Is Habitability A Falsifiable Concept?

Robin Wordsworth,
Ringberg Castle, 21/11/2014
Talk outline

• Why should we care?
• Is habitability a falsifiable concept?  **YES**
• Is the habitability of nearby exoplanets a **maybe** falsifiable concept in the next 20-30 years? **not**
• Narrow vs. wide habitability definitions
• Habitability and coevolution
• General discussion
Why do we care if a theory is falsifiable or not?

Historically, falsifiability was not regarded as a key criterion.

Positivism: scientific theories should be verifiable. In extreme limit of this idea, all non-verifiable human knowledge is without value.

One problem: theories can appear verified and turn out not to be, sometimes centuries later (e.g. Newtonian gravity).

Philosophy of Science II

- Popper: Falsifiability is the key to goodness of a scientific theory
- Theories cannot be proven, only disproved
- Most falsifiable / simplest theory that hasn’t been falsified by observation is the current best approximation to the truth
- By this yardstick Einstein’s special relativity is a very good theory (it can be falsified). String theory is not (it can’t).
- Some example scientific statements from planetary science:
  - ‘Venus has abundant surface liquid water’
  - ‘Mars had abundant surface water 3.8 Ga’
  - ‘The interior of Europa is inhabited by microbes’
The meaning of ‘falsifiable’ in planetary science

• For the most part, observations of existing systems dominate (it’s hard to experiment on planets)
• No neat division into ‘true’ and ‘false’ theories. Particularly for study of past events.
• A few examples:
  – Carbonate-silicate CO2 feedback on Earth
  – Jet formation on gas giant planets – shallow or deep?
  – The Nice model for the solar system

http://www.wolaver.org/space/jupiterclose.htm
http://www.psrd.hawaii.edu/Aug06/cataclysmDynamics.html
http://lasp.colorado.edu/~bagenal/3750/ClassNotes/Class20/Class20.html
Philosophy of Science III

Thomas Kuhn:
Popper is wrong! Plenty of theories stick around despite being partly in disagreement with observations.

• Instead, scientists generally practice within established *paradigms* (testing and expanding the predictions of an existing framework)
• Once in a blue moon, paradigm shifts occur
• Classic example in Earth sciences: Plate tectonics
• Without an established paradigm, a field is protoscience, not a true science
• *Is astrobiology a protoscience?*

Philosophy of Science IV

• Feyerabend: There is no scientific method. Methodological anarchism can and should hold. Science shouldn’t dominate society or be considered superior to other ways of thinking.

• Quine: “in point of epistemological footing, the physical objects and the gods differ only in degree and not in kind.” -Two Dogmas of Empiricism

• See also Derrida, Sokal Affair etc.

• Enough of philosophy. Back to science!
Defining habitability

- More general = harder to test, less scientific in Popperian sense
- End-member definitions:
  - A habitable environment is one that can support any form of life, known or unknown, at any level of productivity
  - A habitable environment is one that can support carbon-based life of the same type as that on Earth at productivity levels high enough for it to be detected using current technology
- Second definition leads to standard follow-the water, habitable zone type argument (e.g. Kasting et al. 1993).
- Our understanding of life is probably too narrow. But we can only work within the limits of our own imaginations (and Carl Sagan’s).

Falsifying ‘narrow’ habitability in the solar system

• Habitability is *experimentally testable* in the inner solar system
• But ethics are dubious...
• NASA has an entire department devoted to making sure these experiments do not happen!

http://planetaryprotection.nasa.gov/
Falsifying ‘narrow’ habitability in the solar system

• Actually, the habitability of Mars may already have been tested...

Gladman et al. (1996)
[see also Mileikosky et al., 2000;
Fairen & Schulze-Makuch, 2013]
Falsifying ‘narrow’ habitability of exoplanets

• Clearly we’re not visiting any exoplanets any time soon → we must look for signs of habitability / life remotely
• Assuming a TPF/Darwin style mission (or ground-based equivalent) in our lifetimes, we can detect atmospheric H2O, CO2, O2 on a nearby Earth-like planet
  – We can retrieve atmospheric pressure, maybe (e.g. Selsis, Wordsworth et al. 2011, Benneke & Seager 2012, Misra et al. 2014)
  – We can try to observe surface liquid water (e.g. Robinson et al. 2010)
• Any results will be fascinating. Falsification of planetary habitability will be very difficult, however. C.f. Venus observations in the 1950s and 60s.
OBSERVATIONS OF VENUS AT 3.15-CM WAVE LENGTH

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ABSTRACT

The observations of radiation from Venus at 3.15-cm wave length on 34 days in May–June, 1956, are described. The apparent black-body temperature for Venus derived from the measurements changed from about 620° ± 110° K (m.e.) in early May to about 560° ± 73° K (m.e.) near inferior conjunction. Two single observations at 9.4-cm wave length are described, which suggest that the radiation follows a thermal spectrum.

