IMPACT EXCHANGE OF MATERIAL BETWEEN PLANETS OF GLIESE 581 . L. S. Brock[1] and H. J. Melosh[1], [1]Department of Earth and Atmospheric Science, Purdue University West Lafayette, IN 47907 (lbrock@purdue.edu)

Introduction: The discovery of meteorites from Mars and the Moon indicates that in our solar system large impacts can transfer rocky material from one planet to another. It has been suggested that living microbes can be exchanged among the planets by this mechanism [1]. An obvious extension is to ask whether this process could also operate in other solar systems.

Our research examines the possibility of exchange of meteorities among the planets of Gliese 581. We chose to focus on this system because it contains at least one planet located close to the "habitable zone" where liquid water is possible (See Fig. 1).

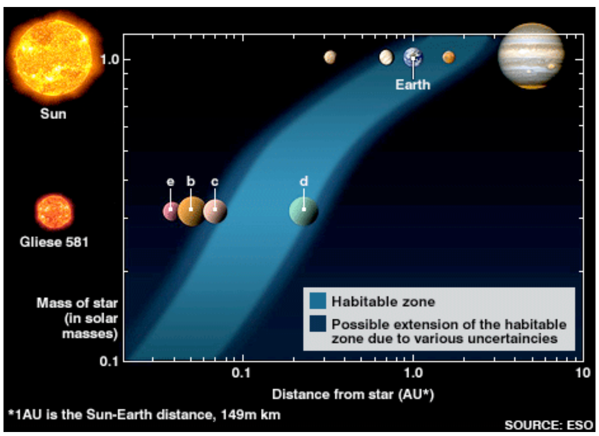

Fig. 1 Illustration of the planets in Gliese 581 system compared to our solar system. From BBC News (http://news.bbc.co.uk/2/hi/8008683.stm).

Gliese 581 is an exosolar system discovered by HARPS at La Sille Observatory in Chile [2]. The system lies ~20 light years from our solar system and contains four confirmed planets, e, b, c, and d respectively (planets f and g, originally reported, are no longer believed to exist [3]). The system is very different from our solar system beginning with its star, which is ~1/3 as massive as our Sun. All four planets of the system lie in close proximity to the star and range from 0.03 to 0.22 AU, putting each planet well inside the orbit of Mercury. Planets e and c are speculated to be rocky in composition due to their range of acceptable masses. Planet d is too massive to be considered only rocky and is thought to be composed of liquid water or ice. Planet b, however, is the most massive planet in the system and is comparable to Neptune.

We focus on planet d because it is closer to the habitable zone of its star than any other planet of this system. Planet d, although perhaps too massive to be mainly rock and ice, could still have a solid ice surface. The most massive planet b, perhaps shrouded in a deep atmosphere like Neptune, could neverthless posses large moons (analogus to Saturn's moon Titan) with solid surfaces that might support life.

We used a computer model[4] to examine the fate of particles ejected from each planet. We assumed that particles were ejected from each planet at a range of initial velocities. The program then followed the evolution of the particle's orbits within the Gliese 581 system. Our goal is to determine whether planet d could exchange astrobiological materials with other planets of the Gliese system and to evaluate individual exchanges between planets e, b, and c.

Methods: We used the Öpik-Arnold method [5] to calculate the fate of 10^4 particles initially ejected from planets e-d. The method assigns each particle an initial orbit (a, e, i) and evaluates the effect that small perturbations have on the particle's orbit As the orbit evolves, the particles may impact a planet, its parent star, or be ejected into interstellar space. The initial velocity ranges (high, medium, low) were scaled from each planet's orbital velocity, which are rather high by solar system standears due to the extremely close proximity of these planets to their central star (Table 1). The actual mass of each planet is uncertain, and the literature cites only a range of acceptable values [2]. We chose the average values reported in Table 1 for our work. Since radii are unknown, density could not be determined directly from the mass. We assigned a density to each planet similar to the density of other planets whose mass and density are both known. For example, planet b was considered an icy Gas Giant with comparable mass to Neptune and thus given and estimated density of 1.5 g/cc (Table 1).

