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Discovery of extra-terrestrial life: assessment by scales of its importance and associated risks

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The Rio Scale accepted by the SETI Committee of the International Academy of Astronautics in 2002 is intended for use in evaluating the impact on society of any announcement regarding the discovery of evidence of extra-terrestrial (ET) *intelligence.* The Rio Scale is mathematically defined using three parameters (class of phenomenon, type of discovery and distance) and a δ factor, the assumed credibility of a claim. This paper proposes a new scale applicable to announcements alleging evidence of *ET life within or outside our Solar System.* The London Scale for astrobiology has mathematical structure and logic similar to the Rio Scale, and uses four parameters (life form, nature of phenomenon, type of discovery and distance) as well as a credibility factor δ to calculate a London Scale index (LSI) with values ranging from 0 to 10. The level of risk or biohazard associated with a purported discovery is evaluated independently of the LSI value and may be ranked in four categories. The combined information is intended to provide a scalar assessment of the scientific importance, validity and potential risks associated with putative evidence of ET life discovered on Earth, on nearby bodies in the Solar System or in our Galaxy.

Keywords: search for extra-terrestrial intelligence; Rio Scale; extra-terrestrial life; London Scale; astrobiology; global catastrophic risks

1. Introduction

The discovery of any form of extra-terrestrial (ET) life would be one of the greatest events in the history of humankind. There is, however, no clear guidance on what to do if and when non-intelligent ET life is found, despite the fact that a discovery could occur at any time. We already know that communicating about such a discovery is likely to be complicated by public attitudes and misperceptions, but it also means a great opportunity to educate people about science—biology in particular. To understand the full impact of an announcement of such a discovery, one must extend beyond the scientific discovery itself and consider the nature of the presumed life as well as the potential consequences of contacting it. Building on previous positive experiences with scales used to assess the importance of other 'low-probability, but high-consequence' phenomena, this

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paper introduces a new scale for evaluating the putative discovery of ET life that is presumably microbial and is likely to be found using various direct or indirect methods either within the Solar System or in association with extra-solar planets.

(a) *Conventional one-dimensional scales*

A variety of simple scales have been suggested for natural phenomena connected with important risks and consequences. For example, extreme weather conditions have been characterized by scales for centuries. Temperature scales were invented (Celsius, Fahrenheit) to quantify hot and cold. Later the Beaufort scale (from 0 to 12) was proposed to express the strength of a storm by wind velocity. Other scales were introduced to classify hurricanes (Saffir–Simpson scale from 1 to 5) and tornadoes (Fijita scale from 0 to 5) respectively, also based on the maximum sustained mean wind velocity experienced or the damage caused by the winds.

Other ordinal scales were developed to characterize natural disasters such as earthquakes. The well-known Richter scale from 1 to 10+ and the Mercalli–Sieberg scale from 1 to 12 convey complicated information clearly and simply, with larger values indicating more devastating effects. Early on, these simple, one-dimensional scales of natural catastrophes were used only *a posteriori* to express the experienced effect. More recently, some scales have been used to convey predictive or explanatory information in the form of warnings and communication to the public (e.g. hurricane and storm warnings, volcanic explosivity index, though not yet earthquake prediction).

In the past couple of decades, several scales have been developed to characterize newly discovered cosmic threats. After it was discovered that both radiation (electromagnetic and corpuscular) and materials (meteors, comets and asteroids) can endanger Earth and human civilization, the mass media often wrote about these space threats and their impacts—but frequently without any scientific assessment of their reality or risk. To clarify the situation, new scales were proposed to communicate the importance and the associated risk for humanity of new, unfamiliar phenomena.

Big solar flares or corona mass ejections are rare events, but they might seriously influence the terrestrial environment. Initially, the scale for flare classification started with a combination of numbers (from 1 to 4) and letters (B, F or N) representing the flare intensity and the brightness. Subsequently, the National Oceanographic and Atmospheric Administration (NOAA) introduced another scale for ranking 'space weather phenomena' of solar origin. The scale, with values of 1–5, also indicates the level of biological risk and the effect on some terrestrial phenomena and on spacecraft.

