The Resilience of Life to Astrophysical Events

Reviewed by Alex Deich, Vedant Dhruv, Travis Dore and Sammy Goldman

Terminator 2: Judgment Day, 1991 Paramount Studios

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Article Summary

Motivation and Setting

“The Resilience of life to Astrophysical Events”

It is not immediately obvious to what field of physics this belongs.

What is obvious:

The resilience of life in relation to the search for extraterrestrial life

Motivating Point:

We may only find extraterrestrial life if it has lived long enough for us to find it.

“The Resilience of life to Astrophysical Events”

How is this definition of life different than similar, previous papers?

Tardigrade

Image from phys.org

Unlikely ways to eradicate tardigrades:

- Loss of ozone layer (SN,GRB)
- Loss of atmosphere
- Impact winter, i.e. no sun (Asteroid)
- Deadly increase in pressure or acidity in oceans (Asteroid)

More likely ways:

- Boiling of ocean
- Radiation

Analyzed:
Asteroids, Supernovae, Gamma Ray Bursts

Things to keep in mind:

- Extremely conservative assumptions are made throughout paper (ex. Uniform ocean across Earth of depth 2.5km)
- Eradicating all life is defined as eradicating tardigrades
- The boiling of all oceans is the only likely scenario deduced giving a lower bound on energy: $E_{LB} = 5.6 \times 10^{24}$ J

Article Summary

Analysis

Asteroid:

Likelihood of planet sterilization

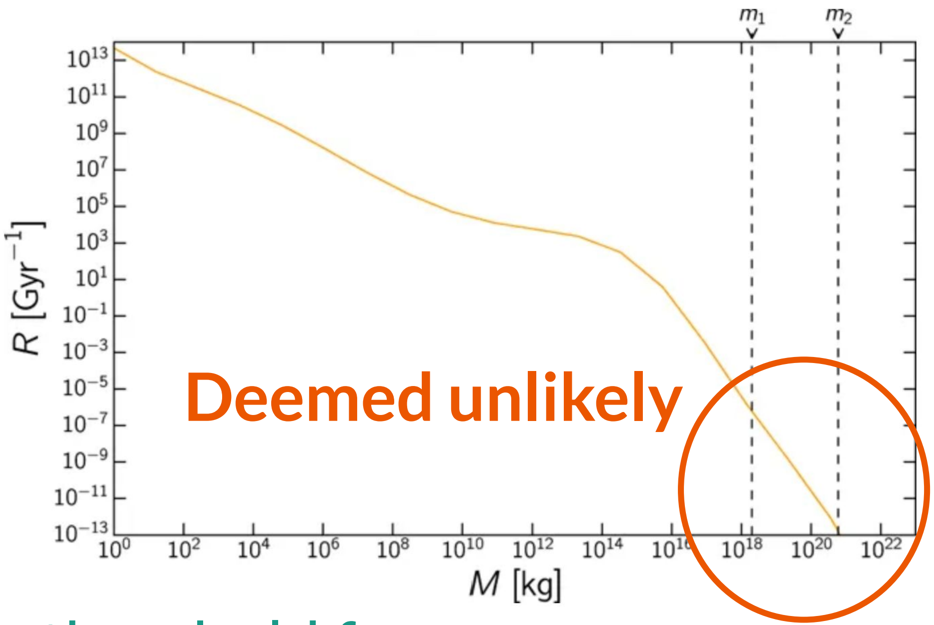
$$M_a = \frac{2\alpha \mathscr{C} T}{v_\infty^2 + v_e^2} M_p$$

M_a: Mass of asteroid to raise temperature by T

M_p: Mass of planet, α: Fraction of planet mass from ocean

C: Heat capacity of water

v_∞: Velocity at infinity, v_e: Escape velocity of planet



Mass threshold for "Earth":

Over ~1.7 x 10^{18} kg

Figure above:

Impact rate by mass, model put together by authors using their references 16,17,25

Supernova:

