More than 30 000 volunteers involved in identification of tiny rare interstellar dust particle candidates collected by the Stardust mission

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Abstract

The NASA Stardust mission returned the first tiny samples of interstellar dust from beyond the borders of our solar system. This region is almost devoid of matter and the interstellar dust particles floating through our solar system are extremely rare and small. Finding a few micrometer sized particles in an aerogel collector required the assistance of >30,000 volunteers over a search period of about 6 years, before individual particles could be analysed. This citizen science effort provided the first direct and astonishing look at particle candidates that reached us from our cosmic neighborhood.

1 The Stardust mission

Stardust, a NASA Discovery-class mission that was launched in 1999, was the first sample-return mission to bring back solid extraterrestrial materials from beyond the Moon. Stardust (Fig. 1) comprised two missions in one spacecraft. It returned the very first samples of material from a known comet – a Jupiter-family

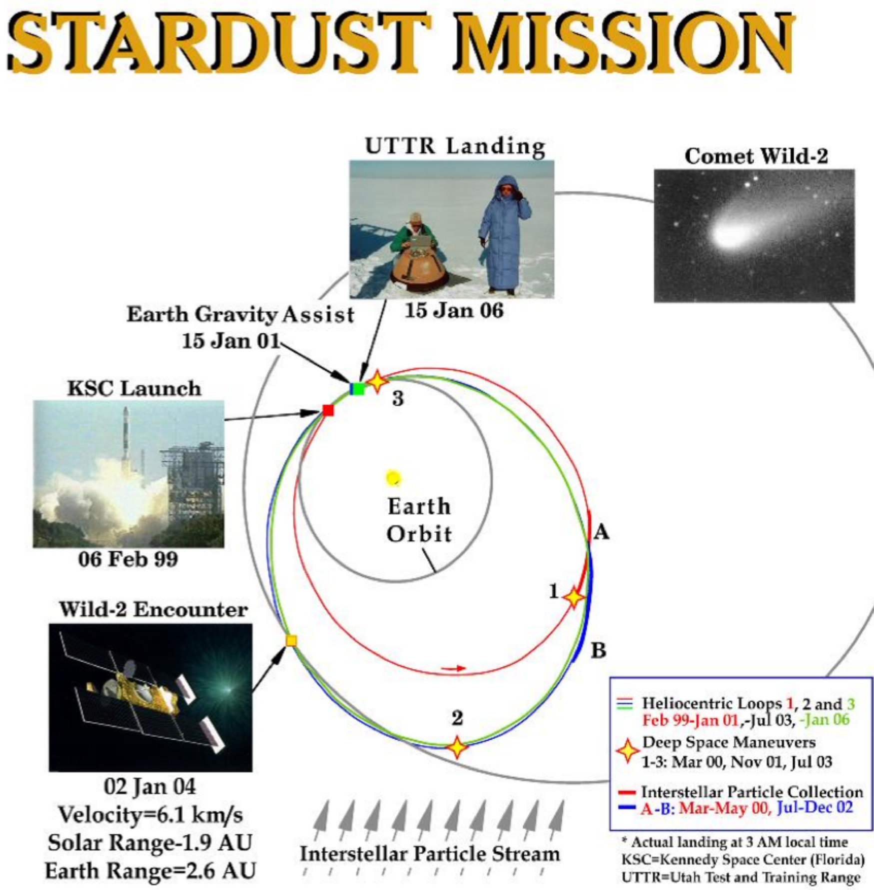

Figure 1: Besides collecting dust from comet Wild 2, the Stardust space probe exposed collectors to the interstellar dust stream from 22 Feb 2000 to 1 May 2000 and from 5 Aug 2002 to 9 Dec 2002 i.e. for a total of 195 days. Courtesy NASA/JPL-Caltech.

comet called Wild 2. It also returned a collector that was exposed to the stream of interstellar dust that penetrates into the inner solar system due to the relative motion of the solar system with respect to the local interstellar medium. Both collectors were returned in a sample return capsule in 2006. The main type of collector material consisted of tiles of aerogel (Fig. 2) which is a synthetic, highly porous ultralight material.

