First results from the Venetia Burney Student Dust Counter on the New Horizons mission

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Received 22 March 2010; revised 20 April 2010; accepted 26 April 2010; published 2 June 2010.

[1] The Venetia Burney Student Dust Counter (SDC) onboard the New Horizons mission is an impact-based dust detector designed to map the size and spatial variability of the interplanetary dust population throughout the solar system. SDC consists of fourteen permanently polarized polyvinylidene fluoride detectors that register a charge upon impact by hypervelocity dust grains. SDC can resolve the masses of grains with $10^{-12} < m < 10^{-9}$ g and measurements to date extend from 2.6 to 15.5 AU. SDC dust flux measurements taken inside the orbit of Jupiter are compared to previous measurements by the Ulysses and Galileo dust detectors to validate the instrument. Measurements taken outside Jupiter's orbit, spanning 6.8 AU to 15.5 AU, are also reported and compared with measurements by the Pioneer 10 and 11 meteoroid detectors and the Voyager 1 and 2 plasma wave instruments. **Citation:** Poppe, A., D. James, B. Jacobsmeyer, and M. Horányi (2010), First results from the Venetia Burney Student Dust Counter on the New Horizons mission, *Geophys. Res. Lett.*, *37*, L11101, doi:10.1029/2010GL043300.

1. Introduction

[2] The population of sub-millimeter sized dust grains within the solar system is comprised of a combination of interplanetary grains from asteroidal and cometary sources and interstellar grains from outside the solar system. Several in-situ measurements of these grains have been made previously by a variety of detectors [*Dietzel et al.*, 1973; *Humes*, 1980; *Grün et al.*, 1995a, 1995b; *Gurnett et al.*, 1997; *Krüger et al.*, 2006; *Altobelli et al.*, 2007] and a comprehensive picture of the interplanetary (IDP) and interstellar (ISD) dust distributions is beginning to emerge. However, there remain significant gaps in the knowledge of the IDP distribution, most notably the paucity of measurements in the outer solar system. To date, only the Pioneer 10 and 11 meteoroid detectors, the Voyager plasma wave instruments and the Cassini Cosmic Dust Analyzer (CDA) have made in-situ measurements outside the orbit of Jupiter. Computer modeling has predicted the spatial density distribution of IDP grains originating from the Edgeworth-Kuiper Belt (EKB) [*Liou and Zook*, 1999; *Moro-Martin and Malhotra*, 2002], yet only the Voyager plasma wave instruments have made continuous measurements of micron sized dust grains in the outer solar system.

[3] The main scientific goals of the Venetia Burney Student Dust Counter on the New Horizons mission are to: (1) map the distribution of dust grains with $m > 10^{-12}$ g along the radial trajectory of New Horizons as the spacecraft leaves the solar system; (2) validate previous outer solar system IDP models; and (3) place limits on the rate of dust production from the Edgeworth-Kuiper Belt (EKB). While cometary and asteroidal dust sources dominate in the inner solar system, production of interplanetary dust particles from the EKB is thought to be the primary source of IDPs in the outer solar system. These dust particles are produced in the EKB via interstellar dust grain bombardment of Kuiper Belt Objects (KBO) and mutual KBO collisions [*Stern*, 1995, 1996; *Yamamoto and Mukai*, 1998]. Upon creation, the particles slowly migrate inwards from the EKB under Poynting-Robertson drag, while also being affected gravitationally by the outer planets [*Liou and Zook*, 1999; *Moro-Martin and Malhotra*, 2002]. Measurements of the IDP distribution are needed to constrain a number of related phenomena across the solar system. Several airless bodies have shown evidence for a dusty exosphere, consisting of dust grains ejected from the surface by interplanetary dust particle bombardment, including the Moon, Phobos and Deimos [*Dubinin et al.*, 1990], Ganymede [*Krüger et al.*, 1999], Europa [*Thiessenhusen et al.*, 2000], the minor moons of Jupiter [*Burns et al.*, 1999] and Pluto-Charon [*Thiessenhusen et al.*, 2002]. Knowledge of the background flux at Saturn can help to distinguish between IDPs and grains ejected by Enceladus [*Spahn et al.*, 2006] and can also put constraints on the compositional evolution of the saturnian ring system [*Cuzzi and Estrada*, 1998].

[4] We describe the SDC instrument and dataset in Section 2, compare SDC measurements inside the orbit of Jupiter to those of the Galileo and Ulysses Dust Detector System in Section 3.1, report on dust flux measurements in the outer solar system in Section 3.2 and finally conclude in Section 4. We dedicate this paper to Dr. A. J. Tuzzolino, who passed away before the first scientific observations became available. His help with the design of the Venetia Burney Student Dust Counter was invaluable and greatly contributed to the success of the instrument.