Table 1

Planet	Average Mass (kg)	Similar Mass	Density Estimate (g/cc)	Orbital Velocity (km/s)
e	1.5e25	Kepler 11 f	6	96
b	1.4e26	Neptune	1.5	83
c	4.7e25	Kepler 11e	6	63
d	6.2e25	Kepler 11c	2	35

Moons. Since we determined that planet b is a massive, Neptune-like planet, we assumed this planet could harbor potential moons. Comparing our potential moons with Neptune's actual moons, we evaluated three sizes of moon (small: <100, medium: >100, large: >1000 km) and determined the probability of impact on said moons from the ratios of their projected area to that of planet b. This helped produce more realistic results in the Gliese 581 system since no current moons have been discovered.

Results: The transfer of particles within the Gliese 581 system depends strongly on the initial ejection velocity (the velocities listed here do not include the necessary escape velocity from the planet itself) . Several numerical simulations were analyzed in the case of high (100km/s), medium (60 km/s), and low ejection velocity (20 km/s). Our standard 10^4 particles were ejected at these various velocities from each planet e, b, c, and d and their fates tabulated. Ejections from planet e were most likely to impact planet d regardless of initial velocity. Ejections from planet b were most likely to impact d and b. Ejections from planet c have a high percentage of impacts on b. However, an increase in initial velocity resulted in a decrease in impacts on b. Ejections from planet d have a low probability of impact on any other planet other than itself with most ejected particles entering an initial hyperbolic orbit and being ejected from the planetary system. Planets b and c require an initial velocity of only 1 km/s (beyond escape velocity) to evolve away from the planet's orbit whereas planets e and d require at least 12 km/s.

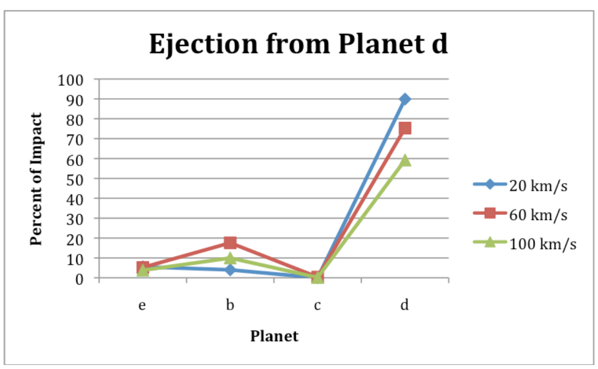

Fig.2 Material ejected from planet d at given velocities and percent of impact on planets e, b, c, and d

Planet b would act like Jupiter in our solar system due to its large mass and frequently perturb ejected material into interstellar space. The probability of impact on planet b would also be slightly less than our results show if affected by potential moons.

Conclusion: Impact ejecta exchange in the Gliese 581 system is very different from our Solar System due to the close proximity of the planets to their central star and the resulting large orbital velocities. Because of this, rather large initial velocities (20 to 100 km/sec) are required for orbital perturbations to allow interplanetary exchanges. Planet d, which is speculated to harbor life or liquid water [6], would have a very small chance of transferring material to the other planets in the Gliese system and this thus far more isolated, biologically, than the inner planets of our own solar system.

References: [1] Melosh, H. J. (1988) *Nature* 332, 687-688. [2] Bonfils X.; et al. (2005) *A&A, 4433,* L15-L18. [3] Tuomi M. (2011) *A&A, 528,* L5. [4] Dones, L. et al. (1999*) Icarus* 142, 509-524. [5] Arnold J.R. (1965) *Astrophys., J14,* 1536-1547. [6] Von Paris P.; et al. (2011) *A&A, A58,* 532.