The Implications of ‘Oumuamua on Panspermia

‘Oumuamua (1/2017 U1) is the first large interstellar object ever detected to visit our Solar System [1]. It can therefore be applied as an anchor to model the plausibility of ***panspermia,*** the hypothesis that life on Earth originated from the bombardment of interstellar ejecta.

Background & Inspiration

In light of ‘Oumuamua, the ISM ejecta flux rates (rate of ejecta traversing space) are **substantially higher than previously thought** [2-3].

Higher **ISM ejecta flux rates** and number densities **imply a higher probability of panspermia** [4].

My Work: Quantifying Plausibility of Panspermia

- Assess factors for panspermia, both **physical and biological.**
- Develop and apply mathematical models to **gauge the probability that panspermia seeded life on Earth.**

Figure 1. ‘Oumuamua [5].

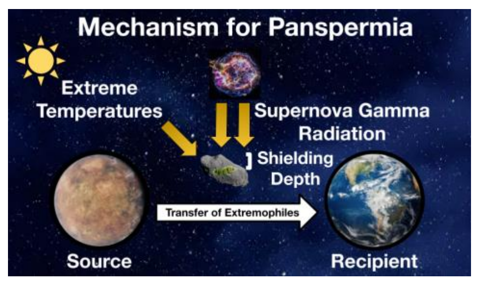


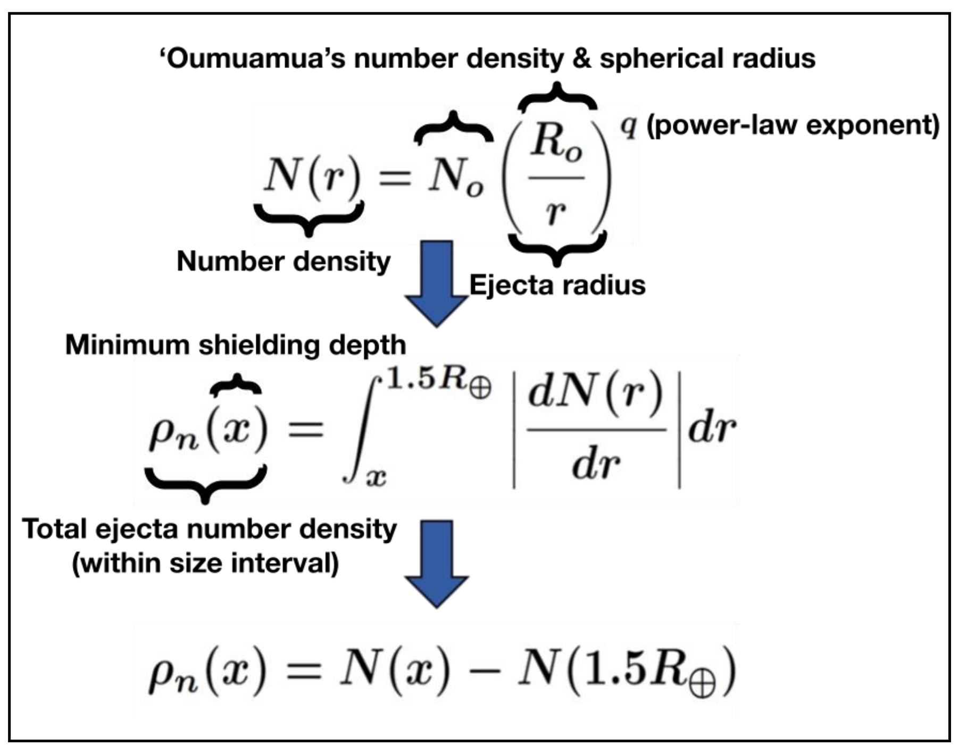
Figure 2. Panspermia mechanism [6-10].

Methodology

Build on previous studies by quantifying the total number of impact events on Earth prior to the earliest fossilized evidence for life and the minimum supernova gamma radiation shielding depth of ejecta.

1. Develop models for the ISM ejecta number density and mass density. **We use ‘Oumuamua’s properties e.g. size as anchors.**
2. Approximate the mass flux and flux density of ejecta in the ISM and derive the **total number of collisions events on Earth** prior to life.
3. Find the **minimum ejecta size** to shield extremophiles from supernova gamma radiation and apply this restriction to the total collision events.
4. Place our results in the context of panspermia and life in the universe.