2. SDC Instrument and Dataset Description

[5] The Venetia Burney Student Dust Counter (SDC) on the New Horizons mission [*Stern*, 2008] consists of fourteen independent permanently-polarized polyvinylidene fluoride (PVDF) detectors, twelve of which are exposed to space with the remaining two encased in aluminum and placed on the underside of the instrument [*Horányi et al.*, 2007]. The instrument detects dust particle impacts by recording the

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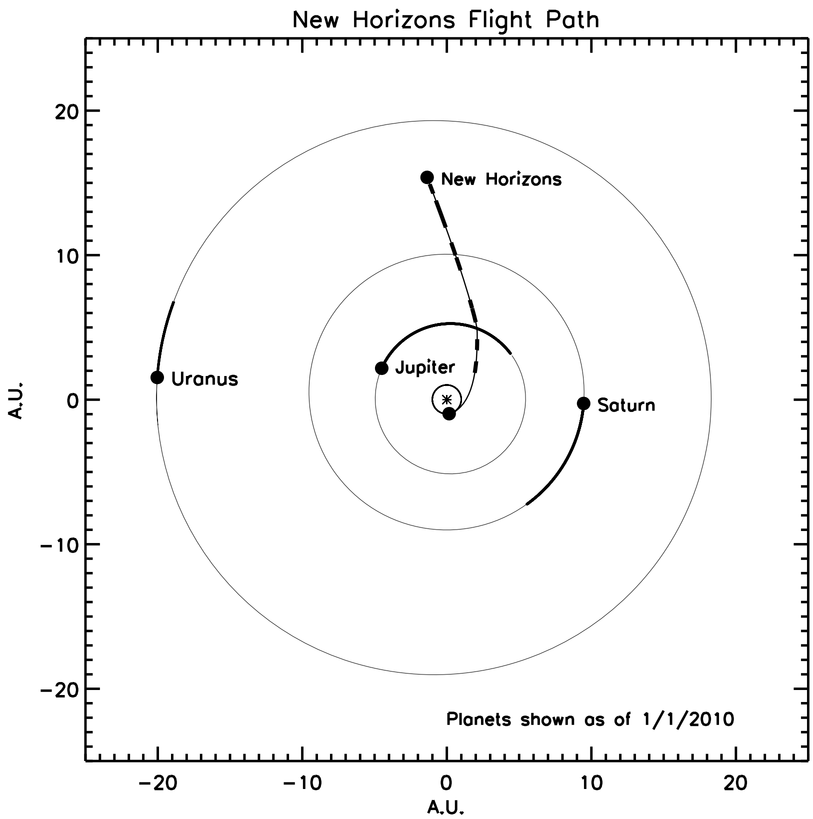

Figure 1. New Horizons flight path with thicker portions indicating SDC observation periods. Planets are shown as of January 1, 2010, with bold tracks indicating movement since January 19, 2006.

charge generated by the PVDF upon impact. The detector response is a power-law function of the mass and velocity of the impacting particle [*Simpson and Tuzzolino*, 1985; *James et al.*, 2010]. Since SDC makes one measurement (charge) for two variables (mass, velocity), all particle velocities are calculated from the assumption that the grains follow circular Kepler orbits around the Sun. Each detector has a configurable software threshold that sets the minimum recordable charge in order to filter out noise events, most of which are due to random thermal electronics noise, electromagnetic interference and mechanical vibrations. Upon detection of a signal above threshold, the instrument records the time, detector number, threshold and signal amplitude. The two reference detectors are used to establish a background noise event rate, since dust impacts and noise events register identically on the instrument. Any events which are coincident within one second either between two separate detectors or a single detector are considered noise and discarded as false.

[6] Due to the long flight time (~9 years) of New Horizons between the Jupiter encounter and Pluto fly-by, the spacecraft enters a hibernation state for approximately 10 months per year, during which all instruments and non-critical spacecraft subsystems are deactivated, with the exception of SDC. Data collected during hibernation is stored internally to SDC and downlinked to Earth during occasional wake-up periods. While SDC did make measurements in the inner solar system before the Jupiter fly-by, all hibernation periods have been after the Jupiter fly-by. The New Horizons trajectory is shown in Figure 1, from launch on January 19, 2006 to January 1, 2010.

