RESEARCH ARTICLE

Quantitative indexing and tardigrade analysis of exoplanets

Madhu Kashyap Jagadeesh [1]

[1] Department of Physics, Jyoti Nivas College, Bengaluru-560095, Karnataka, India

Abstract: Search of life elsewhere in the galaxy is very fascinating area for planetary scientists and astrobiologists. Earth Similarity Index (ESI) is defined as geometrical mean of four physical parameters (Such as radius, density, escape velocity and surface temperature), which is ranging from 1 (identical to Earth) to 0 (dissimilar to Earth). In this work, ESI is re-defined as six parameters by introducing the two new physical parameters like revolution and surface gravity and is called as New Earth Similarity Index (NESI). The main focus of this paper is to search Tardigrade water-life on exoplanets by varying the temperature parameter in NESI, which is called as Tardigrade Similarity Index (TSI), which is ranging from 1 (Potentially Tardigrade can survive) to 0 (Tardigrade Cannot survive). The NESI and TSI data is cataloged and analyzed for almost 3370 confirmed exoplanets and the results are discussed.

Keywords: Revolution of exoplanets; Tardigrade Similarity Index; surface gravity of exoplanets; and New Earth Similarity Index.

1. Introduction

Exploring the unknown worlds outside our solar system (i.e., exoplanets) is the new era of the current research. Presently with the huge flow of data from Planetary Habitability Laboratory PHL-HEC [1], maintained by university of Puerto Rico, Arecibo. Indexing will be a main criteria to give a proper structure to these raw data from space missions such as CoRoT and Kepler. Nearly half a decade ago, Schulze-Makuch *et al*.(2011) has defined Earth Similarity Index (ESI) as a geometrical mean of four physical parameters (such as: radius, density, escape velocity and surface temperature). In this paper, the New Earth Similarity Index (NESI) is re-defined as geometrical mean of six physical parameters (namely: radius, density, escape velocity, surface temperature, revolution, surface gravity). Since revolution is not directly available as the raw data, here the values are calculated for 3370 (as of September 2016) confirmed exoplanets. We are always interested in life-forms, which can survive outside our planet and tardigrade is the likely candidate (Jnsson *et al*. 2008). Tardigrade primarily known as moss piglets or water bears (Copley J. 1999), and they can survive at di erent temperature scales (Examples: 151 deg C for few minutes (Horikawa, Daiki D. 2012), 20 deg C for 30 years (Tsujimoto *et al*. 2015), 200 deg C for days (Horikawa, Daiki D. 2012), 272 deg C for few minutes (Becquerel P. 1950) in lower temperature scale).

The structure of the paper is as follows: In section 2, the NESI has been introduced and analysis of 3370 confirmed exoplanets are done, section 3 has the results of TSI, and section 4 gives the discussion and conclusion part of the work.

2. New earth similarity index and its analysis

In 2011, Schulze-Makuch *et al*., defined the Earth similarity index as

$$ESI_x = \left\{1 - \left|\frac{x - x_0}{x + x_0}\right|\right\}^{w_x} \tag{1}$$

doi: 10.18686/eoaa.v2i1.

Where x is the planetary property of the exoplanet, W_X is the weight exponent and x_0 is the reference to Earth in ESI.

In this paper we follow the above equation to calculate the NESI of individual planetary property, with the weight exponents as defined below. The New Earth Similarity Index (NESI) is defined as the geometrical mean of six

kas7890.astro@gmail.com

http://phl.upr.edu/projects/habitable-exoplanets-catalog/data/database

physical parameters (such as: radius, density, escape velocity, surface gravity, revolution and surface temperature). Mathematically it can be denoted as:

$$NESI = \left(NESI_R \times NESI_\rho \times NESI_{Ve} \times NESI_T \times NESI_g \times NESI_P\right)^{\frac{1}{6}} \quad (2)$$

The weight exponents for upper and lower limits of parameters are calculated as (Schulze-Makuch et al.(2011)): radius 0.5 to 1.9 EU, mass 0.1 to 10 EU, density 0.7 to 1.5 EU, surface temperature 273 to 323 K and escape velocity 0.4 to 1.4 EU. Similarly, we de ne the new limits of gravity as 0.16 to 17 EU and revolution as 0.61 to 1.88 EU. These limits are based on the human centrifuge experiment which clearly showed the untrained humans tolerating 17 EU, with eye balls in (Brent et al. 2012). In 2016 Jason Bittel discovered that tardigrade protein can be used on human DNA to get protected from radiation, which is a key idea to target tardigrade's survival on exoplanets The revolution is scaled on the basis of habitable zone of sun-like (G-type) stars.