To some degree all the above-mentioned scales are, however, incomplete, because the scale values may characterize only the strength or quality of the phenomenon without taking into account the relative position of the observer or recipient of information. For example, an earthquake of value 8 on the Richter scale indicates a devastating event at its epicenter, but might be insignificant further away. Likewise, the assigned strength of a distant storm may be factual, but a single value does not necessarily convey useful information to those afar, unless additional details, for example, the direction and the rate of movement, are also available along with intensity.

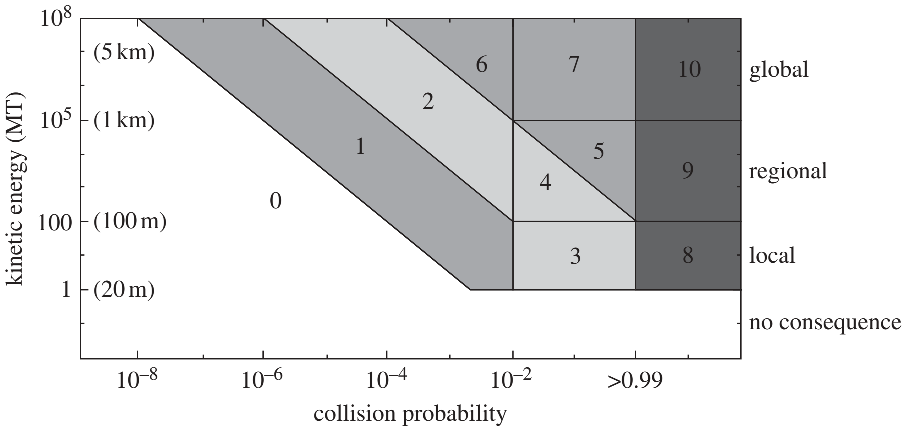

Figure 1. How to determine the value of the Torino Scale. The kinetic energy (as well as the size given in parentheses) of the NEO and the collision probability determine a point on the graph. Each point is inside a sector labelled by the corresponding value of the Torino Scale.

(*b*) *The Torino Scale for asteroid/comet impact predictions*

Attempts to introduce more complexity can be seen with the recent development of a scale to communicate about the level of threat posed by newly discovered near-Earth asteroids (NEAs) or comets (collectively referred to as NEOs—near-Earth objects). The degree of potential threat from an object depends on whether it will be on a collision course with the Earth in the future, *and* whether its mass and diameter are large enough to do significant damage at the local, regional or global levels. If the trajectory misses the Earth *or* the NEO is only a small-sized object (say less than 1–2 m diameter), then the risk of significant damage is essentially zero[1]. (Such small 'asteroids', or more exactly meteoroids, have become observable only recently outside the Earth's atmosphere through the use of radar or optical telescopes.)

The two-dimensional Torino Scale [1] takes into account both the damage caused by the potential impact of an NEO of an estimated kinetic energy and the probability that it will collide with the Earth. The Torino Scale was the first attempt to combine the effect of two, equally important parameters into one ordinal scale, and display it as simple scalar output, which ranges from 0 (no hazard) to 10 (certain collision of global consequences; figure 1). Another important property of the Torino Scale is that it provides an initial value based on preliminary measurements and information about the newly discovered object and a risk forecast of its potential impact for mankind. As later, more precise astronomical observations are made, the risk forecast may be revised either upwards, or (in general) downwards, thus making it a dynamic scale. Additionally, the Torino Scale values are based on exactly measurable input quantities—the scale does not include any consideration of the observations' reliability. Importantly, the complex scientific input is translated into distinct categories

[1]While small objects may cause damage, and even death, the scale is designed to quantify the degree of concern from objects that may cause *widespread* damage—similar to concerns about hurricanes or storms.

Table 1. Public description for Torino Scale index values.