3. Interplanetary Dust Measurements

3.1. Comparison to Ulysses and Galileo Inside 5 AU

[7] The interplanetary dust distribution has been measured inside Jupiter's orbit by the DDS on both the Ulysses and Galileo spacecraft [*Grün et al.*, 1992a, 1992b, 1995a, 1995b]. The Ulysses spacecraft made a continuous set of measurements in the ecliptic plane in the inner solar system before being shifted into a highly inclined orbit around the Sun, while the Galileo spacecraft made several sets of measurements through the inner solar system on its way to Jupiter. The Ulysses and Galileo instruments were significantly more complex than SDC, consisting of a hemispherical target with multiple electric grids spanning the detector aperture. An incoming dust particle passes through the grids, impacts the hemispherical target and generates an impact plasma of ions and electrons. A strong electric field separates the ions and electrons, each of which are directed to charge-sensitive amplifiers. Calibration of the ion and electron pulse characteristics allowed the speed and mass of the impacting particle to be independently determined. While the minimum detectable particle size for the DDS instruments varies as a function of the impact speed, the instruments were sensitive to particles with mass, $m > 10^{-15}$ g at impact velocities of ~50 km/sec. By recording the instrument pointing at the time of impact, the velocity vector could

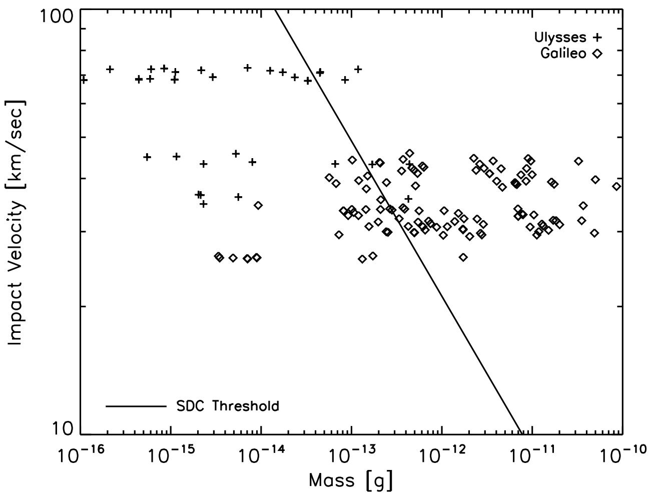

Figure 2. The SDC-apparent mass and impact velocity of Ulysses- and Galileo-measured dust particles along with the SDC threshold curve. Particles above the line would register above the minimum threshold on SDC.

be determined for each particle. SDC is a much simpler, lighter and lower-power instrument with a minimum threshold of approximately 10^{-12} g, but lacks the ability to obtain independent speed and impact velocity measurements. The diversity of dust instrumentation, sensitivities, pointing and trajectories prevents a straightforward comparison of impact fluxes between these instruments. However, an in-depth analysis of the Ulysses and Galileo datasets can provide a robust comparison to the SDC measurements.

[8] In order to compare the Ulysses and Galileo DDS measurements with SDC measurements, we derive an effective flux by adjusting the Ulysses and Galileo data to the sensitivity, pointing and trajectory of SDC. We use the two periods of SDC measurements inside 5 AU: 2.66–3.55 AU and 3.99–4.69 AU. After selecting data in this range from the Ulysses and Galileo datasets, the impacts were divided into interplanetary and interstellar dust impacts. To distinguish these two populations, we used criteria established previously [*Grün et al.*, 1994; *Landgraf et al.*, 2000]. First discovered by Ulysses [*Grün et al.*, 1994] and later observed by Galileo, interstellar dust travels through the solar system at ~26 km/sec from an ecliptic longitude of approximately 252°. Before the Jupiter gravity assist, the New Horizons spacecraft was on a trajectory varying from ecliptic longitude 215° to 250° and therefore SDC, with a viewing cone angle of 45°, was exposed to the interstellar dust flow. SDC's assumption that all particles are on circular Kepler orbits causes the mass of interstellar dust particles to be mis-interpreted. Once the Ulysses and Galileo dust impacts were properly sorted, the theoretical DDS impact velocity for all impacts was calculated and along with the DDS calibration curves, used to re-calculate the grain mass [*Altobelli et al.*, 2005]. The DDS impact velocity for each grain was transformed into the New Horizons frame to determine the theoretical impact speed of the grain into SDC. With the impact speed and mass, the amount of charge generated for each grain by the SDC detectors was calculated, using the SDC calibration curve (adjusted for a detector temperature of −95°C):

$$N = 5.078 \times 10^{14} m^{1.052} v^{2.883}, \quad (1)$$

where N is the number of electrons generated, m is the particle mass in grams, and v is the impact velocity in km/sec [*James et al.*, 2010]. The minimum sensitivity of SDC during this time in number of electrons was 8×10^5 e. Figure 2 shows the SDC-apparent impact velocity and mass of the Ulysses and Galileo hits used in this analysis. Additionally, the SDC threshold as a function of mass and impact velocity is shown as the solid line. In order to calculate an effective flux for SDC based on the SDC-observable hits, the Ulysses and Galileo instrument viewing times and areas were also taken into account. To establish error bars for the Ulysses and Galileo fluxes, the analysis was repeated with the mass and velocity scaled both high and low by the multiplicative error factors.