Likelihood of planet sterilization

$$d_{SN} = \left(\frac{3}{32\pi M_p^{1/2}\rho}\right)^{\frac{1}{3}} \left(\frac{E_s}{\alpha \mathscr{C} T}\right)^{\frac{1}{2}}$$

d_{SN}: Devastation from supernova distance

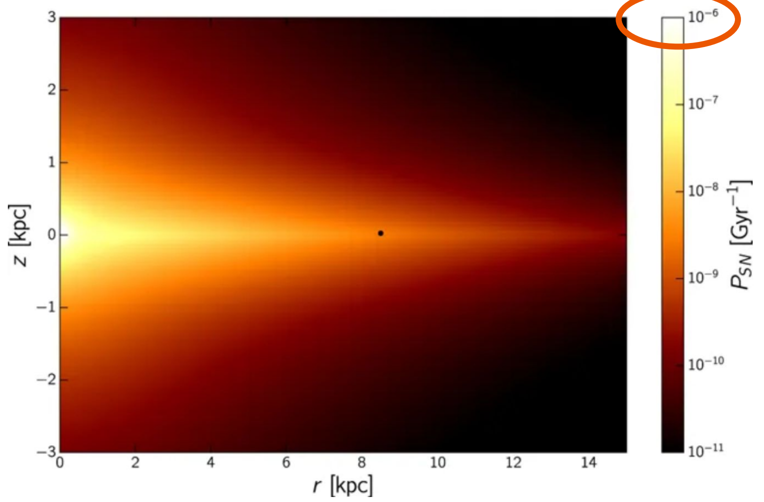
ρ : Density of planet

E_S: ~10^44 J

For "Earth":

d_{SN} = .04 pc

Likelihood map of SN sterilization in Milky Way



<u>Deemed unlikely</u>. 1 in 10,000 chance over a billion years.

Gamma Ray Bursts: Likelihood of planet sterilization

$$E = E_{GRB}\frac{\pi r^2}{\Omega d^2} = \frac{10^{62} r^2}{d^2}\,\mathrm{J}$$

E_{GRB}: Typical GRB energy (~10^{44} J)

r: Radius of planet,   d: Distance from GRB

Similar analysis to SN.

For "Earth" this corresponds to a distance of 13.8 pc (upper limit)

Using the known occurrence rates, the authors deduce a likelihood of 3.2×10^{-10} over a billion years

Literature Analysis

- Previous studies have focused on impact of astrophysical scenarios on terrestrial life and the Earth's atmosphere.
- Three ways that supernovae, gamma-ray bursts and cosmic rays can impact life on Earth,
    - Depletion of ozone layer due to ionizing radiation.[1]
    - Directs effects of radiation on ground-based lifeforms.[2][3][4]
    - Impact of expanding shock wave/ gas shell.[2]

[1] Ruderman, M. A. (1974). Possible consequences of nearby supernova explosions for atmospheric ozone and terrestrial life. *Science*, *184*(4141), 1079-1081.

[2] Beech, M. (2011). The past, present and future supernova threat to Earth's biosphere. *Astrophysics and Space Science*, *336*(2), 287-302.

[3] Dar, A., Laor, A., & Shaviv, N. J. (1998). Life extinctions by cosmic ray jets. *Physical review letters*, *80*(26), 5813.

[4] Piran, T., & Jimenez, R. (2014). Possible role of gamma ray bursts on life extinction in the universe. *Physical review letters*, *113*(23), 231102.

Literature Analysis

- Likelihood of an asteroid/ comet impact having globally catastrophic consequence is rare (1 in 10,000 over the next hundred years for an asteroid ~2km).[5]
- Web-based for estimating the regional environmental consequences of an impact on Earth,[6]

  https://impact.ese.ic.ac.uk/ImpactEarth/ImpactEffects/

[5] Chapman, C. R., & Morrison, D. (1994). Impacts on the Earth by asteroids and comets: assessing the hazard. *Nature*, *367*(6458), 33.

[6] Collins, G. S., Melosh, H. J., & Marcus, R. A. (2005). Earth impact effects program: A web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth. *Meteoritics & planetary science*, *40*(6), 817-840.

