Superhabitable Worlds

René Heller¹
John Armstrong²

¹ Origins Institute, McMaster U, Hamilton (ON), Canada

² Department of Physics, Weber State U, Ogden (UT), USA

(Heller & Armstrong 2014, AsBio)
Let’s Talk About Habitability vs. the HZ
Let’s Talk About Habitability vs. the HZ

Gl 581 d is a \(~7\,M\oplus\) planet near/in the stellar habitable zone of a \(~0.3\,M\odot\) star (Udry+ 2007, A&A; Mayor+ 2009, A&A)
Let’s Talk About Habitability vs. the HZ

Gl 581 d is a ~7 $M_\oplus$ planet near/in the stellar habitable zone of a ~0.3 $M_\odot$ star (Udry+ 2007, A&A; Mayor+ 2009, A&A)

Gl 581 d is “habitable, but not much like home” (Schilling 2007, Science)
Let’s Talk About Habitability vs. the HZ

Gl 581 d is a ~7 $M_\oplus$ planet near/in the stellar habitable zone of a ~0.3 $M_\odot$ star (Udry+ 2007, A&A; Mayor+ 2009, A&A)

Gl 581 d is “habitable, but not much like home” (Schilling 2007, Science)

“Being inside the habitable zone is a necessary but not a sufficient condition for habitability” (Selsis+ 2007, A&A)

René Heller
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?

Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?


“the fraction of Sun-like stars that have planets like Earth” (Catanzarite & Shao 2011, ApJ)
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?


“the fraction of Sun-like stars that have planets like Earth” (Catanzarite & Shao 2011, ApJ)

“the fraction of Sun-like stars with Earth-like planets in their habitable zones” (O’Malley-James+ 2013, IJA)
Let’s Talk About $\eta^+$

$\eta^+$ is a measure for the abundance of ..., well, of what?


“the fraction of Sun-like stars that have planets like Earth” (Catanzarite & Shao 2011, ApJ)

“the fraction of Sun-like stars with Earth-like planets in their habitable zones” (O’Malley-James+ 2013, IJA)

“the fraction of Sun-like stars that have at least one planet in the habitable zone” (Lunine+ 2008, AsBio)

René Heller
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?

“frequency of Earth-mass planets in the habitable zone”

Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?

“frequency of Earth-mass planets in the habitable zone”


the fraction of “Earth-like planets with $M \sin i = 0.5–2 \, M_{\text{Earth}}$ and $P < 50$ days” (Howard+ 2010, Science)
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?

“frequency of Earth-mass planets in the habitable zone”

the fraction of “Earth-like planets with $M \sin i = 0.5–2 M_{\text{Earth}}$ and $P < 50$ days”
(Howard+ 2010, Science)

“the frequency of habitable planets orbiting M dwarfs”
(Bonfils+ 2013a, A&A)
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?

“frequency of Earth-mass planets in the habitable zone”

the fraction of “Earth-like planets with $M \sin i = 0.5–2 M_{\text{Earth}}$ and $P < 50$ days”
(Howard+ 2010, Science)

“the frequency of habitable planets orbiting M dwarfs”
(Bonfils+ 2013a, A&A)

“the frequency of $1 < m \sin i < 10 M^\oplus$ planets in the habitable zone of M dwarfs”
(Bonfils+ 2013b, EPJ Web of Conf.)
Let’s Talk About $\eta^\oplus$

$\eta^\oplus$ is a measure for the abundance of ..., well, of what?

“the frequency of terrestrial planets in the habitable zone (...) of solar-like stars in our galaxy”  (Jenkins 2012, AAS 220, 318.05)
Let’s Talk About $\eta^{\oplus}$

$\eta^{\oplus}$ is a measure for the abundance of ..., well, of what?