0	*no hazard*. The likelihood of collision is zero, or the object is too small
1	*normal*. A routine discovery in which a pass near Earth is predicted that poses no unusual level of danger
2	*meriting attention by astronomers*. An object, making a somewhat close, but not highly unusual, near-Earth pass
3	*meriting attention by astronomers*. A 1% or greater chance of collision capable of localized destruction
4	*meriting attention by astronomers*. A 1% or greater chance of collision capable of regional devastation
5	*threatening*. A close encounter posing a serious, but still uncertain, threat of regional devastation
6	*threatening*. A close encounter by a large object posing a serious, but still uncertain, threat of a global catastrophe
7	*threatening*. A very close encounter of a large object, occurring this century, posing an unprecedented, but still uncertain, threat of a global catastrophe
8	*collisions*. A collision is certain, capable of causing localized destruction
9	*certain collisions*. A collision is certain, capable of causing unprecedented regional devastation
10	*certain collisions*. A collision is certain, capable of causing a global climatic catastrophe

that are useful for communicating with both the scientific community and the public. A shortened version of these 'public descriptions' for the Torino Scale index values is shown in table 1.

2. The Rio Scale for a putative discovery of extra-terrestrial intelligence

In anticipation of the likely public interest in detection of a putative ET signal or artefact, the Rio Scale was developed as an ordinal scale valued between 0 and 10, to quantify the impact of any public announcement regarding evidence of ET *intelligence* or *technological civilization*. The concept was first proposed by Almár & Tarter [2] at a Search for Extra-Terrestrial Intelligence (SETI) symposium in Rio de Janeiro (hence its name) in order to bring some objectivity to the otherwise subjective interpretation of any claimed detection of extra-terrestrial intelligence (ETI) [3][2].

(*a*) *Structure*

As originally proposed and subsequently refined, the Rio Scale index (RSI) is mathematically defined as

$$\mathrm{RSI} = Q \times \delta,$$

where Q, an estimated level of consequences, is the sum of three parameters, and δ represents the assessed credibility of a claimed discovery. The value for Q is quantified as a function of the class of the reported phenomenon, the type of discovery and the estimated distance to the phenomenon detected. SETA means

[2] A separate two-dimensional *San Marino scale* has also been developed to assess the risk associated with *transmitting* a message to a hypothetical ET civilization. For details see Almar & Shuch [3].

Table 2. Parameter values and reliability factor associated with the Rio Scale index.

class of phenomenon	value
reported phenomenon	
traces of astroengineering or indication of technological activity by an extant or extinct civilization at any distance, or an ET artefact the purpose of which is unknown	1
leakage radiation, without possible interpretation, or ET artefact whose purpose is understandable	2
omni-directional beacon designed to draw attention, or ET artefact with message of a general character	3
Earth-specific beacon to draw our attention, or an ET artefact with a message to mankind	4
omni-directional message with decipherable information, or a functioning ET artefact or space probe	5
Earth-specific message, or an ET artefact capable of contact or a physical encounter	6
discovery type	
from archival data; an *a posteriori* discovery without possibility of verification	1
non-SETI/SETA observation; transient phenomenon that is reliable but never repeated	2
SETI/SETA observation; transient phenomenon that has been verified but never repeated	3
non-SETI/SETA observation; steady phenomenon verifiable by repeated observation or investigation	4
SETI/SETA observation; steady phenomenon verifiable by repeated observation or investigation	5
distance	
extragalactic	1
within the Galaxy	2
within a distance that allows communication (at light speed) within a human lifetime	3
within the Solar System	4
reliability factor (δ)	
obviously fake or fraudulent	0
very uncertain, but worthy of verification efforts	1/6
possible, but should be verified before being taken seriously	2/6
very probable, with verification already carried out	3/6
absolutely reliable, without any doubt	4/6

the search for extra-terrestrial *artefacts*. (A credible artefact would constitute evidence for intelligent ET life even without ET beings.) The value assigned for δ is somewhat more subjective, and is likely to vary over time. Table 2 shows the values assigned to the three Q-associated parameters and the reliability factor in the RSI.

