VIABILITY OF LITHOPANSPERMIA BETWEEN PLANETS OF GLIESE 581. K. E. Broad[1] L. S. Brock[2] and H. J. Melosh[1], [1]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.

Introduction: Soon after the discovery that some achondrite meteorites are of Martian origin (McSween, 1985), the possibility arose that Earth and Mars might share a common pool of life (Melosh, 1988). Further, it was later determined that the transfer of dormant microorganisms is highly probable in our solar system (Mileikowsky et al., 2000), otherwise known as "lithopanspermia." In the work reported here, we extend this concept to extrasolar systems.

The Gliese 581 multiplanet system (also referred to as GJ 581 in this work) is fitting for our focus in studying impact exchange and the possibility of lithopanspermia. Of spectral class M3V and approximately one third the mass of our Sun (0.31 M_{Sun}), Gliese 581 hosts a planetary system consisting of four to six planets (Bonfils et al., 2005b, Udry et al., 2007, Mayor et al., 2009). However, because of the uncertainty of the existence of the outermost planets in the system, we focus on the four originally discovered planets e, b, c and d. Of particular interest are two super-Earths in the system, GJ 581 c and GJ 581 d. These planets are suggested to be of rocky composition, one residing on the "warmer" edge of the habitable zone, the other on the outer edge (Udry et al., 2007). GJ 581 e is the smallest, most recently discovered and orbits closest to its host star (Mayor et al., 2009). Neptune-mass GJ 581 b was the first detected in the system (Bonfils et al., 2005b). The orbital parameters used were determined by Forveille et al. (2011). Using these parameters, we apply the Öpik-Arnold method to determine the likelihood of transfer of rocky materials within the system. This evaluation has been performed on our solar system (Mileikowsky et al., 2000) and similar work has been done on close-proximity, resonant planet pairs in potentially habitable systems (Steffen and Gongjie, 2016) and on the TRAPPIST-1 system (Krijt et al., 2017).

The Öpik-Arnold Method: Previously applied to our solar system (Melosh and Tonks, 1993), we apply the statistical Öpik-Arnold Method to the GJ 581 extrasolar system. This method parameterizes the Keplerian orbit of a small particle ejected from one of the planets by its semi-major axis, eccentricity and inclination (a, e, i) and evolves these orbital elements statistically over long timescales, taking into account close planetary encounters. It stops the particle's evolution if an impact takes place, it is ejected from the system, or it becomes isolated in its orbit for more than 4 billion orbital periods (460 Myr for this system). It then scores these results for the each of the small bodies ejected (10,000, in our study).

The Öpik-Arnold Method is useful for determining the general character of orbital evolution of impact ejecta, providing quick results that are within a factor of two of more time-consuming full orbital integrations (Dones et al., 1999). We assume that the small bodies are ejected from their parent planet at velocities greater than escape velocity and obtain orbits around the star. 10,000 particles of impact ejecta were considered, leaving each of the four planets in the system at various initial velocities and randomly distributed directions. The resulting fates of the ejecta particles (including time in space, approach velocity and planet of impact or ejection) were then analyzed and compared.

Results: Overall, it is clear that the arrival velocities are distributed in an approximately gaussian fashion, while the distributions of time in space are very close to gaussian (that is, they plot as nearly straight lines in a probability plot), as shown in figures 1 and 2, which display results for ejection from d and impact on c and ejection from c and impact on d. The results extracted from these figures are discussed below. It should be noted that results were extracted from transfer between GJ 581 e and b, but we report the details of the exchange between GJ 581 c and d which are located within the habitable zone and therefore are most interesting for lithopanspermia.

Ejection from GJ 581 c and impact on GJ 581 d: At low departure velocities, ejecta from c mainly falls back onto c itself after a few centuries. As impact velocity increases, less ejecta returns to c, but most evolves inward striking planets e and b. At most about 10% reaches planet d. At the highest departure velocities, the probability of reaching d decreases as more ejecta obtain an initially hyperbolic orbit. Approach velocity to planet d is typically about 30 km/sec and the exchange time a few tens of thousands of years. These approach velocities are higher for inner planets e and b.