Panspermia: ‘Oumuamua-Constrained Physical & Biological Models



‘Oumuamua’s number density & spherical radius

$$\underbrace{N(r)}_{\text{Number density}} = \overbrace{N_o}\left(\frac{R_o}{\underbrace{r}_{\text{Ejecta radius}}}\right)^{\overbrace{q}}$$

q **(power-law exponent)**

Minimum shielding depth

$$\underbrace{\rho_n(\overbrace{x})}_{\substack{\text{Total ejecta number density} \\ \text{(within size interval)}}} = \int_x^{1.5R_\oplus} \left|\frac{dN(r)}{dr}\right| dr$$

$$\rho_n(x) = N(x) - N(1.5R_\oplus)$$

Flux: $\Phi_n(\rho_n(x)) = \rho_n(x) v_o \hat{t}$

Coll: $C_n(\Phi_n) = \Phi_n \tau \sigma_\oplus h_\oplus h_\odot$

$\tau \approx 0.8\,\mathrm{Gyr}$ **Prior to life**

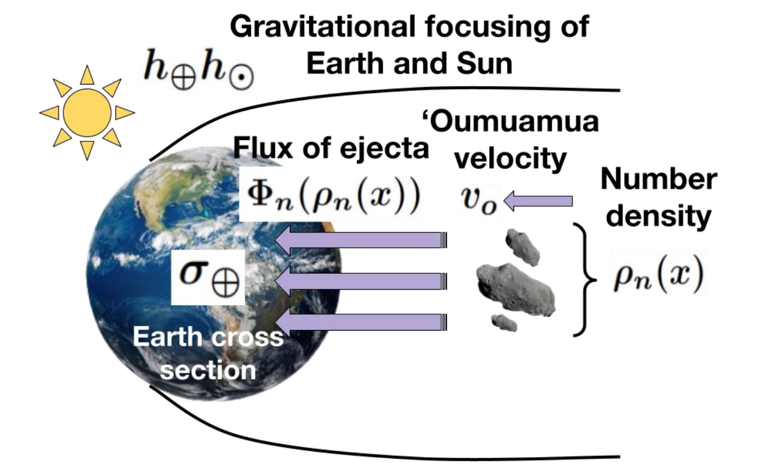


Figure 3. Flux & impact events model [6-7].

$$E_f = \frac{6000\pi r^2\left(e^{\mu x} - 1\right)}{\mu}$$

$$E_f = E_i\left(\frac{\pi r^2}{4\pi d^2 \hat{d}^2}\right)$$

$$x \approx \frac{\ln\left(E_i \mu\right) - \ln(24000\pi d^2 \hat{d}^2)}{\mu}$$

$\mu\ [\mathrm{m}^{-1}]$ is the ejecta’s attenuation coefficient [11].

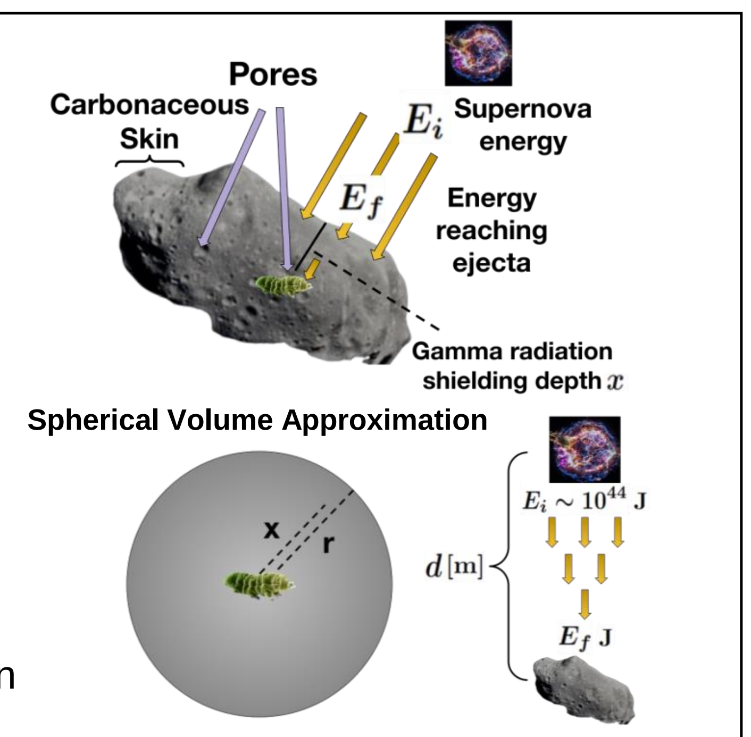


Figure 4. Radiation transfer, supernova to ejecta [6, 8-9].