Selecting the relevant line in each of the three parameter sub-categories and adding the numbers for each category gives a Q value from 3 to 15. If a sub-category is uncertain, two limiting values for Q can only be determined. Then, multiplying the Q value by the reliability factor (δ) yields an RSI value that can range from 0 to 10 (11 separate qualitative categories). The 0–10 ranking is essentially an interpretation that a discovery is meaningless or insignificant (0, 1) to moderate (4) to extraordinary (10).

Over time, the RSI values assigned to any SETI detection can be expected to change—either upwards or downwards—to reflect new information about the signal. The RSI was accepted by the SETI Committee of the International Academy of Astronautics (IAA) in 2002. It is likely that the IAA's Post-Detection Task Group will be charged with assessing the proper RSI value in cases of a claimed ETI detection.

3. SETI and astrobiology: are they converging?

Fifty years ago SETI started as a simple project in radio astronomy searching for artificial ET signals and messages in the microwave spectrum coming from interstellar distances (Project Ozma). Somewhat later, one might say that astrobiology (at that time called exobiology or bioastronomy) began its early searches for possible ET life within the Solar System when NASA sent space probes to Mars with sophisticated equipment looking for simple life forms based on life as we know it (*Viking* missions in 1970s). In the following decades, the basic principles did not change: the SETI community carried out searches using more and more sophisticated radio telescopes and multi-channel spectrum analysers, with targets being strictly outside the Solar System; and astrobiologists continued to focus on planetary missions and research within the Solar System.

In the last 15 years, however, as conventional searches have continued, some unconventional suggestions have emerged in both communities. For example, SETA have been proposed and carried out in the Solar System and astrobiologists have studied meteorites in order to find traces of extinct ET life. Recently both the SETI and astrobiology communities have became interested in carrying out 'targeted searches' of potentially habitable extra-solar planets (e.g. the *Kepler, Gaia* and *Darwin* missions). Further, the SETI community has accepted that investigations in the optical and infrared regions might also be useful. The astrobiology community has accepted that optical (spectroscopic) observations of exoplanets might be of interest when looking for biomarkers (e.g. biogenic atmospheric signatures associated with known living systems). The detection of hundreds of exoplanets has changed the focus of astrobiological studies, which now mainly extend beyond the Solar System. Thus, what were initially very different targets and search methods used in SETI and astrobiology, respectively, seem to be converging.

What does this trend mean for the future announcement of a putative discovery of either ET life or ET intelligence? The simple old assumptions are not valid any more. A SETI discovery need not be confined to far-away phenomena registered only by radio telescopes; and astrobiologists may not need to rely only on tangible samples brought back by spacecraft from a nearby planet. Today there are other possible discovery scenarios both in SETI and astrobiology research that could result in announcements of important discoveries. To address the scientific complexity and possible confusion associated with announcements about purported discoveries of evidence for ET life, there is need for a scale similar to the Rio Scale, but useful for evaluating the importance, reliability and associated risk of a discovery of ET *life* that is presumably non-intelligent and relatively nearby (in the Solar System or Galaxy). Such a scale may be useful when communicating about the complex factors involved in evaluating new astrobiological 'discoveries' of ET life.

4. A new scale: the London Scale for extra-terrestrial life

In this section, we introduce the London Scale for astrobiology[3] whose structure and logic are intentionally analogous to the Rio Scale for ET intelligence. It has been developed as an ordinal scale with index values between 0 and 10, which can be used to evaluate and present complex information about the scientific importance, validity and potential consequences of an alleged discovery of ET life via various astrobiological methods and within the Solar System or Galaxy. The London Scale index (LSI) is mathematically defined as

$$\mathrm{LSI} = Q \times \delta,$$

where Q (scientific importance) is the sum of four parameters (life form, nature of evidence, method of discovery and distance), and δ represents the assessed credibility of a claimed discovery.