“the frequency of terrestrial planets in the habitable zone (...) of solar-like stars in our galaxy”  (Jenkins 2012, AAS 220, 318.05)

“the number of planets with $0.1 \ M^{\oplus} < M_p < 10 \ M^{\oplus}$ in the 3 Gyr CHZ (a < 0.02AU)” [around white dwarfs] (Agol 2011, ApJ)
Let’s Talk About $\eta^\oplus$

10 definitions, only 2 agree $\Rightarrow$ 9 different meanings of $\eta^\oplus$

The meaning of a term is defined by its use in language (Wittgenstein 1952, *Philosophische Untersuchungen*).

$\Rightarrow$ 9 different values for $\eta^\oplus$
Let’s Talk About $\eta^\oplus$

10 definitions, only 2 agree $\Rightarrow$ 9 different meanings of $\eta^\oplus$

The meaning of a term is defined by its use in language (Wittgenstein 1952, Philosophische Untersuchungen).

$\Rightarrow$ 9 different values for $\eta^\oplus$

As an interdisciplinary science, astrobiology is prone to logical problems arising from language.

René Heller
A Set of Terrestrial Planets

\[ T = \{t \in T \mid t \text{ terrestrial}\} \]
A Set of Terrestrial Planets

\[ T = \{ t \in T | \text{t terrestrial} \} \]

\[ E = \{ e \in T | \text{e Earth-like} \} \]
A Set of Terrestrial Planets

\[ T = \{ t \in T \mid \text{t terrestrial} \} \]
\[ E = \{ e \in T \mid \text{e Earth-like} \} \]
\[ H = \{ h \in T \mid \text{h habitable} \} \]
\[ U = \{ u \in T \mid \text{u uninhabitable} \} \]
A Set of Terrestrial Planets

\[ T = \{ t \in T \mid t \text{ terrestrial} \} \]
\[ E = \{ e \in T \mid e \text{ Earth-like} \} \]
\[ H = \{ h \in T \mid h \text{ habitable} \} \]
\[ U = \{ u \in T \mid u \text{ uninhabitable} \} \]
\[ S = \{ s \in T \mid s \text{ superhabitable} \} \]
A Set of Terrestrial Planets

\[\begin{align*}
T &= \{t \in T \mid t \text{ terrestrial}\} \\
E &= \{e \in T \mid e \text{ Earth-like}\} \\
H &= \{h \in T \mid h \text{ habitable}\} \\
U &= \{u \in T \mid u \text{ uninhabitable}\} \\
S &= \{s \in T \mid s \text{ superhabitable}\} \\
I &= \{i \in T \mid i \text{ inhabited}\}
\end{align*}\]
A Set of Terrestrial Planets

A randomly drawn element $s \in S$ is more likely to be inhabited than a randomly chosen element $e \in E$. 

$T = \{t \in T \mid t$ terrestrial$\}$

$E = \{e \in T \mid e$ Earth-like$\}$

$H = \{h \in T \mid h$ habitable$\}$

$U = \{u \in T \mid u$ uninhabitable$\}$

$S = \{s \in T \mid s$ superhabitable$\}$

$I = \{i \in T \mid i$ inhabited$\}$

René Heller
With $p$ as the probability of being inhabited, we have

$$p(s) > p(e) \quad (s \in S, \ e \in E)$$
A Set of Terrestrial Planets

\[ |S \cap I| / |S| = p(s) > |E \cap I| / |E| = p(e) \]

\( (s \in S, e \in E) \)

\(|X| = \text{cardinality of } X\)
A Set of Terrestrial Planets

Assume

2 superhabitable nearby planets & both inhabited,
100 Earth-like nearby planets & 10 inhabited

\[ p(s) = \frac{2}{2} = 1 > p(e) = \frac{10}{100} = 0.1 \]
The Principle of Mediocracy

If an item is randomly drawn from one of several categories, it is likelier to come from the most numerous category than from any of the other less numerous categories (Kukla 2010, Extraterrestrials: A Philosophical Perspective).
The Principle of Mediocrity

If an item is randomly drawn from one of several categories, it is likelier to come from the most numerous category than from any of the other less numerous categories. (Kukla 2010, Extraterrestrials: A Philosophical Perspective).