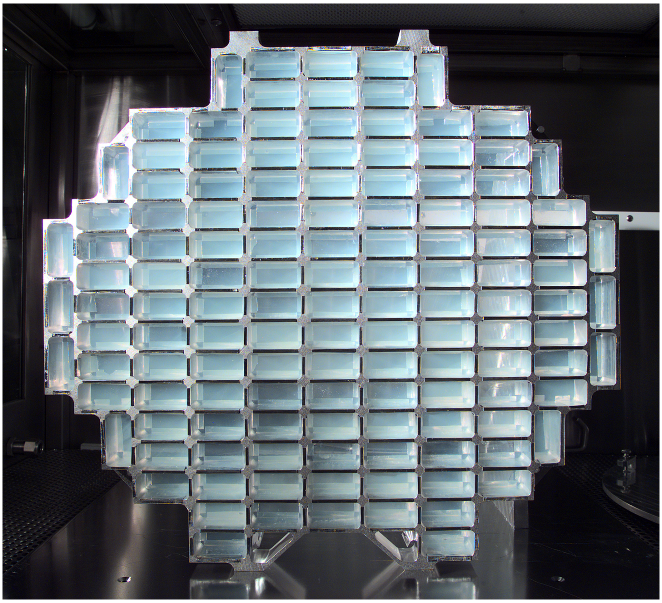

Figure 2: The Stardust interstellar dust collector consisted of 132 tiles of aerogel measuring 20 x 40 mm, within aluminum frames in between serving as well for detecting interstellar dust impacts.

The Stardust cometary collection consists of about 300 μg of material, and the identification of impacts in the cometary collector is straightforward – even the smallest impacts are easily visible under a low-power microscope (Fig. 3). The identification of impacts in the interstellar collector has been vastly more challenging. The interstellar collection is orders of magnitude smaller than the cometary collection – we presently estimate that the entire collection of captured interstellar dust is more than 1 million times smaller than the cometary collection, and as few as about 12 impacts of micrometer-sized interstellar particles are probably present in the aerogel collectors.

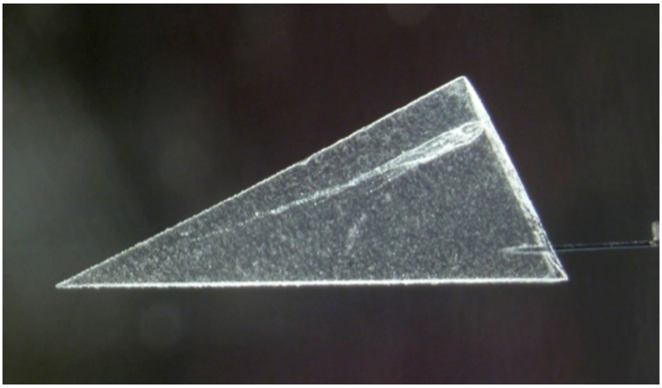

Figure 3: Track of a 15μm cometary particle in aerogel, captured at 6.1 km/s in the coma of Jupiter-family comet 81P/Wild 2 in January 2004. The Stardust cometary grain collection was much more numerous and easy to identify, contrary to the interstellar dust collection. Identification of faint and rare interstellar grain tracks needed a citizen science effort.

2 Searching for particle capture tracks by 30 714 volunteers

Before any analyses could be conducted, the impacts of interstellar dust had to be identified. An international team of c. 80 scientists worldwide (the ISPE – Inter Stellar dust Preliminary examination team) was established to address this challenging problem for nearly 8 years. After considering and rejecting several approaches to this very challenging problem, we turned to amateurs for help. Using an automated microscope, we collected stacks of images of the aerogel collectors, each stack taken from a 480 x 360 micrometer field of view with a spatial resolution of 0.47 micrometer per pixel.

We developed a virtual microscope that runs on any web browser – this functions as a real microscope does, by allowing the user to focus up and down in each field of view to search for the tiny tracks of interstellar dust particles (Fig. 4). So far more than 100 million searches for interstellar dust have collectively been carried out by more than 30,000 participants in Stardust@home, which are listed at http://stardustathome.ssl.berkeley.edu/sciencedusters.

Rather than blindly trust the search results from the volunteers - the vast majority of whom have been unknown to us - we developed a rigorous, quantitative approach in order to reliably validate the data [1,2]. We randomly injected calibration