The Q factor is quantified based on specific values assigned to key phenomena and methods of discovery. The parameters associated with the Q value are intended to flow from objective, relevant categorical facts about the purported discovery. The first two parameters relate to the class of phenomenon discovered, the other two relate to methods and distance, as follows:

- *Type of life* discovered, which may range from something similar to terrestrial life, to a variant in structure or chemical composition, or, in the extreme, to a completely alien life form.
- *Nature of the evidence*, which focuses on the variety of possible forms that may be associated with the evidence (alive, dead, dormant, pieces, fossil, biomarkers, etc.). Different values are assessed across the range of evidence from chemical biomarkers, fossils or dormant states, to obviously organized simple or complex life forms.
- *Type or method of discovery*, which focuses on how directly or indirectly the phenomenon can be studied, ranging from remote sensing approaches to manipulative methods, direct observation of materials and experiments.
- *Distance to the discovered life form,* which is also considered, relates indirectly to how detailed and repeated the study of the discovery can be. Distance values vary based on whether the discovery is beyond the Solar System, at intermediate distances where *in situ* research may be possible, or on Earth.
- Similar to the Rio Scale, the assigned *credibility value* δ is somewhat more subjective and likely to vary over time as new research or findings add useful information.

[3]The London Scale is named after the location of this Royal Society Discussion Meeting in January 2010 on 'The detection of extra-terrestrial life and the consequences for science and society'.

Table 3. Parameter values and reliability factor associated with London Scale index.

class of phenomenon	value
life form	
possible signature of life, but indirect information only (e.g. volatile, trace)	1
terrestrial-type life form, but some uncertainty remains	2
life definitely, but a previously unknown variant of terrestrial life (in structure or composition) (e.g. if DNA is present, different amino acids are used)	3
likely to be non-terrestrial, but some uncertainty remains	4
completely alien life form	5
nature of evidence	
biomarkers (indirect evidence, like volatiles, metabolites, biochemical signatures, etc.)	1
fossilized life or remnants of life forms	2
uncertain whether living or not (like a virus)	3
extant life with suspended functioning (like a spore)	4
simple life (low level of organization)	5
complex life (high level of organization)	6
type or method of discovery	
by remote sensing from the surface of the Earth or from satellites, flybys, etc.	1
by a surface robot, *in situ*, on another celestial body	2
by a manned mission, *in situ*, on another celestial body	3
by analysing something found on Earth's surface or in the atmosphere (e.g. meteorite and atmospheric sample)	4
by analysing the result of a sample return mission (origin of the sample is well known)	5
distance to the discovered life form at time of announcement	
beyond the Solar System (*in situ* research impossible)	1
on or outside the orbit of Jupiter, but in the Solar System (*in situ* research possible, but difficult)	2
inside the orbit of Jupiter (*in situ* research more easily possible)	3
zero distance (on Earth)	4
reliability factor (δ)	
obviously fake or fraudulent	0
probably not real	0.1
controversial, but not rejectable	0.2
testable, needs further evidence	0.3
probably real	0.4
certain or highly reliable	0.5

(*a*) *Definition of different parameters*

Table 3 shows the scales for the four parameter values as well as the categories used to rate the reliability factor δ.

Selecting the relevant line in each of the four parameter sub-categories and adding the numbers for each category gives a Q value from 4 to 20. If a sub-category is uncertain, two limiting values for Q can be determined. Then, multiplying the Q value by the reliability factor (δ) yields an LSI value that can range from 0 to 10, with higher values indicative of more scientifically important, credible discoveries. The London Scale value assigned to any ET discovery can be expected to change—either upwards or downwards—over time as new findings or research provide additional information.