[9] The SDC fluxes for this period were calculated in a straightforward manner. Coincident events are first removed from the dataset and the average dust impact rate is then determined for both the exposed science detectors and the covered reference detectors. Eleven of the twelve science detectors are used, as detector #11 has degraded significantly since launch [*Horányi et al.*, 2007]. The dust impact flux is found by subtracting the raw reference rate from the raw science rate for all hits with mass greater than 2×10^{-12} g and dividing by the detector area and integration time. The error bars are calculated by adding the standard deviation for the science and reference channels in quadrature. Table 1 compares the calculated fluxes for all three instruments over the two periods selected. Within error bars, all three measurements agree. This agreement validates the SDC dataset and allows us to confidently report on the measured fluxes in the outer solar system.

3.2. Measurements Outside 5 AU

[10] As of January 7, 2010, measurements of dust fluxes by SDC have extended to approximately 15.5 AU. Figure 3 shows the cumulative average number of hits for the science and reference detectors as a function of time and heliocentric distance, while Figure 4 shows the SDC measured flux for grains with mass, $m > 2 \times 10^{-12}$ g (radius, $r > 0.58$ μm, assuming a grain density, $\rho = 2.5$ g/cm^{-3}), as a function of heliocentric distance. Fluxes for SDC are calculated in the same manner described in Section 3.1 and remain fairly constant out to 15 AU, at about 2.5×10^{-4} m^{-2} s^{-1}. The interplanetary dust measurements in the outer solar system suitable for comparison are the Pioneer 10 and 11 meteoroid detection experiments and the Voyager 1 and 2 plasma wave instruments (PWS). The Voyager PWS instruments measured an average interplanetary dust density in the outer solar system of 2×10^{-8} m^{-3} for grains with mass, $m > 10^{-11}$ g.

Table 1. Fluxes Inside 5 AU[a]

Distance (AU)	Ulysses	Galileo	SDC
2.66–3.55	$0.4^{1.2}_{0.0}$	$1.5^{1.8}_{0.7}$	$1.1^{3.2}_{0.0}$
3.99–4.67	$0.2^{0.7}_{0.0}$	$1.3^{1.7}_{0.3}$	$1.1^{4.1}_{0.0}$

[a] $m > 1.5 \times 10^{-12}$ g, [10^{-4} sec^{-1} m^2].

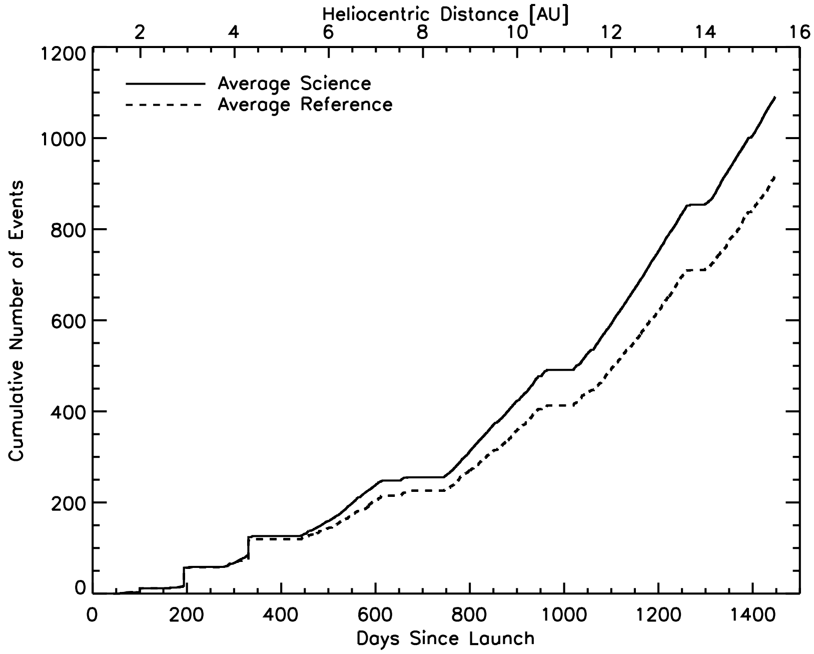

Figure 3. Average cumulative hits for the science and reference detectors on SDC as a function of days since launch and heliocentric distance (AU). Flat periods indicate regions where the instrument was turned off.

