A BOLD AND HASTY SPECULATION ABOUT ADVANCED CIVILIZATION-BEARING PLANETS APPEARING IN EXOPLANET DATABASES.

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Introduction: Undoubtedly, humankind have been fascinated for long by the possible existence of extraterrestrial civilizations, as well as the search for any form of living organisms in the Universe and the possible origin of life. The combination of all those questions might result in the theory of directed panspermia, suggesting that life spread in the Universe intentionally by developed civilizations capable of transporting, e.g., complex organic molecules (possible bricks of life) or living organisms through interstellar space and fertilizing planets [1,2].

This study aims to point to some potential advanced civilization-bearing planets, the habitat of "technological species" [3], which might/may be capable of sending objects targeting other star systems. Applying a preliminary filtering workflow, considering the type of planets, their allocation in the habitable zone (HZ), and Earth analogues, including some chronological constraints, may (or may not) lead to some potential civilization-bearing candidates.

Data and Search: In the search for potential civilization-bearing planets, NASA`s Exoplanet Archive were used. In the searching process the following factors were considered.

Classification of ocean-bearing planets. Based on our ordinary knowledge, water is a crucial component of biological evolution on Earth. Therefore, the study focuses on potential ocean-bearing planets, starting with their classification based on commonly used physical properties, and geology (**Fig. 1, Table 1**).

Value	Physical parameter	Ref.
1.5-2 R⊕	The "Radius Gap"	[4]
0.5-1.25(1.5) R⊕	Terrestrials` R range	[5,6]
1-8 M⊕	Ocean planets` M range	[7]
10 (14.5) M⊕	M_{max} of super-Earths	[8,9]
1.25-1.75 R⊕	Super-Earths` R range	[6]
3-20 M⊕	Sub-Neptunes` M range	[9]
1.75-3 R⊕	Sub-Neptunes` R range	[6]

Table 1. Some *definitive physical parameters considered during the classification of ocean-bearing exoplanets*

Two main types of ocean-bearing exoplanets were separated, one formation pathway resulting in terrestrial and super-Earth type planets and another in the formation of sub-Neptunes [7,10-24] (**Fig. 1**). A group of exoplanets, similar to sub-Neptunes, are often referred to as ocean planets or water worlds as well [7,21,23].