Ejection from GJ 581 d and impact on GJ 581 c: At low departure velocities, ejecta from d mainly falls back onto itself after a few centuries. As ejection velocity increases, less ejecta returns to d, but more evolves inward striking mostly planets c and b, with at most 13 % reaching planet c. Impact on inner planet b is favored over impact on c. Approach velocity to planet c is typically much more than 30 km/sec and the exchange time is a few tens of thousands of years. Approach velocities are higher and exchange times are longer for inner planets e and b.

Discussion: While the transfer of ejecta between planets is possible in the Gliese 581 system, the potentially habitable planets are more biologically isolated. Any astrobiological material existing on Gliese 581 d, or one of its hypothetical exomoons, has a small chance of being exchanged with other planets in the system. Further, a significant fraction of ejecta from d is released in an initial hyperbolic orbit, leaving the exosystem entirely. Further, high impact velocities cause a low probability of biological exchange despite shorter exchange times. This in combination of extremely high escape velocities of each planet makes the probability of survival of microbial life inside these ejecta extremely low.

In the Gliese 581 system, as well as for other planets in the habitable zone around low-mass stars, the probability of biological exchange thus appears to be low.

Figures:

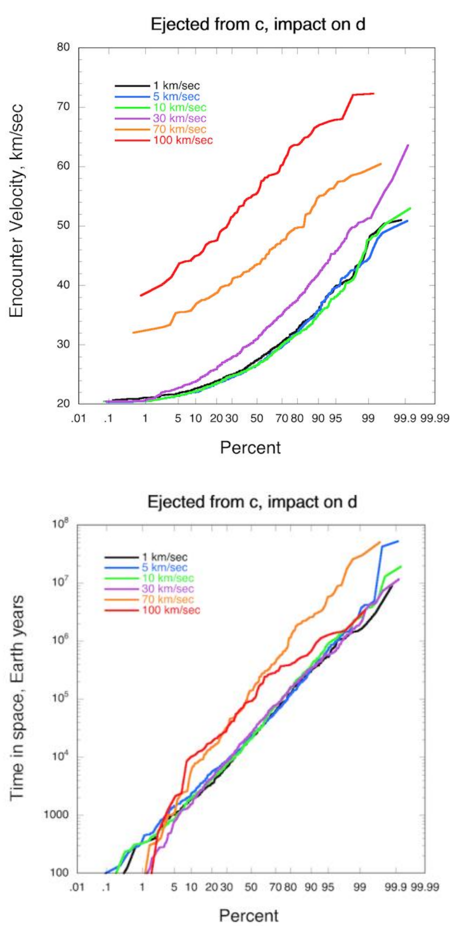

Figure 1. Probability distributions of the encounter velocity and times in space of material ejected at various velocities from planet c that encounter planet d.

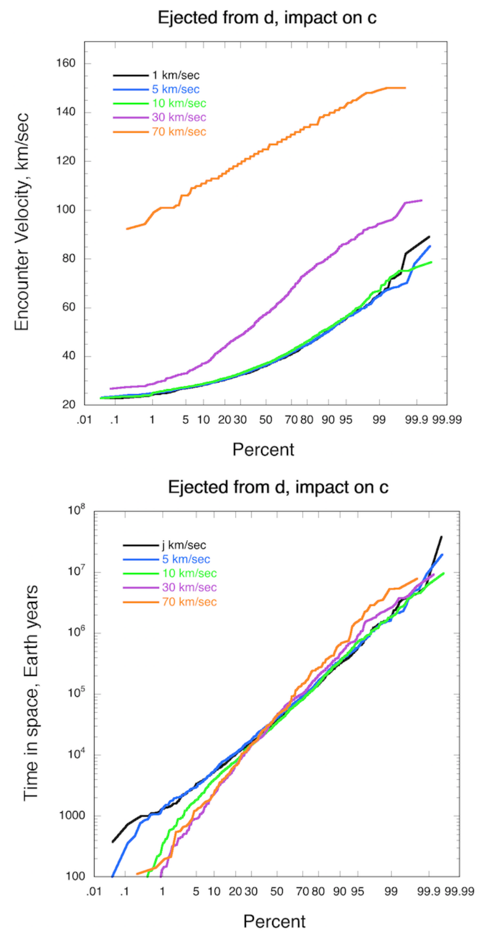

Figure 2. Probability distributions of the encounter velocity and times in space of material ejected at various velocities from planet d that encounter planet c.

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