Consider two sets $A$ and $B$:

$|A| < |B|$

$A \cap B = \emptyset$

"union"

$A \cup B = M = \{m \mid m \in A \lor m \in B\}$
The Principle of Mediocrity

If an item is randomly drawn from one of several categories, it is likelier to come from the most numerous category than from any of the other less numerous categories (Kukla 2010, Extraterrestrials: A Philosophical Perspective).

Consider two sets $A$ and $B$:

\[
\begin{align*}
|A| &< |B| \\
A \cap B & = \emptyset \\
A \cup B & = M = \{m \mid m \in A \lor m \in B\}
\end{align*}
\]

Then \[p(\hat{m} \in B) > p(\hat{m} \in A)\.]
The Principle of Mediocrity

If an item is randomly drawn from one of several categories, it is likelier to come from the most numerous category than from any of the other less numerous categories (Kukla 2010, Extraterrestrials: A Philosophical Perspective).

Consider two sets $A$ and $B$:

- $|A| < |B|$
- $A \cap B = \emptyset$
- $A \cup B = M = \{m \mid m \in A \lor m \in B\}$

Then

$$p(m \in B) > p(m \in A).$$

René Heller
The Principle of Mediocracy

The following reading is subliminally applied in searches for living planets:

$m$ (here: $e_\oplus$) has already been drawn from $E \cap I$. 
The Principle of Mediocracy

The following reading is subliminally applied in searches for living planets:

$m$ (here: $e_{\oplus}$) has already been drawn from $E \cap I$.

It is claimed that $|E \cap I| / |E| > |\bar{E} \cap I| / |\bar{E}|$

"$e_{\oplus} \in (E \cap I) \Rightarrow |E \cap I| / |E| > |\bar{E} \cap I| / |\bar{E}|$"
The Principle of Mediocrity

The following reading is subliminally applied in searches for living planets:

\[ m \text{ (here: } e_\oplus \text{) has already been drawn from } E \cap I. \]

It is claimed that \[ |E \cap I|/|E| > |\bar{E} \cap I|/|\bar{E}| \]

```
| prior e_\oplus | posteriors | E \cap I | E | \bar{E} \cap I | \bar{E} |
```

“\[ e_\oplus \in (E \cap I) \Rightarrow |E \cap I|/|E| > |\bar{E} \cap I|/|\bar{E}| \]”

This interpretation is not logic.
The Principle of Mediocracy

This interpretation is not logic.

(1) humans have not chosen Earth randomly.
The Principle of Mediocrity

This interpretation is not logic.

(1) humans have not chosen Earth randomly.

(2) Numerous drawings

(= many observations of inhabited and non-inhabited Earth-like and non-Earth-like planets)

are required to reconstruct $|E \cap I| \gg |\tilde{E} \cap I|$ with statistical significance.

René Heller
Conclusions

(1) As an interdisciplinary science, astrobiology is prone to logical problems arising from language (e.g. concerning “habitability” and $\eta^\oplus$).
Conclusions

(1) As an interdisciplinary science, astrobiology is prone to logical problems arising from language (e.g. concerning “habitability” and $\eta_\oplus$).

(2) There should be a set of planets, “superhabitable worlds”, that is more likely to be inhabited than Earth-like planets.

Heller & Armstrong (2014, AsBio)
Heller (2015, SciAm)
Conclusions

(1) As an interdisciplinary science, astrobiology is prone to logical problems arising from language (e.g. concerning “habitability” and $\eta^\oplus$).

(2) There should be a set of planets, “superhabitable worlds”, that is more likely to be inhabited than Earth-like planets. 

Heller & Armstrong (2014, AsBio)  
Heller (2015, SciAm)

(3) The principle or mediocrity does not suggest that Earth-like planets are the most likely type of world to be inhabited.
References

*SciAm* **312**, 32–39

*AsBio* **14**, 50–66

Lammer et al. (2009) What makes a planet habitable?

*AsBio* **5**, 100–126

René Heller