Planetary Property	**Ref. Value**	**Weight Exponents**
	for NESI	for NESI
Mean Radius	1EU	0.57
Bulk Density	1EU	1.07
Escape Velocity	1EU	0.70
Revolution	1EU	0.70
Surface gravity	1EU	0.13
Surface Temperature	288K	5.58

Table 1. NESI Parametric Table

Here, EU = Earth Units, where Earths radius is 6371 km, density is 5.51 g/cm^3, escape velocity is 11.19 km/s, Revolution is 365.25 days and surface gravity is 9.8 m/s^2.

The NESI is further divided into Interior NESI and Surface NESI. The interior NESI is defined as the geometrical mean of radius and density. Mathematically it takes the form:

$$NESI = \left(NESI_R \times NESI_\rho\right)^{\frac{1}{2}} \quad (3)$$

Similarly, the surface NESI is defined as the geometrical mean of surface temperature, escape velocity, revolution of the planet and surface gravity. Empirically is of the form:

$$NESI = \left(NESI_{Ve} \times NESI_T \times NESI_g \times NESI_P\right)^{\frac{1}{4}} \quad (4)$$

$$NESI = (NESI_I \times NESI_S)^{\frac{1}{2}} \quad (5)$$

The global NESI takes the form:

Names	**Radius**	**Density**	**Temp**	**E. Vel**	**Rev**	**g**	**N E SI$_S$**	**N E SI$_I$**	**NESI**
	(EU)	**(EU)**	**(K)**	**(EU)**					
Earth	1.00	1.00	288	1.00	1.00	1.00	1.00	1.00	1.00
Mars	0.53	0.73	240	0.45	1.88	0.37	0.74	0.81	0.77
Kepler-452 b	1.63	1.09	296.4	1.7	1.05	1.77	0.92	0.90	0.91
GJ 667C c	1.54	1.05	280	1.57	0.07	1.61	0.66	0.92	0.78

Kepler-296 e	1.48	1.03	303	1.50	0.08	1.52	0.67	0.93	0.79

Table 2. A sample of calculated NESI

The entire analysis for 3370 exoplanets is cataloged in separate rocky and gas exoplanets les, which is available at(Kashyap 2017).

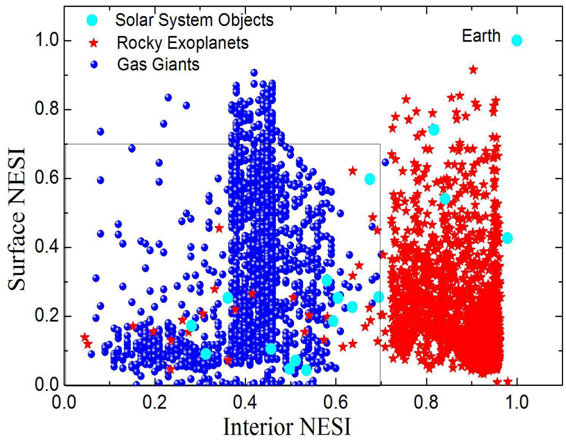

Figure 1. Plot of interior NESI versus surface NESI. Blue dots are the giant planets, red dots are the rocky planets, and cyan circles are the Solar System objects (Table 2). However, the limit for NESI is marked by a solid line which is 0:70.

The peaks in the plot are due to distribution phenomenon of similarity indices. This scatter plot denotes the optimistic range of each and every gas giants and rocky exoplanets, with respect to Earth-like planets.

3. Tardigrade similarity index

The Tardigrade Similarity Index (TSI) for rocky-water planetary objects is defined similarly as NESI, with different weight exponent for surface temperature. And the corresponding weight exponent is scaled on the basis of tardigrade survive rate at different temperature scales (Examples: 151 deg C for few minutes (Horikawa, Daiki D. 2012), 20 deg C for 30 years (Tsujimoto *et al*. 2015), 200 deg C for days (Horikawa, Daiki D. 2012), 272 deg C for few minutes (Becquerel P. 1950) in lower temperature scale).