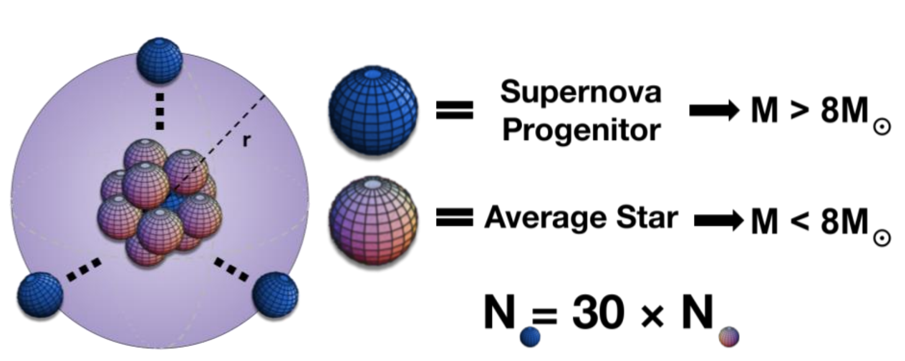


Figure 5. Sphere packing model [12].

We apply the sphere packing model based on the stellar density and dimensions of the Orion A cluster to approximate the distance between an ejecta and its nearest supernova progenitor.

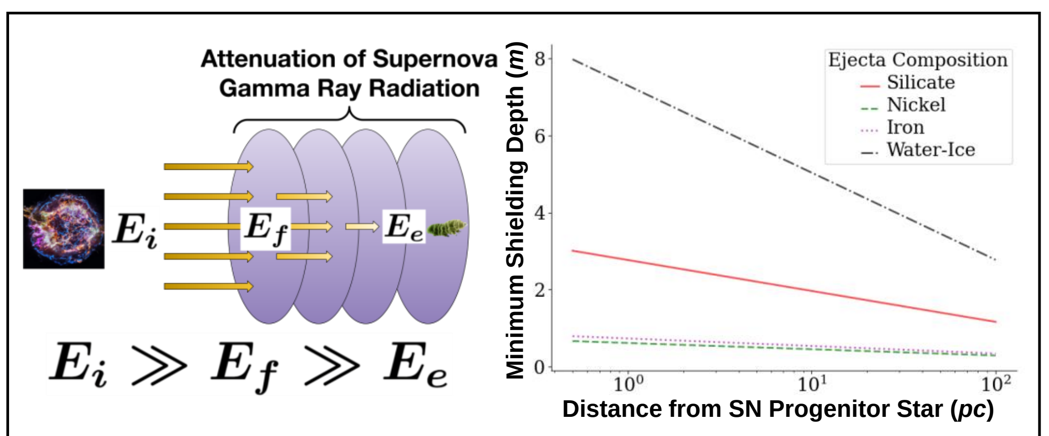


Figure 6. Shielding depth vs. distance from SN progenitor [8-9].

The number density abundances of ejecta compositions mirrors that of water-ice and volatile minor bodies in the Solar System as shown in the recent Dawn and OSIRIUS-Rex explorations [13].

Min. Shielding x m (1)	Density ρ_m $r \le \infty$ kg·au^{-3} (2)	Density ρ_m $r \le 1.5R_\oplus$ kg·au^{-3} (3)	% Difference % (4)	Total Coll. Mass C_m kg (5)	Total Coll. Events C_n number (6)
Water-ice (6.6)	5×10^9	5×10^9	5×10^{-2}	6×10^{11}	2×10^5
0.001	1×10^{12}	1×10^{12}	3×10^{-4}	1×10^{14}	1×10^{19}
0.01	3×10^{11}	3×10^{11}	1×10^{-3}	3×10^{13}	3×10^{15}
0.1	6×10^{10}	6×10^{10}	4×10^{-3}	7×10^{12}	7×10^{11}
1	2×10^{10}	2×10^{10}	2×10^{-2}	2×10^{12}	2×10^8
10	4×10^9	4×10^9	6×10^{-2}	4×10^{11}	4×10^4

Table 1. Modeled data for the ISM mass density $\rho_m(x)$, total collision mass $C_m(\Phi_m)$, and total number of impact events $C_n(\Phi_n)$ from the time period of Earth's formation to the earliest fossilized evidence of life $\sim 0.8\ \mathrm{Gyr}$ given $q = 3.6$.

Results: Panspermia & Galactic Life

Given minimum ejecta size $x \approx 6.6\ \mathrm{m}$, we model the total number of collision events on Earth prior to life as $C_n \approx 1.9 \times 10^5$ for $q = 3.6$.

