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NON-RANDOM SPATIAL DISTRIBUTION OF IMPACTS IN THE STARDUST COMETARY COLLECTOR. Andrew J. Westphal[1], Ronald K. Bastien[2], Janet Borg[3], John Bridges[4], Donald E. Brownlee[5], Mark J. Burchell[6], Andrew F. Cheng[7], Benton C. Clark[8], Zahia Djouadi[3], Christine Floss[9], Ian Franchi[4], Zack Gainsforth[1], Giles Graham[10], Simon F. Green[4], Philipp R. Heck[11], Mihaly Horányi[12], Peter Hoppe[11], Friedrich P. Hörz[2], Joachim Huth[11], Anton Kearsley[13], Hugues Leroux[14], Kuljeet Marhas[9], Keiko Nakamura-Messenger[2], Scott A. Sandford[15], Thomas H. See[2], Frank J. Stadermann[9], Nick E. Teslich[10], Samuel Tsitrin[1], Jack L. Warren[2], Penelope J. Wozniakiewicz[13,16], Michael E. Zolensky[2] , [1] *University of California at Berkeley, Berkeley CA 94720, USA* [1] *KT NASA Johnson Space Center, Houston, TX 77058, USA* [3] *IAS, Université Paris-Sud, UMR8617, F-91405 Orsay-Cedex, France* [4] *Open University, Milton Keynes MK7 6AA, UK* [5] *University of Washington, Seattle, WA 98195, USA* [6] *University of Kent, Canterbury, Kent CT2 7NH, UK* [7] *Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 USA* [8] *Lockheed Martin Corporation, Littleton, CO, USA* [9] *Washington University, St. Louis MO 63130, USA* [10] *IGPP, Lawrence Livermore National Laboratory, 7000 East Avenue, L-413, Livermore, CA 94550, USA* [11] *Max-Plank-Institute für Chemie, P. O. Box 3060, D-55020 Mainz, Germany* [12] *University of Colorado, Boulder, CO 80309-0392, USA* [13] *The Natural History Museum, London SW7 5BD, UK* [14] *Université des Sciences et Technologies de Lille, France* [15] *NASA-Ames Research Center, Moffett Field, CA 94035 USA* [16] *Imperial College London, South Kensington Campus, London SW11 3RA, UK.*

Introduction

In January 2004, the Stardust spacecraft flew through the coma of comet P81/Wild2[1] at a relative speed of 6.1 km sec^{-1}. Cometary dust was collected at in a 0.1 m^2 collector consisting of aerogel tiles and aluminum foils. Two years later, the samples successfully returned to earth and were recovered. We report the discovery that impacts in the Stardust cometary collector are not distributed randomly in the collecting media, but appear to be clustered on scales smaller than $\sim$10 cm. We also report the discovery of at least two populations of oblique tracks. We evaluated several hypotheses that could explain the observations. No hypothesis was consistent with all the observations, but the preponderance of evidence points toward at least one impact on the central Whipple shield of the spacecraft as the origin of both clustering and low-angle oblique tracks. High-angle oblique tracks unambiguously originate from a non-cometary impact on the spacecraft bus just forward of the collector. Here we summarize the observations, and review the evidence for and against three scenarios that we have considered for explaining the impact clustering found on the Stardust aerogel and foil collectors.

Observations

1. We used two statistical tools to test for randomness in the spatial distribution of impacts: the two-point correlation function $\hat{\xi}$ [3] and a single sum-inverse-square distance statistic $\hat{\zeta}$[5]. Since we found it to be insensitive to weak clustering, we did not use the mean nearest neighbor statistic [4]. There is statistically significant clustering of small tracks (maximum throat diameters $\sim$ 100 μm) (Fig. 1) and small craters (*e.g.*, Fig. 2) on all length scales from microns to tens of centimeters. The evidence for clustering among large tracks ($\gg$ 100 μm) and craters ($>$ 10 μm) is statistically significant but weaker.

2. We observe off-normal tracks in aerogel tiles, distributed among normal-incidence tracks (Fig. 3). These tracks display a systematically different morphology than normal-incidence tracks. We observe a divergence of off-normal tracks between tiles 9 (many tracks) and 44 (two tracks) consistent with an origin on the central Whipple shield. The distribution of the intersection of track trajectories with the plane of the Whipple shield shows many tracks below -20 cm and no tracks above $+20$ cm. (0 cm is the projected center of the tray, and the positive direction is away from the spacecraft bus).

