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Panspermia in tightly-packed habitable multi-planet systems

Dimitri Veras (1), David J. Armstrong (1), Hendrik Schaefer (2), Jose F. Gutierrez-Marcos (2), Mark Hollands (1)
(1) Department of Physics, University of Warwick, Coventry CV4 7AL, UK
(2) School of Life Sciences, University of Warwick, Coventry CV4 7AL, UK
(d.veras@warwick.ac.uk)

Abstract

The discovery of multiple planets in the habitable zone of the TRAPPIST-1 system is a watershed in exoplanetary science. As missions such as PLATO extend habitable zone sensitivity out to 1 au, we can expect an increasing number of similarly exciting systems. Consequently, developing analytical techniques to quantify extrasolar intra-system panspermia will become increasingly important. Here, we apply an impulse formalism from [2] to determine the asteroid impact characteristics which would be necessary to transport life both inwards and outwards within tightly-packed multi-planet habitable systems. We provide estimates for the dissemination of life within those systems, and assess the prospects for eukaryotic and microbial survival at both impact and in space.

1. Introduction

Although studies of the transport of life-bearing rocks between planets has a long history [4], the discovery of the potentially life-bearing Martian meteorite ALH84001 in the mid-1990s accelerated investigations into panspermia within the Solar system. The last two decades has since featured detailed work outlining delivery dynamics, impact physics and chemistry, and biological survival requirements with respect to Earth, Mars and other solar system bodies. Consequently, a detailed foundation for panspermia-related processes has been established.

Despite these advances, the applicability of these processes to extrasolar planetary systems is still in question, partly because in those systems we lack the detailed knowledge of our own planetary system. Nevertheless, efforts to characterize panspermia between different extrasolar systems, or between the solar system and extrasolar systems, have contributed to our understanding. However, panspermia amongst extrasolar planets within the same system has received little attention. A potential reason for this dearth of study is the lack of observational evidence of multiple planets in the habitable zone of the same star. This situation has now changed with the groundbreaking discovery of multiple potentially habitable planets in the TRAPPIST-1 system [1], and the subsequent analyses [3,5].

2. Our contributions

Here, we study several aspects of panserpermia within multi-planet habitable systems, with a focus on analytics and dynamical delivery, but also addressing eukaryotic and microbial survival given an arbitrary flux from the central star. We also consider the timescales for Hohmann transfers for advanced life.

Advancing the impulse formalism of [2] allows us to assess prospects for panspermia algebraically, i.e., without resorting to numerical simulations, which have been common features of previous studies.

Figure 1 illustrates how the direction of ejecta from an impact translates into the orbital location for different kick speeds. Figure 2 illustrates how vertically coincident (with regard to orbital inclination) multiple planets (in this one case, the TRAPPIST-1 planets) must be in order for panspermia to occur.

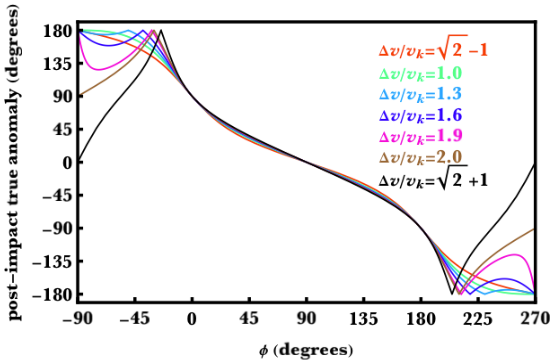

Figure 1: Relating the post-impact true anomaly with kick direction from impact.

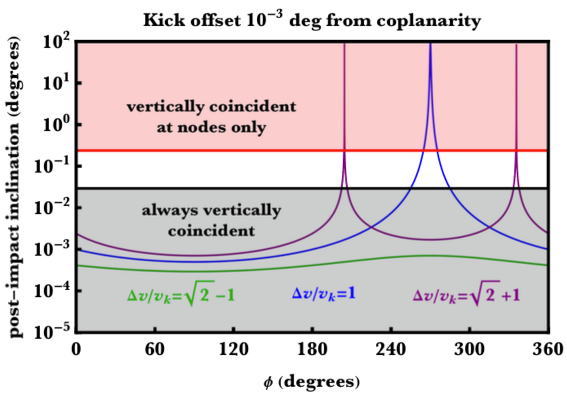

Figure 2: How the kick direction affects the inclination of the ejecta orbit. By assuming coplanarity amongst all TRAPPIST-1 planets, we plot, for three different values of the ratio of kick velocity to circular Keplerian velocity ($\Delta v/v_K$), the dependence on the kick direction in the source's orbital plane φ. The gray region corresponds to where the resulting ejecta orbital inclination is never large enough to exceed the radius of any TRAPPIST-1 target at any point in the orbit, and the red region corresponds to the opposite extreme, where vertical coincidence occurs only near the orbital nodes.

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