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Deposition of steeply infalling debris — pebbles, boulders, snowballs, asteroids, comets — around stars

John C. Brown (1), **Dimitri Veras** (2), Boris T. Gänsicke (2)
(1) School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK
(2) Department of Physics, University of Warwick, Coventry CV4 7AL, UK
(d.veras@warwick.ac.uk)
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Abstract

When Comet Lovejoy plunged into the Sun, and survived, questions arose about the physics of infall of small bodies. [1,2] has already described this infall in detail. However, a more general analysis for any type of star has been missing. [3] generalized previous studies, with specific applications to white dwarfs.

High-metallicity pollution is common in white dwarf stars hosting remnant planetary systems. However, they rarely have detectable debris accretion discs, possibly because much of the influx is fast steeply infalling debris in star-grazing orbits, producing a more tenuous signature than a slowly accreting disc. Processes governing such deposition between the Roche radius and photosphere have so far received little attention and we model them here analytically by extending recent work on sun-grazing comets to white dwarf systems. We find that the evolution of cm-to-km size infallers most strongly depends on two combinations of parameters, which effectively measure sublimation rate and binding strength. We then provide an algorithm to determine the fate of infallers for any white dwarf, and apply the algorithm to four limiting combinations of hot versus cool (young/old) white dwarfs with snowy (weak, volatile) versus rocky (strong, refractory) infallers.

We find: (i) Total sublimation above the photosphere befalls all small infallers across the entire white dwarf temperature range, the threshold size rising with it and 100× larger for rock than snow. (ii) All very large objects fragment tidally regardless of temperature: for rock, $a0 \gtrsim 10^5$ cm; for snow, $a0 \gtrsim 10^3 - 3 \times 10^4$ cm across all white dwarf cooling ages. (iii) A considerable range of infaller sizes avoids fragmentation and total sublimation, yielding impacts or grazes with cold white dwarfs. This range rapidly narrows with increasing temperature, especially for snowy bodies. Finally, we briefly discuss how the various forms of deposited debris may finally reach the photosphere surface itself.

1. Figures

Destruction of infalling bodies occurs by a combination of: (a) sublimative mass-loss by an energy flux of starlight that is sufficiently large to raise the bodies above the vaporization temperature of at least some, and eventually all, of their components; (b) fragmentation due to the stellar tidal or possibly internal pressure forces exceeding the internal strength and self-gravity of the body; and (c) frictional ablative mass-loss and ram-pressure pancaking and deceleration effects in the dense low atmosphere.

The importance of these various processes all decline with distance, but at differing rates. An example of all three processes at work can be found in Fig. 1, which details the fate of rocky infallers of sizes ranging from 10^0 to 10^6 metres. The white dwarf has an effective temperature of about 15,000 K. Fig. 2 then provides a more abstract representation of the different regimes, which may be applicable to any stars and any impactors. Finally, Fig. 3 provides an algorithm from [3] that one may apply to any system in order to determine the fate of infallers. This algorithm may be used to help determine the fate of planetary systems.

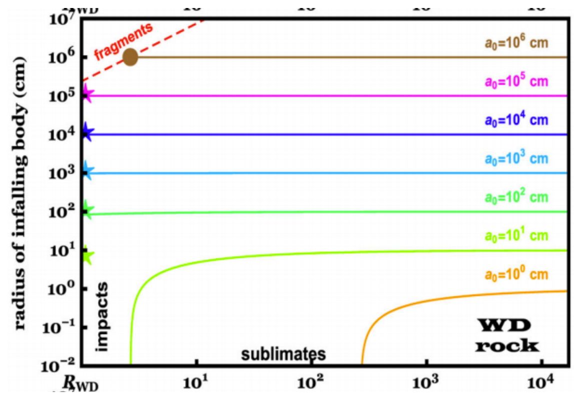

Figure 1: Size evolutions and fates for rocky bodies falling in towards a white dwarf with an effective temperature of about 15,000 K.

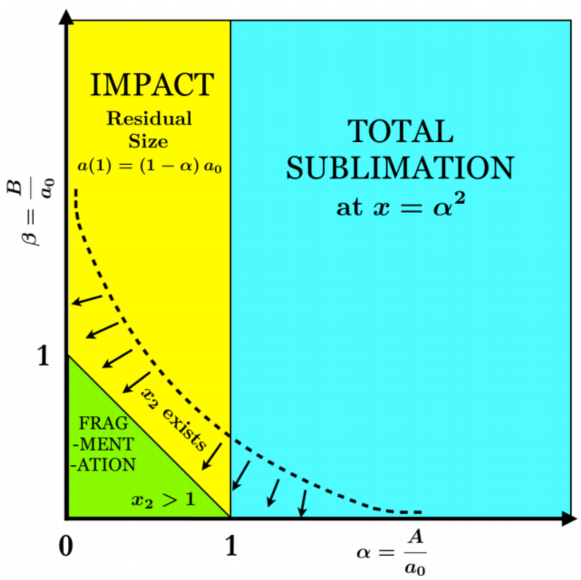

Figure 2: The three distinct domains of infaller destruction in the α, β plane (see [3] for definitions) – total sublimation, impact after partial sublimation, and fragmentation after partial sublimation. Fragmentation is restricted to the green triangular domain in the bottom left corner.

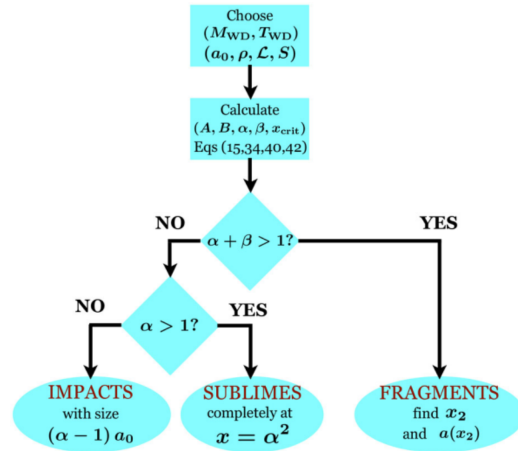

Figure 3: Schematic flow chart of how to determine the mode and position of destruction of any infaller for any star starting from adopted values of the physical parameters of each.

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[3] Brown, J.C., Veras, D., Gänsicke, B.T.: Deposition of steeply infalling debris around white dwarf stars, MNRAS, Vol. 468, 1575-1593, 2017.