I. INTRODUCTION

Thermal radiation from planets has not previously been investigated at radio wave lengths because of the small flux density of radiation at the earth. The strong bursts of long-wave-length radio noise which were first identified with Jupiter by Burke and Franklin (1955, 1956) and subsequently by others (Kraus 1956a, Shain 1956) and also later identified with Venus by Kraus (1956b, 1957) are presumably associated with some electrical phenomena in the atmospheres of the planets. The flux density of this impulsive radiation from Jupiter apparently falls off rapidly with decreasing wave length and has not yet been measured at wave lengths shorter than about 11 meters (Smith 1955). If the impulsive radiation from Venus has similar spectral characteristics, it should not be an important factor compared to thermal radiation at centimeter wave lengths.

Preliminary estimates indicated that thermal radiation from Venus at inferior conjunction was expected to have a flux density of about 10−3 watts/square meter (m.e.) at 3.15 cm wavelength.
The Habitable Zone


Reducing atmospheres allow potent warming by hydrogen collision-induced absorption

\[
\alpha(\omega) = \frac{1}{3} \frac{4\pi^2}{\hbar c V} \omega \left(1 - e^{-\frac{\hbar \omega}{k_B T}}\right) J(\omega)
\]

\[
J(\omega) = \frac{1}{4\pi \epsilon_0} \int_{-\infty}^{\infty} dt e^{-i \omega t} \sum_i P_i \langle i | \mu(0) \cdot \mu(t) | i \rangle
\]

\[
J(\omega) = \mathcal{F}[C'(t)]; \quad C'(t) = \frac{1}{4\pi \epsilon_0} \langle \mu(0) \cdot \mu(t) \rangle
\]

Wordsworth & Pierrehumbert 2013a, Science
Reducing atmospheres favour complex prebiotic chemistry

Stellar XUV flux

\[ \text{CO}_2, \text{SO}_2 \] strongly reducing atmosphere Miller-Urey prebiotic chemistry?

\[ \text{H}_2 \text{ escape to space} \]

\[ T_{\text{surf}} \sim 300 \text{ K} \] liquid water

oxidised mantle?

Wordsworth 2012, Icarus
Abiotic oxygen-dominated atmospheres

- Even within the ‘standard’ habitable zone, a huge range of atmospheric scenarios is possible
- Thought experiment: how would Earth with a low N2 atmosphere evolve?
- Initially it must lose H via H2O photolysis and hence oxidise, creating gaseous and surface O2
- This would continue indefinitely until O2 buildup was sufficient to create a stable atmosphere with a cold trap

Planetary redox evolution II: Abiotic oxygen-dominated atmospheres

- O$_2$-dominated atmospheres in the habitable zone do not have to indicate the presence of life.
- The atmospheric diversity of Earth-mass planets is likely to be high. Little to no justification for assuming Earth-like atmospheric composition in habitability modelling studies.
- Redox balance is fundamental to atmospheric evolution!

Habitability and biosphere-environment coevolution

• Earth’s modification by life as it has evolved is well-established. Only the extent of modification is debated today.

• Life has the potential both to increase global habitability ['Gaia’; e.g. the GOE] and decrease or destroy it ['Medea’; e.g. biologically initiated snowball events]. What happens and when is still very poorly understood.

http://becuo.com/real-earth-from-space-nasa
http://www.nature.com/nature/journal/v451/n7176/fig_tab/nature06587_F2.html (Kump et al. 2008)
Habitability and biosphere-environment coevolution

- Habitability is contextual: from the point of view of a hypothetical primitive anaerobe descending on a meteorite, Earth today is not a hospitable planet.
- Initial conditions are important! The origin of life on Earth is vital to *all* thinking about habitability and biosignatures. But there’s currently far too little interaction between the OOL community and exoplanet habitability researchers.

http://becuo.com/real-earth-from-space-nasa
http://www.nature.com/nature/journal/v451/n7176/fig_tab/nature06587_F2.html (Kump et al. 2008)
Conclusions / talking points

• Habitability narrowly defined is directly falsifiable for solar system planets, somewhat falsifiable for nearby exoplanets, and hence is useful
• Nonetheless, it is too restrictive and Earth-centric to be regarded as an astrobiological ‘paradigm’
• Planetary redox is just as fundamental to thinking about habitability (and biogenesis) as liquid water
• The non-linearity of habitability (biosphere-environment coevolution) is insufficiently explored and probably essential to the problem