Mathematically it can be denoted as:

$$TSI = \left(TSI_R \times TSI_\rho \times TSI_{Ve} \times TSI_T \times TSI_g \times TSI_P\right)^{\frac{1}{6}} \qquad (6)$$

The weight exponent range for all the physical parameters are same as NESI, except the temperature parameter, which ranges from 1.15 to 424.15 K for tardigrade to survive for few minutes.

Planetary Property	**Ref. Value**	**Weight Exponents**
	for TSI	**for TSI**
Mean Radius	1EU	0.57
Bulk Density	1EU	1.07
Escape Velocity	1EU	0.70
Revolution	1EU	0.70
Surface gravity	1EU	0.13
Surface Temperature	288K	0.21

Table 3. TSI Parametric Table

Here, EU = Earth Units, where Earths radius is 6371 km, density is 5.51 g/cm^3, escape velocity is 11.19 km/s, Revolution is 365.25 days, and surface gravity is 9.8 m/s^2.

4. Madhu Kashyap Jagadeesh

The TSI is classified into Interior TSI and Surface TSI. The interior TSI is the geometrical mean of TSI radius and density.

$$TSI = (TSI_R \times TSI_\rho)^{\frac{1}{2}} \quad (7)$$

Similarly, the surface TSI is defined as the geometrical mean TSI of surface temperature, escape velocity, revolution of the planet and surface gravity.

$$TSI = (TSI_{Ve} \times TSI_T \times TSI_g \times TSI_P)^{\frac{1}{4}} \quad (8)$$

The global TSI takes the form:

$$TSI = (TSI_I \times TSI_S)^{\frac{1}{2}} \quad (9)$$

Table 4. A sample of calculated TSI for rocky-water composition

	Names	Radius	Density	Temp	E. Vel	Rev	G	T SI_S		TSI	
		(EU)	(EU)	(K)	(EU)						
	Earth	1.00	1.00	288	1.00	1.00	1.00	1.00	1.00	1.00	
	Mars	0.53	0.73	240	0.45	1.88	0.37	0.84	0.81	0.82	
	Kepler-62 f	1.41	1.00	230	1.41	0.73	1.41	0.93	0.95	0.94	
	Kepler-100 d	1.51	0.86	745	1.41	0.085	1.31	0.68	0.90	0.78	
	K2-3 c	1.64	0.47	384	1.13	0.06	0.78	0.68	0.73	0.70	

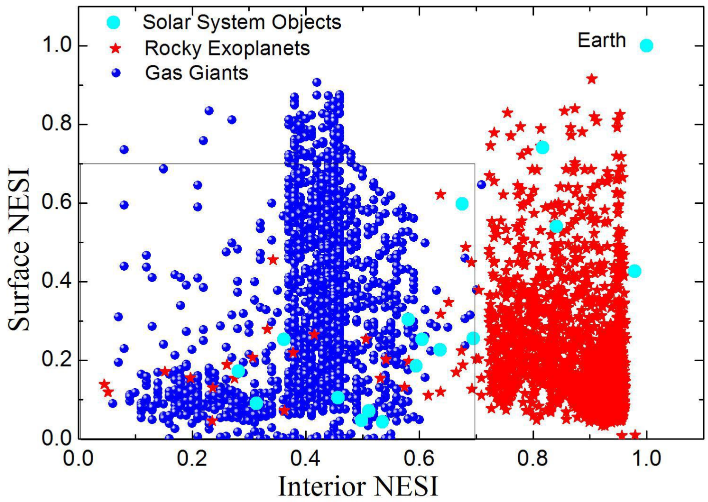

Figure 2. Plot of interior TSI versus surface TSI. Blue dots are the water-gas planets, red dots are the rocky-water planets, and green circles are the Solar System objects (Table 4). However, the limit for TSI is marked by a solid line which is 0:60.

