TERRESTRIAL PLANETS ARE RARE. T. L. Clarke[1], [1]Institute for Simulation and Training, University of Central Florida, 3280 Progress Drive, Orlando, FL 32826, tclarke@ist.ucf.edu

Introduction: The discovery of many massive, Jovian and larger, extrasolar planets in recent years [1] can lead to the expectation that these systems will contain a comparable number of terrestrial-size planets based on analogy with the solar system. This paper suggests that even in systems where large planets have formed, the formation of smaller terrestrial sized planets is not inevitable. The formation of terrestrial planets may depend on the presence of Al26 in the solar nebula to provide heat to melt planetesimals and facilitate planetary accretion. Since presence of significant Al26 is dependant on a nearby supernova occurring within the half life of Al26, the probability of terrestrial planet formation would be substantially reduced.

Discussion: In [2] the role that Al26 heating plays in the spatial distribution of asteroid types was identified. Since the amount of Al26 incorporated into a planetesimal depends on how long it takes the planetesimal to accrete from the solar nebula in comparison to the 720,000 year half life of Al26 and theories of accretion show that it takes longer to accrete a planetesimal the further it is away from the nascent sun, planetesimals at greater solar distance will have less undecayed Al26, and hence less heat input from radioactive decay. Any planetesimal larger than about 30 km and closer to the sun than 3.5 AU, heats to the melting point of water; closer than about 2.5 AU silicate minerals melt. These results agree with observations of the spectra of asteroids as correlated with the properties of meteorites. Closer than 2.7 AU asteroids appear to be igneous, between 2.7 AU and 3.4 AU they are metamorphic,and beyond 3.4 AU they are primitive. These results are also supported by recent data from Mars pathfinder that [3] suggest a chondritic origin for terrestrial planets does not fit elemental abundances.

In planetary systems formed without Al26 heating, planetesimals form in the relatively gas-free region near the star, but they are "dry" planetesimals since nothing heats them to the melting point of water, much less that of minerals. The planetesimals grow to the size of asteroids, but then stop since their gravitational encounters are relatively elastic; that is, since they are rigid rock/ice, tidal friction is low and there is no way to shed energy and transfer angular momentum during an encounter. The result is a star, perhaps with a smallish planet at the position of Mercury since there would have been some melting at that distance, and a large asteroid belt covering the orbits of Venus, Earth, Mars and the present asteroid belt. The outer system would contain gas giants since liquid gases would provide the viscous fluids necessary to condensation or where other mechanisms such as gravitational instability [4] can lead to planet formation.

But in a system with Al26 the initial presence of heating caused everything inside of the current asteroid belt to be well melted. During encounters between planetesimals there would be viscous flow in these bodies providing a means to loose energy and transfer encounter angular momentum into rotational angular momentum. The tidal dissipation is given by the rate of change of energy with time [5] $\frac{dE}{dt} = \frac{21}{2}\frac{k}{Q}\frac{MR^5}{a^3}e^2 n^3$ where R is the body radius, M is the mass, k is the tidal Love number, Q is the dissipation quality factor and (a,e,n) are orbital parameters. For rigid bodies $10^3<Q/k<10^4$, but for melted bodies Q/k would be order unity. Thus collisions in a system with AL26 would be much more inelastic leading to formation of terrestrial-sized planets in the inner system.

A supernova injecting Al26 into the proto-solar nebula just as it begins to collapse is a fairly unusual event. Estimates based on the strength of the Al26 gamma emission [6] give a formation rate of 5±4/yr and a supernova rate of 3.4±2.8/century. The naive estimate would thus put the probability of a nearby supernova at ~ 1%. Thus only a small fraction of planetary systems would be expected to have terrestrial planets.

Conclusion: In addition to the the paucity of planetary systems with terrestrial planets with its implications for the Drake equation and answering Fermi's question, this idea has other implications. Planetary systems without terrestrial planets should have an extensive inner asteroid belt region; possibly detectable in the infrared. Also, double asteroids will be of the igneous or metamorphic types since only they would be subject to viscous orbital dissipation to provide a means to loose energy and transfer angular momentum forming stable orbits. Primitive asteroidal types would not be able to do so and will not be found in gravitationally-bound pairs.

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