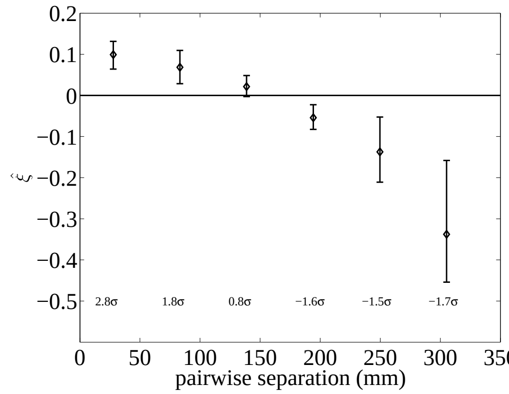

Figure 1: The two-point correlation function $\hat{\xi}$ plotted versus track separation. The statistical significance of the departure from random ($\hat{\xi} = 0$) is given for each point.

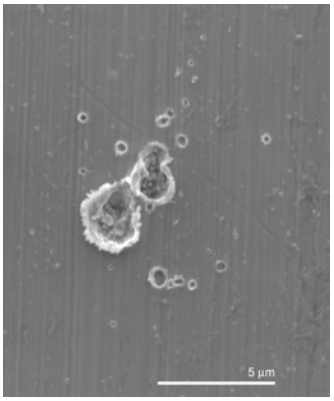

Figure 2: A cluster of 37 craters in foil 8N, discovered and imaged by the OU group. The craters are distributed over 350 μm^2.

4. There is a large discrepancy in the spectral index and fluence at small particle sizes between the DFMI (PVDF de-

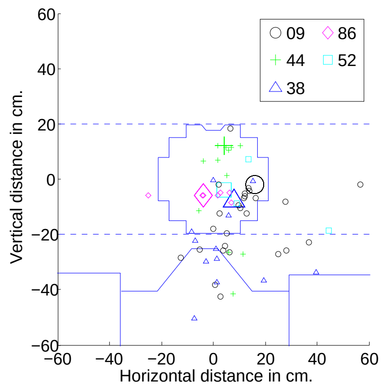

Figure 3: Aerogel tracks projected onto the plane of the central Whipple shield. The spacecraft bus is at the bottom of the picture. The Wild2 nucleus passed below the spacecraft. The Whipple shield outline is shown at -40 cm on the y axis and includes the trapezoidal protrusion. The rectangular Whipple shields to each side are the solar panel shields and are located in a different plane. Parallax between the solar Whipple shields and the impact sites has been ignored for readability. The outline of the collector is shown at the center. Symbols indicate the tile of origin; the tiles are the magnified symbols.

tector) observations made during the cometary encounter[2] and the crater observations made from the returned sample tray. Both crater and track analyses yield consistently fewer small particles than DFMI. DFMI observed two periods of dust collection, centered on the closest approach time and another ~ 4000 km downrange of closest approach.

5. There is no evidence of spacecraft material in the impacts. It is not clear that this is a constraint, because of the relative lack of relevant experimental data on the presence of forward-scattered target material in highly oblique impacts of small friable projectiles.

Hypotheses

We have considered the following hypotheses:

• All impacts are primary, with a small radial velocity with respect to the nucleus, and clustering occurs in the coma due to some unknown mechanism. This hypothesis is consistent with the observations of clustering and lack of spacecraft materials in impacts, but is not consistent with the presence of off-normal tracks nor the DFMI/crater discrepancy. It is also not consistent with the expected large separation speeds expected for disintegrating dust in the cometary coma. Electrostatic repulsion sets a seemingly hard lower limit of $\gg 1$ cm sec^{-1} on the dispersion speed of disintegrating dust [5]. This lower limit is based on straightforward physical principles.

• All impacts are primary, with a large radial velocity, and clustering occurs in the coma due to some unknown mechanism. This hypothesis is consistent with the observations of clustering, lack of spacecraft materials in impacts, the presence of off-normal tracks, and could reconcile the DFMI data near closest approach with the cratering observations. This hypothesis is not consistent with the large separation speeds expected for disintegrating charged dust, nor with the DFMI data at $\sim$11 minutes after closest approach.

• Large impacts are primary, but there is a population of small grains due to at least one impact on the central Whipple shield. This appears to be consistent with all the observations, with the exception of the discrepancy between the cratering and DFMI measurements of dust fluences, the marginally significant clustering observed in both $\hat{\xi}_1$ and $\hat{\zeta}$ for large ($> 300\,\mu$m) tracks, and (possibly) the lack of spacecraft materials in impacts.

Although no hypothesis explains all observations, we conclude that the preponderance of evidence points to an impact on the central Whipple shield as the origin of both off-normal tracks and clustering. To be sure, none of the scenarios have been completely ruled out — it is even possible that all three mechanisms operate. Nevertheless, it is clear that researchers should be aware of the possibility that tracks, particularly off-normal tracks, may have been “pre-processed” before capture by a collision with the central Whipple shield, and should be vigilant to contamination from the spacecraft.

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