The TSI scatter plot denotes the optimistic range of each and every water-gas and rocky-water exoplanets, with

respect to Tardigrade survival ability. The closest rocky-water composition [2] planet Kepler-62 f (super Earth)[3]could be possible for tardigrades to survive in in-active state. The rest of the catalog for all water-gas and rocky water exoplanets are made available at (Kashyap 2017).

4. Discussion and conclusion

The Search for Earth-twin is becoming more vibrant area in planetary science research. We know that, ESI was defined for only four physical parameters. But it is necessary to understand the need for compiling more physical parameters to find Earth-like planet. Hence, in this paper the NESI has been introduced to get more accurate results. The results obtained above clarifies it on comparison with ESI with 4 parameters (Schulze-Makuch *et al*. 2011; Kashyap *et al*. 2017). In 2008 (Jnsson *et al*. 2008), showed that Tardigrade could survive in space for 10 days. Thus the Tardigrade Similarity Index (TSI) is introduced and analyzed for all water medium exoplanets and solar system objects, where this extremophile life could survive. The future work in this area for the quest in search of life can be done by upgrading NESI and TSI with more physical parameters(such as: tilt of the planet, albedo factor, magnetic field, ... etc).In order to search more life forms atmospheric study in detail plays a major role, and also analyzing the astrochemistry of the exoplanets becomes very crucial. Recently Jason Bittel discovered that tardigrade protein can be used on human DNA to get protected from radiation, which is a key idea to target tardigrade's survival on exoplanets.

Acknowledgments

This research has made use of the Extrasolar Planets Encyclopaedia at http://www.exoplanet.eu, Exoplanets Data Explorer at http://exoplanets.org, the Habitable Zone Gallery at http://www.hzgallery.org/, 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 at http://exoplanetarchive.ipac.caltech.edu/ and NASA Exoplanet Archive at http://exoplanetarchive.ipac.caltech.edu and NASA Astrophysics Data System Abstract Service.

References

1. Becquerel, P. (1950). La suspension de la vie au dessous de 1/20 K absolu par demagnetization adiabatique de l'alun de fer dans le vide les plus elve. C. R. Hebd. Sances Acad. Sci. Paris, 231, 261.
2. Brent Y. Creer, Captain Harald A. Smedal, USN (MC), and Rodney C.Vtlfngrove (2012). Centrifuge Study of Pilot Tolerance to Acceleration and the Effects of Acceleration on Pilot Performance. NASA Technical note D-337.
3. Copley J. (1999).Indestructible, New Scientist, Retrieved 2010.
4. Horikawa, Daiki D. (2012). Alexander V. Altenbach; Joan M. Bernhard; Joseph Seckbach, eds. Anoxia Evidence for Eukaryote Survival and Paleontological Strategies. (21st ed.). Springer Netherlands, 205. ISBN 978-94-007-1895-1. Retrieved 2012-01-21.
5. Jason Bittel (2016). Tardigrade protein helps human DNA withstand radiation . Nature doi:10.1038/nature.2016.20648
6. Jnsson K., Ingemar; Rabbow, Elke; Schill, Ralph O.; Harms-Ringdahl, Mats and Rettberg, Petra (2008). Tardigrades survive exposure to space in low Earth orbit. Current Biology, 18, 729.
7. Kashyap J. M. (2017). NESI and NTSI, Mendeley Data, v.1, http://dx.doi.org/10.17632/ymdbs5tyjg.1Kashyap J. M., Gudennavar S. B., Doshi U.,Safonova M. (2017). Similarity indexing of exoplanets in search for potential habitability: application to Mars-like worlds., Astrophysics and Space Science, 362, 146. Doi: 10.1007/s10509-017-3131-y
8. Schulze-Makuch, D., Mndez, A., Fairn, A. D., *et al*. (2011a). A Two-Tiered Approach to Assessing the Habitability of Exoplanets. Astrobiology, 11, 1041.
9. Tsujimoto, Megumu; Imura, Satoshi; Kanda, Hiroshi (2015). Recovery and reproduction of an Antarctic tardigrade retrieved from a moss sample frozen for over 30 years. Cryobiology, 72, 78.
10. PHL-EChttp://phl.upr.edu/projects/habitable-exoplanets-catalog/data/database
11. Kepler-62f: A Possible Water World By Elizabeth Howell, Space.com , 2016