Undoubtedly, if a claimed discovery involves life forms that are complex or dissimilar to terrestrial forms and involves direct scientific method(s) and instruments used on Earth by researchers, it is likely to be viewed as more credible evidence for ET life than something studied only afar and by remote methods. Already, we can anticipate a variety of discovery scenarios that may involve media announcements about ET life. Experience has shown that some discoveries involve long-term scientific research debates (e.g. meteorite ALH84001), while others are more hypothetical (e.g. the Hungarian dark dune spots–Mars suface organisms (DDS–MSO) hypothesis) or represent questionable phenomena not generally accepted yet (e.g. Hoyle–Wickramasinghe and other panspermia hypotheses), and still others may be lacking decisive evidence (e.g. red rain) or remain highly suspect as hoaxes. Applying a standard scale to various ‘discoveries’ is a way for the science community and the public to examine the disparate factors that go into a claim or announcement. The appendix provides assessments of recent examples of ET life discovery announcements, and shows how the London Scale may be used to evaluate the claims and assess their validity. In addition to ranking the discoveries, such a scale is useful to highlight and understand the types or categories of information that may be needed for further validation or dismissal of a claim.

(*b*) *The importance of a discovery or finding*

The implications of a significant, credible discovery are likewise interesting to contemplate. Currently there is no policy on what to do if and when ET life is found, nor any indication of what group or groups should be involved in making judgments about future actions [4]. If a discovery is verified as truly ET, it raises a variety of societal questions about impacts and perspectives that are beyond the science community *per se*. In addition to the diverse scientific questions that will arise, there are likely to be questions of how communications should or will be handled in the post-detection period and by whom (officials, journalists, educators, Internet, etc.). Already, people have begun to speculate how individuals, private and public sectors, societies, religious groups and cultures will react to an announcement about the putative discovery of ET life and whether, and under what conditions, additional contact or missions will be allowed. Some even wonder whether and how a verified discovery of ET life might alter our world views or sense of self in either the short or long terms. Many of these issues have elicited the attention of interdisciplinary groups and workshops in recent years.

(*c*) *The London Scale assessment of risk and biohazards*

The London Scale focuses first and foremost on the scientific importance and validity of a discovery. Because the societal implications of a verified discovery are so profound, it is appropriate to consider what kind of risks, if any, are associated with the discovery in order to ensure that risks are being overseen in scientifically appropriate, safe and legal ways.

Not all discoveries represent the same type or degree of risk or would lead to serious consequences. Technically, risk is a relationship between the hazard (e.g. ET life) combined with the exposure (is there contact, how often, in what way?) and vulnerability (is there susceptibility?). There are two main types of risk:

Table 4. Risk categories belonging to the type of ET life discovery.

category	type of discovery/action	risk concerns
I	remotely sensed signatures of life or any type of ET life discovered robotically on other celestial bodies	no direct biohazards; no risk upon discovery
II	sample return from bodies without biological potential and unlikely to harbour ET life	no biohazard; no risks from returned materials
III	ET life delivered by natural influx of some type	not controllable; no known risk to date
IV	intentional sample return from any body with biological potential regardless of whether ET life has been discovered on the body or not (includes human missions)	assumed biohazardous until proven otherwise via rigorous testing

contaminating indigenous ET environments with transported terrestrial microbes (forward contamination) and contamination of Earth by ET life, either naturally or through human actions (back contamination).

Under the Outer Space Treaty of 1967, planetary protection policies require adoption of controls to avoid *forward contamination*, because it could interfere with science observations or be interpreted as false positives. In the event an ET life is discovered and verified, some argue that forward contamination controls would likely become more stringent, but the discovery itself would not necessarily stop exploration.

The risk of *back contamination* depends on both exposure and vulnerability, mainly on Earth. If ET material arrives on Earth by *natural influx* (as do tonnes of cosmic dust and meteorites annually), it becomes part of the background of Earth exposure, which may or may not be problematic. The alternative to natural influx is *deliberate handling* of ET materials, regardless of whether they contain ET life. Because technology can be designed to contain and isolate returned samples en route to Earth and during subsequent handling, the risks of exposure are controllable, but not zero [5]. Current planetary protection policy requires that any samples returned from bodies with biological potential are subject to stringent controls and containment throughout the return flight and should be treated as potentially hazardous until proven otherwise through rigorous testing. To the extent that humans are directly involved in a discovery (e.g. handling or collecting samples, analysing alien life in laboratories), serious questions arise about laboratory worker and/or astronaut safety [6]. ET pathogens might also be regarded as synergic with the general problem of biohazard (see [7] or [8]).