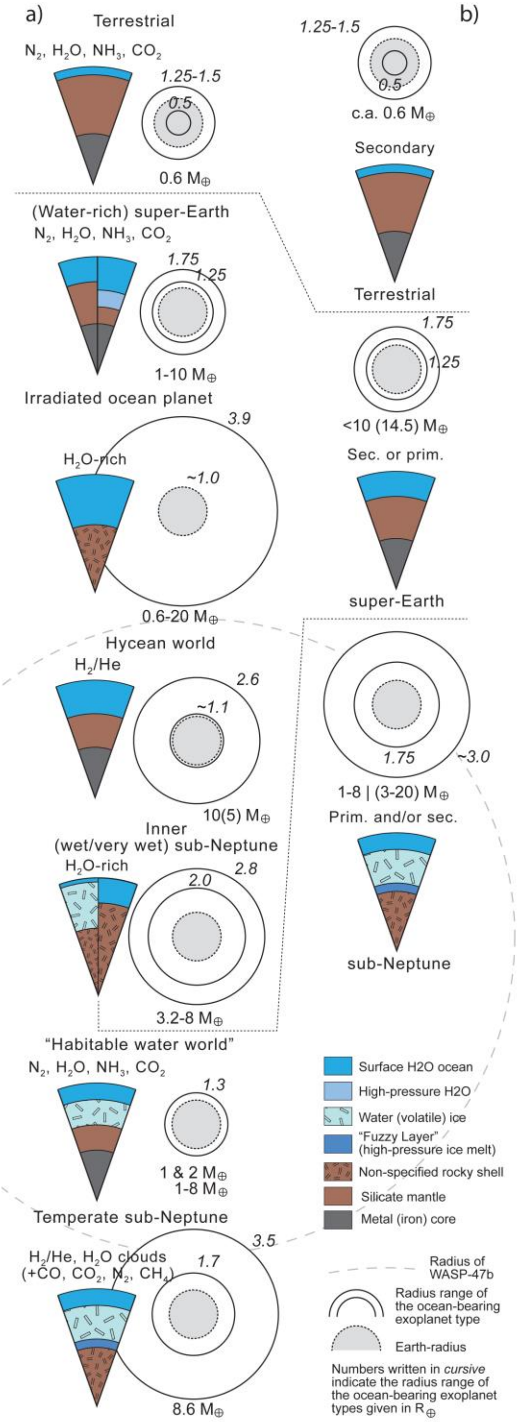

Figure 1. *Literature-based classification of ocean bearing planets* [7,10-24]. *a) various models found in the literature, and b) simplified classification based on the similarities and differences in the geological structure of planets.*

HZ. Locating in the HZ suggests that the planet theoretically has an atmosphere and surface ocean, and the conditions may fit a world where biological evolution can evolve [25].

Arguments about Earth analogues. Considering the already speculative nature of the study, no further assumptions were made about the biological evolution and formation of civilization on sub-Neptunes, and they were excluded from the list of target planets [3].

Chronological constraints. Using Earth as analogue it took 4.6 Gyr to "raise" a civilization capable of sending objects and reaching interstellar space (the Voyagers and the Golden Record). From the angle of directed panspermia, a theoretical planet with an advanced civilization on it needs to be at least 4.6 Ga old to send, e.g., microbes to Earth to fertilize it (≤3.5 Ga ago [26]). Continuing this line of speculation, a star system with a host star at least c.a. 9.2 Ga age is needed. Planets of that star system might send some object after its Earth-analog, 4.6 Gyr long evolvement. Considering the appearance of the known lifeforms on Earth [26], the candidate star system may be younger, 8.1 Ga old. Further calculations can be made about the minimum age of the source planet. Considering e.g., the speed of biological evolution, i.e. following the establishment of the atmosphere (first 1 Ga [27]), the appearance of vertebrates (later mammals and humans) took roughly 3.1 to 3.2 Gyr. Accelerated biological evolution on the candidate exoplanets may push the minimum age to c.a. 5 Ga by saving the c.a. 3 Gyr gap between the appearance of the first living entities and the appearance of vertebrates.

Results and Discussion: Out of the 5271 planets in NASA`s Exoplanet Archive, there are only seven that fulfill the introduced requirements of a potential civilization-bearing planet (**Table 2**).

Star system	Type	Age	Planet	No	Ref.
Teegarden`s Star*	red dwarf (M7.0 V)	8	b, c (T)	2	[28]
GJ 1061	red dwarf (M5.5 V)	7	c, d (T/*sE*)	3	[29]
Kepler-452**	Sun-like main seq. (G2)	6	b (sE)	1	[30]
LHS 1140	red dwarf (M4.5 V)	5	b (sE)	2	[31,32]
Ross 128	red dwarf (M4)	5	b (T/*sE*)	1	[33]

Table 2. *Putative star systems and planets with advanced civilizations. Age is in Ga; No indicates the known planets in the star system. T and sE stand for terrestrial and super-Earth respectively; sE in cursive indicates that some studies consider the exoplanet super-Earth type. * Teegarden`s Star b and c are known as one of the closest, potentially habitable worlds to Earth* [28].***explanation in the text (below).*

Kepler-452`s spectral type is similar to Sun, and Kepler-452 b`s semi-major axis is close to Earth (a: 1.046 au), which may make Kepler-452 b one of the key candidates, harboring advanced civilization.

Conclusions: The results of this bold and rapid speculation about potential advanced civilization-bearing planets, from the angle of directed panspermia point to seven planets out of the list of known exoplanets, with the focus on Kepler-452 b. Along the preliminary results, many flaws in the calculation need to be addressed (non-exhaustive list), such as i) the application of only Earth-based analogues; ii) potential biases and uncertainties in the chronological constraints; iii) no unified nomenclatures and criteria exist in the classification of (exo)planets; and iv) oversimplification may appear in many cases.

Acknowledgments: This research has made use of the NASA Exoplanet Archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program.

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