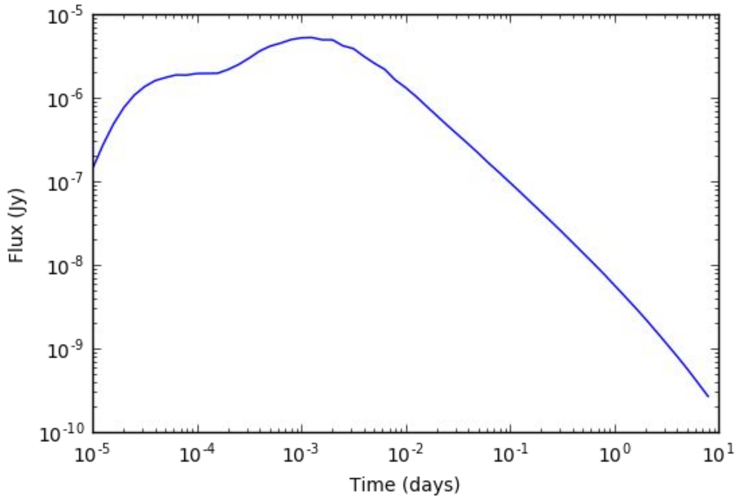
Criticisms and Strengths

While the conclusions as stated are largely well-supported, we find the following:

- Are tardigrades really a universal measure of life's resilience? Life elsewhere in the universe does not necessarily have any relation.
- In a few places, the authors refer to their result as an "absolute upper bound," which we find to be undeservedly strong language.
- Our professors would be pretty upset if we wrote a paper with no uncertainties listed

Calculations redone

- Having re-calculated three of the author’s conclusions (specifically: The supernova sterilization rate, the ocean temperature-asteroid relation, and the GRB sterilization rate, which was done using a numerical approach), we agree with their findings, to within an order of magnitude.



The flux due to a GRB at 1pc, agreeing with a result from the paper

Conclusions

Paper’s conclusions:

- Once life occurs on a planet it is difficult to (completely) remove.
- Absolute upper bound on probability of sterilization (due to astrophysical) event at $P < 10^{-7}$ per billion years.
- Complete removal of life most likely only occurs when the host star of a planet dies.

Conclusions

Our Conclusions:

- Use of terminology “absolute” upper bound is potentially too strong
    - Only three forms of sterilization events are considered, and long term effects are not taken into account.
- Calculations are all correct, but the scenarios analyzed search a narrow range of outcomes
- Unclear on what the results of this analysis have to say about the Fermi paradox and the prevalence of life in the universe.
- Ultimately, analysis is too simple to make any strong statements.

Citation Evaluation and Impact

Citation Evaluation

Altmetrics
11 citations

SCOPUS
13 citations

- SCOPUS citations include all 11 from Altmetrics
- Young paper (2017) with not much time to gain citations
  - Not a lot to analyze
- Most significant papers to cite this paper are done by an author (Avi Loeb)

Citation Evaluation

Alternative metrics allow us to measure impact beyond raw citation number

Altmetrics

Field Citation Ratio: 4.85
(specific to subject)

Relative Citation Ratio: .67
(specific to field)

SCOPUS

Field Weighted Citation Impact:
1.2
(similar papers, unclear how exactly defined)

Non-Traditional Impact

Alternative metrics allow us to measure impact beyond raw citation number

Altmetrics

Tweets	*258*
News Outlets	*146*
Blogs	*27*
Facebook Pages	*11*

SCOPUS

Tweets	*204*
News Outlets	*164*
Blogs	*22*
Facebook Pages	*N/A*

Overall Impact

Academic impact in scientific field seems minimal, but it has generated a lot of interest!

Important Caveat: In order to be impactful in a field, there needs to be a field the first place. This paper suffers from lack of a field.

Evidence:

- Citing articles range from astrobiology, to astrophysics, to planetary science
- *Altmetrics:* very good FCR vs poor RCR
- arXiv lists preprint subject as “Popular Science”, no other good classification
- Articles interviewing physicists:
  https://www.sciencenews.org/article/astronomers-say-time-start-taking-search-aliens-seriously
  https://qz.com/1666253/scientists-searching-for-alien-life-arent-very-popular-in-science/

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