Risk *to Earth* of a discovery of ET life falls into one of four categories based entirely on existing planetary protection considerations (table 4).

(*d*) *Who should decide the London Scale index value and the appropriate risk category?*

Unlike the SETI community with its post-detection committee, there is no established group of experts to review all discovery claims for ET life. In general, as public claims for ET discoveries are made, they are reviewed over time by general consensus of the scientific community. For discoveries associated with space missions, agencies are already committed to having advisory groups for reviewing data and findings prior to announcement. In either case, the LSI value can help in the communication of a discovery—and may be adjusted accordingly. Because of the possible synergy with biohazard, in general, it might be appropriate to refer also to the efforts led by the United Nations (UN Security Council Resolution 1540), which calls the attention of national governments to the risk of pathogens and the efforts by other international organizations to establish a firm international framework for quantifying bio-related risks.

5. Conclusions

In this paper, we have proposed a tool for the evaluation of claims for the discovery of ET life via astrobiological searches. While building upon experiences with other scales, the ideas included in this paper represent the opinion and judgment of the authors. Further discussion within the broadest possible segment of the scientific community is desirable in order to refine and improve the current suggestions. This Discussion Meeting of the Royal Society provides a forum for the commencement of the discussion of this scale. Ultimately, if the London Scale is to prove of future value, it must become more widely known. Once it is refined and accepted by the scientific community at large, the London Scale can then be introduced and explained to the media and through them to the general public.

In many ways, the current situation is similar to that of the early Torino Scale. Its developer, Richard Binzel, noted: ‘My view is that any tool that helps understanding is a good tool’ and ‘I have always believed and understood there is a long learning curve in the public at large having some understanding of what the numbers mean’ but ‘We want to make sure this is available as a tool for people to interpret new discoveries’ [9] (pp. 2–3). The discovery of ET life, whether intelligent or non-intelligent, will undoubtedly affect all humans by fundamentally changing views about ourselves and our place in the Universe. Any such discovery deserves responsible, deliberate discussion by scientists and society alike. Our hope is that the London Scale helps to stimulate those discussions.

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Appendix A. Examples

Experts from many different disciplines are invited to join in analysing some announcements of putative discoveries, like the following four. How should they be rated by the London Scale? A preliminary estimate is given after each of the cases. Clearly, exercises such as this can be useful in ‘calibrating’ the scale and detecting potential problems.

(a) ALH84001 meteorite

This is probably the best-known claim concerning the discovery of traces of ET life. On 7 August 1996, a press conference was held at NASA Headquarters to announce the discovery of evidence of possible fossil life in the ALH84001 meteorite, which had come from Mars and been found by an expedition on Antarctica. There is a high abundance of carbonate minerals in it. The main pieces of evidence presented at the press conference were: the presence of compositional layering within the carbonates similar to layering in terrestrial carbonates produced by biological activity; the presence of mineral grains that, on Earth, are associated with certain types of bacteria; the presence of organic molecules that may have been produced by the decay of living matter; and the presence of sausage- or rice-shaped objects that might be fossil Martian bacteria [10]. Also the presence of chains of magnetite grains has been demonstrated. These are similar magnetic mineral grains that occur within fossil bacteria and which are clearly connected to biological activity.

Later, however, several scientific counter-arguments have been published and the discovery has not been generally accepted. But the original group announcing the discovery continued to investigate all possibilities. Recently they have published a paper, which concluded that the 'magnetic bacteria' features found in the meteorite were not formed by some non-biological thermal event [11].

