea about “place for everybody and everything” in the vastness of the universe is, in fact, wrong.

Table 1. An extended view of Kardashev’s scale.

Kardashev’s Type	manages resources	comments
0 – 0.x	pre-technological society – of particular area of the planet, or a particular type of planetary resources	humanity about 0.8 at present
1 – 1.x	of its home planet – of a number of planets and other bodies within a planetary system	Introdus / Krell machine type scenarios as exceptions – detectability <i>superadditive</i>
2 – 2.x	of its home star and planetary system – of a number of planetary systems within a region of the home galaxy	Dyson shell-like contraptions – detectability <i>superadditive</i>
3 – 3.x	of its home galaxy – of a number of galaxies within a region of the universe	absent from the Milky Way, closer galaxies – detectability <i>superadditive</i>
4 – 4.x	of the universe within cosmological horizon – of a number of topologically connected universes	causal disconnect occurs at particular epoch, depending on the cosmological model – detectability irrelevant??
5	of the multiverse	topological structure crucial

Table 2. As an addition to Table 1, here I list conceivable ways in which Kardashev’s scale could be considered incomplete. While these defeater scenarios are arguably too speculative or of too small probability measure, we should keep them in mind in surveying the overall astrobiological landscape.

Kind of incompleteness	defeater scenarios
BEFORE THE SCALE	dead space, “rare Earth”
SCALE IMPRACTICAL	galactic archaeology, Introdus, the Krell Machine
BEYOND THE SCALE	simulated universes, “new cosmogony”, Boltzmann brains

¹²This might have an interesting consequence for the concept of “success” or “discovery” in the domain of SETI studies. In contrast to the conventional image of “first contact” powerfully suggested by the pop-cultural discourse (e.g. Sagan (1985) and the subsequent movie), supported by the orthodox SETI circles, especially radioastronomers (Tarter 2001), and encoded in the famous “Wow!” signal (e.g. Gray and Marvel 2001), we might not have any particular decisive moment of discovery. Rather, we might face slow accrument of “inexplicable” cases without natural or non-artificial explanation, leading gradually to mainstream acceptance of astroengineering as not only legitimate, but the best explanation.

While this obvious conclusion has occasionally been recognized, its importance and practical consequences for SETI projects have not been fully understood and adopted so far. Instead, rather unhealthy obsession with the value of Drake's N continues to this day. Rethinking Kardashev's classification should have a salutary effect in this area as well. The truly important issue, especially following the null result of the \hat{G} search for Type 3 civilizations (Griffiths et al. 2015), the most detailed and comprehensive such observation effort thus far, is whether Type 2.x civilizations are detectable from a range of realistic distances, intragalactic as well as intergalactic. This challenge for innovative, imaginative, creative, and bold SETI will remain open for at least a couple of decades to come. Among other things, it will help understanding the prospects and pitfalls of the future of humanity itself, hopefully contributing to a new ecological and ethical consensus necessary for the long-term survival and prosperity of our species.

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КАРДАШЕВЉЕВА КЛАСИФИКАЦИЈА НАКОН 50+ ГОДИНА: ФИНО ОРУЂЕ СА МОГУЋНОСТИМА ЗА ПОБОЉШАЊЕ

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Прегледни рад по позиву

У овом раду даје се преглед историје и статуса чувене класификације ванземаљских цивилизација коју је пре нешто више од пола века предложио велики руски астрофизичар Николај Семјонович Кардашев. Иако се Кардашевљева класификација (или Кардашевљева скала) често сматра превише поједностављеном и стога су биле предлагана многа побољшања, усложњавања и алтернативе, она је још увек једно од главних оруђа за теоријско истраживање проблема потраге за ванземаљском интелигенцијом (SETI). Током ових 50+ година, учињено је неколико покушаја да се класификација модификује или реформише; неке од њих овде разматрамо, заједно са

сценаријима који стварају тешкоће за стандардну верзију. Скорашњи резултати на пољу како теоријских, тако и посматрачких SETI истраживања, нарочито Ć инфрацрвени преглед (2014-2015), уверљиво су показали како нагласак на детектабилности, инхерентан у Кардашевљевој скали, стиче нови значај и свежину. Више нових концептуалних помака, као што је Дајсоновски SETI, слаже се изузетно добро са оваквим развојем догађаја. Због свега овога, закључујемо да је привидна једноставност скале обманујућа: рад Кардашева нуди мноштво још увек недовољно проучених методолошких и епистемолошких поука, те остаје можда и највредније наслеђе "отаца оснивача" SETI пројеката.