The Plausibility of Panspermia

- f_B is the probability that a random ejecta harbors microbial extremophile life. Adams & Napier (2022) hypothesizes that $10^{-13} \le f_B \le 10^{-10}$ [14]. Combining this estimate with $C_n \approx 1.9 \times 10^5$, we have the **number of potential biologically active ejecta that impacted Earth prior to life** $\sim 10^{-8} \le C_n f_B \le 10^{-5}$**.**
- f_{su} is the **poorly constrained fraction** of ejecta that reach the surface of Earth upon impact and f_{se} is the fraction of those ejecta that successfully seed life [14]. Placing an **upper-limit** to the probability that panspermia seeded life on Earth, we have $C_n f_B f_{su} f_{se} \le 10^{-5}$, or 0.001%**.**

Life in Our Galaxy

- $\sim 4 \times 10^9$ Earth-sized rocky planets in Habitable Zone of Sun-like FGK stars, taken by multiplying $\eta_\oplus \sim 0.1 - 0.25$ by Galaxy’s stellar density [15]. For Earth analogs, we apply another **factor of 10 in addition to** $\sim 4 \times 10^9$ **considering life-seeding over galactic history.**
- **As many as 10^5 worlds in our Galaxy may be populated with life.**

Conclusions & Impact

- Reexamined the probability of panspermia based on ‘Oumuamua. Panspermia has great implications on extraterrestrial life, an increasingly important topic for humanity (July 2023 UFO hearings).
- Inspire future interdisciplinary research in astronomy and astrophysics.
- ***Under the most optimistic conditions, our universe may potentially be teeming with life!***

References

1. Trilling, D. E., Robinson, T., Roegge, A., Chandler, C. O., Smith, N., Loeffler, M., Trujillo, C., Navarro-Meza, S., & Glaspie, L. M. (2017). Implications for planetary system formation from interstellar object 1I/2017 u1 ('Oumuamua). *The Astrophysical Journal Letters*, *850*(2), L38. https://doi.org/10.3847/2041-8213/aa9989
2. Jewitt, D., & Seligman, D. Z. (2023). The interstellar interlopers. *Annual Review of Astronomy and Astrophysics*, *61*, 197-236. https://doi.org/10.1146/annurev-astro-071221-054221
3. Levine, W. G., Cabot, S. H. C., Seligman, D., & Laughlin, G. (2021). Constraints on the occurrence of 'Oumuamua-Like objects. *The Astrophysical Journal*, *922*(1), 39. https://doi.org/10.3847/1538-4357/ac1fe6
4. Ginsburg, I., Lingam, M., & Loeb, A. (2018). Galactic panspermia. *The Astrophysical Journal Letters*, *868*(1), L12. https://doi.org/10.3847/2041-8213/aaef2d
5. 'Oumuamua [Image]. (n.d.). NASA. https://science.nasa.gov/solar-system/comets/oumuamua/
6. Ida and Dactyl [Photograph]. (n.d.). NASA RPS. https://rps.nasa.gov/resources/94/ida-and-dactyl/
7. Earth [Image]. (2023, April 12). UCLA Newsroom. https://newsroom.ucla.edu/releases/earth-like-planets-may-be-an-inevitability
8. Cassiopeia a (Cas a) [Image]. (n.d.). NASA. https://science.nasa.gov/resource/cassiopeia-a-supernova-remnant/
9. Tardigrade [Image]. (2020, April 7). ThoughtCo. https://www.thoughtco.com/extremophiles-extreme-organisms-373905
10. Hurt, R. (2023, January 10). *TOI 700 E* [Image]. JPL. https://www.jpl.nasa.gov/news/nasas-tess-discovers-planetary-systems-second-earth-size-world
11. Sloan, D., Alves Batista, R., & Loeb, A. (2017). The resilience of life to astrophysical events. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-05796-x
12. Hexagonal close packing of spheres [Image]. (n.d.). Wolfram MathWorld. https://mathworld.wolfram.com/HyperspherePacking.html
13. Hamilton, V. E., Simon, A. A., Christensen, P. R., Reuter, D. C., Clark, B. E., Barucci, M. A., Bowles, N. E., Boynton, W. V., Brucato, J. R., Cloutis, E. A., Connolly, H. C., Donaldson Hanna, K. L., Emery, J. P., Enos, H. L., Fornasier, S., Haberle, C. W., Hanna, R. D., Howell, E. S., Kaplan, H. H., . . . Sandford, S. A. (2019). Evidence for widespread hydrated minerals on asteroid (101955) bennu. *Nature Astronomy*, *3*(4), 332-340. https://doi.org/10.1038/s41550-019-0722-2
14. Adams, F. C., & Napier, K. J. (2022). Transfer of rocks between planetary systems: Panspermia revisited. *Astrobiology*, *22*(12). https://doi.org/10.1089/ast.2021.0187
15. Bergsten, G. J., Pascucci, I., Hardegree-Ullman, K. K., Fernandes, R. B., Christiansen, J. L., & Mulders, G. D. (2023). No evidence for more earth-sized planets in the habitable zone of kepler's M versus FGK stars. *The Astronomical Journal*, *166*(6), 234. https://doi.org/10.3847/1538-3881/ad03ea

All figures & tables not cited were created in full by the presenter. Most figure citations correspond to internal images