The SDC measured density at $m > 10^{-11}$ g, using the average New Horizons speed of ~20 km/sec in the outer solar system, is approximately 10^{-10} m^{-3}. This discrepancy is mitigated by the large uncertainty in mass detection threshold for the Voyager spacecraft, which at a factor of ten in mass [*Gurnett et al.*, 1997], includes the SDC measured density of 1.3×10^{-8} m^{-3} for grains with $m > 2 \times 10^{-12}$ g.

[11] Both of the Pioneer detectors made measurements in outer solar system of approximately 2×10^{-6} and 8×10^{-7} m^{-2} s^{-1} at minimum detection thresholds of 8.3×10^{-10} g and 6.0×10^{-9} g, respectively. SDC detected no grains at either of these thresholds for the entire set of outer solar system measurements, which places an upper limit on the flux at 2×10^{-7} m^{-2} s^{-1}. The apparent deficit of large SDC events suggests a bias in the SDC data with respect to impact mass. Using the Pioneer 10 flux measured in the outer solar system of ~2×10^{-6} m^{-2} s^{-1} [*Humes*, 1980], the SDC measurement area of 0.11 m^2 and a total outer solar system integration time to date of 488 days, Poisson statistics gives the probability of ~10^{-4} that SDC would measure no impacts. We attribute this deficit to the design limits of PVDF-style detectors. Previous laboratory work has shown that signal generation for larger particles that penetrate the detector yield a lower signal than would be expected from a simple extrapolation of the non-penetrating impact scaling law [*Tuzzolino et al.*, 2003]. Our calibration predicts that grains larger than 2.0 μm (8.3×10^{-11} g) will penetrate the detector and therefore, comparison with Pioneer measurements are expected to differ.

4. Summary

[12] We have reported on the first four years of measurements by the Venetia Burney Student Dust Counter, including the first-ever measurements of sub-micron sized grains in the outer solar system. The SDC measurements made inside 5 AU were compared to previous interplanetary and interstellar dust measurements by the Ulysses and Galileo DDS instruments. Taking into account the instrument sensitivities, viewing areas and pointing, the IDP fluxes in the inner solar system across the three instruments were found to be in good agreement. Flux measurements by SDC in the outer solar system were reported, with an average flux of approximately 2.5×10^{-4} m^{-2} s^{-1} for grains larger than 2×10^{-12} g. SDC will continue to make interplanetary dust measurements throughout the outer solar system and beyond the orbit of Pluto. In the years 2013–2016, SDC is expected to see a dramatic increase in the interplanetary dust flux, due to the capture

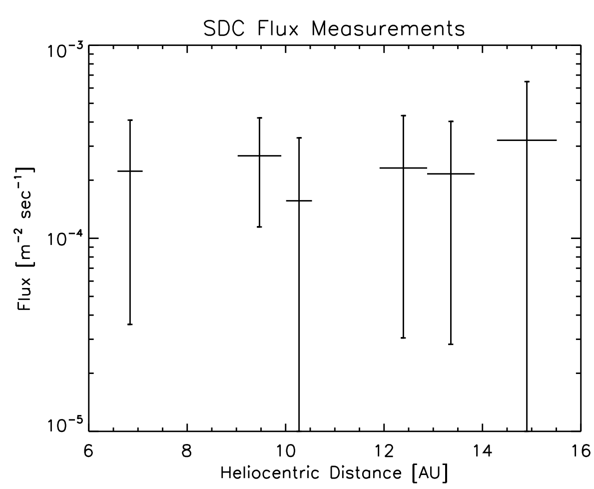

Figure 4. SDC measured fluxes in the outer solar system for particles with mass, $m > 2 \times 10^{-12}$ g (radius, $r > 0.58$ μm).

of EKB-generated dust grains in mean-motion resonances with Neptune [*Liou and Zook*, 1999; *Moro-Martin and Malhotra*, 2002; *Landgraf et al.*, 2002].

[13] **Acknowledgments.** The authors thank S. A. Stern for inviting the Student Dust Counter on the New Horizons mission. We also thank the staff at the Dust Accelerator Facility at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany, especially E. Grün and R. Srama for their help in calibrating the SDC detectors.

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