Preliminary estimate of the London Scale index: $(2 + 2 + 4 + 4)0.3$, $\mathrm{LSI} = 3.6$.

(b) The Hungarian DDS–MSO hypothesis

The claim has been published in several papers since 2001. The following quotation is from [12]: 'The main thesis is that there could be life in the dark dune spots (DDSs) of the southern polar regions of Mars, at latitudes between $-60°$ and $-80°$. The spots have a characteristic annual morphological cycle and it is suspected that liquid water forms in them every year. We propose that a consortium of simple organisms (similar to bacteria) comes to light every year, driven by sunlight absorbed by the photosynthetic members of the consortium. A crucial feature of the proposed habitat is that life processes take place only under the cover of water ice/frost/snow. By the time this frost disappears from the dunes, the putative microbes, named Mars surface organisms (MSOs), must revert to a dormant state. The hypothesis has been worked out in considerable detail, it has not been convincingly refuted so far, and it is certainly testable by scientific methods.' Recently traces of current water or brine flows have been discovered near the DDSs on the Martian surface (figure 2).

Preliminary estimate of the London Scale index: $(2 + 5 + 1 + 3)0.3$, $\mathrm{LSI} = 3.3$.

(c) Hoyle–Wickramasinghe hypothesis of panspermia

F. Hoyle and C. Wickramasinghe have worked for three decades to pioneer the modern version of panspermia, arguing that germs and seeds are still coming from space via comets. They have proposed a decisive experiment to the Indian Space Research Organisation to collect large quantities of stratospheric air using sterile equipment carried aboard balloons and to search the samples for different kinds of alien microbial life. Since 2000 several balloon flights to the stratosphere have been realized over India. In 2002, it was claimed that germs recovered in

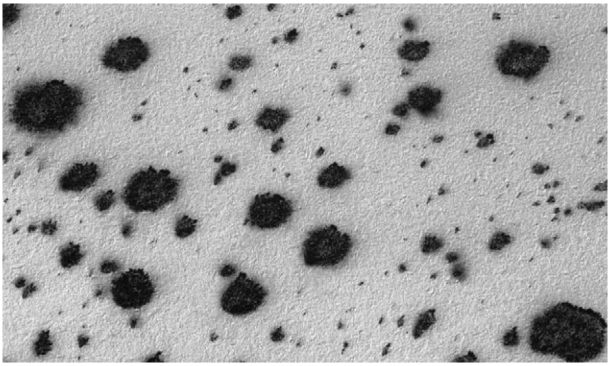

Figure 2. Dark dune spots on the south polar region of Mars at local spring (MRO HiRISE image of a 500 × 300 m region). Courtesy of NASA and Collegium Budapest.

the high atmosphere have been cultured. In 2004, a paper on the confirmation of viable but non-culturable bacteria in a stratospheric sample was published [13]. In 2009, it was announced that 'Three new species of bacteria, which are not found on Earth and which are highly resistant to ultraviolet radiation, have been discovered in the upper stratosphere by Indian scientists'. Results of a thorough laboratory microscopic study are not yet available.

Preliminary estimate of the London Scale index: $(2+4+4+4)0.1$ or 0.2, LSI = 1.4–2.8.

(*d*) *Red rain in Kerala, India*

From 25 July to 23 September 2001, red rain sporadically fell on the southern Indian state of Kerala. In early 2006, these events gained widespread attention when the media reported that two physicists of the Mahatma Gandhi University in Kottayam proposed a controversial hypothesis that the coloured particles were ET cells [14]. In 2008, they announced that the red cells found in the red rain in Kerala, India, are now considered a possible case of an extra-terrestrial life form. These cells can undergo rapid replication even at an extreme high temperature of 300°C. They can also be cultured in diverse unconventional chemical substrates.

The hypothesis has been criticized by several experts because of the lack of supportive evidence of non-terrestrial origin through confirmatory laboratory experiments done by others.

Preliminary estimate of the London Scale index: $(2+3+4+4)0.1$, LSI = 1.3.

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