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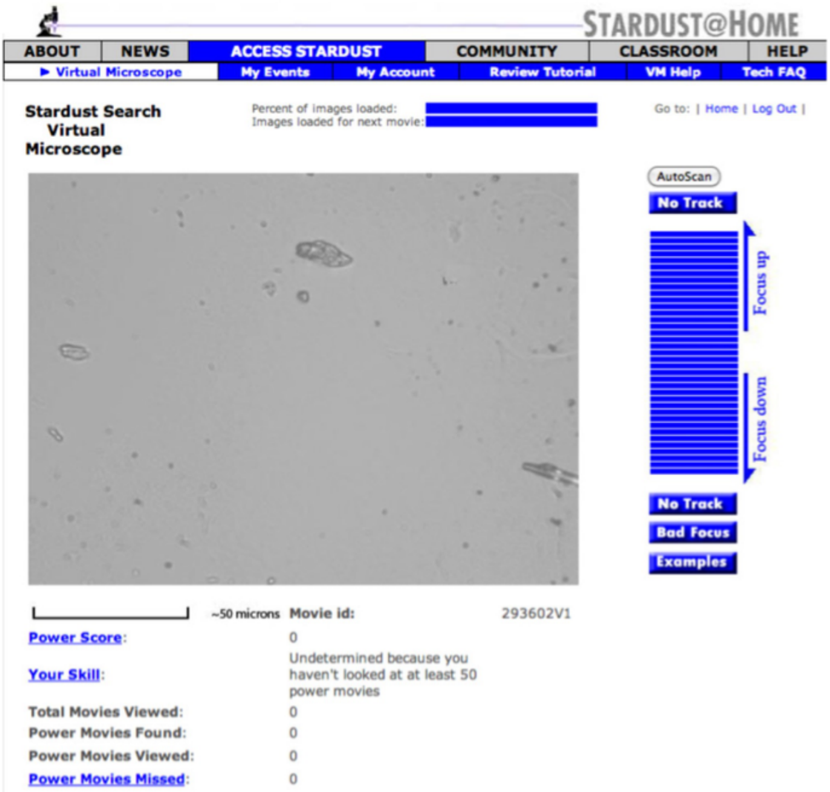

Figure 4: The internet-based Stardust Search Virtual Microscope, a tool mimicking a laboratory microscope searching for interstellar particle tracks.

image stacks into the data stream to measure detection efficiency. Approximately 20% of the searched images are known calibrations.

3 Calibration tracks produced by the Heidelberg dust accelerator

Once we discovered impacts in the interstellar dust collector, we used their stacks as calibrations, but before that time calibration stacks were acquired from aerogel collectors exposed to hypervelocity dust at the Heidelberg Hypervelocity Dust Accelerator (Fig. 5). The Heidelberg Dust accelerator is able to accelerate tiny dust particles to velocities up to 100 km per second. This is much more than conventional light gas guns, which achieve only c. 6 km per second. Individual particles are charged and accelerated by a high voltage of 6 million volts. As only conductive particles can be accelerated, we developed a method to coat mineral particles within the Stardust interstellar dust preliminary examination phase. Beyond calibration purposes, these experiments also contributed to evaluate the impact speed upon capture of interstellar dust: While high impact speeds cause "bulbous" tracks (Fig, 6a), lower impact speeds cause narrow "whisker" tracks (Fig. 6b).

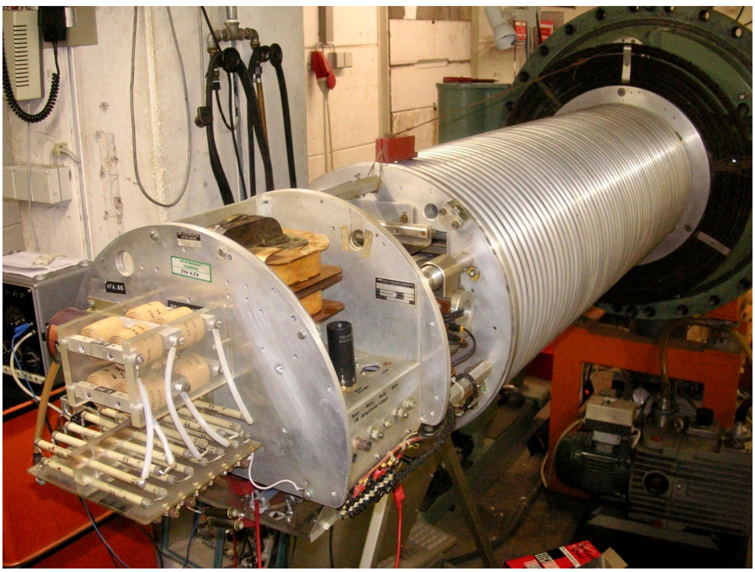

Figure 5: The Heidelberg dust accelerator can accelerate tiny particles up to 100 km per second using an acceleration voltage of 6 million volts. Particles shot on Aerogel served as calibration images for stardust@home searchers before finding interstellar dust particles.

In the approach having volunteers to find rare structures and tracks, we took inspiration from the giant particle detectors like Super-Kamiokande, which consist of thousands of extremely noisy and inefficient detectors, but which achieve nearly unit efficiency through combining the outputs of these detectors. In Stardust@home, the original goal was to combine the results of 30 searches per field of view. In practice, we learned that individual detection efficiencies were >70% even for very small tracks, so such large multiplicity turned out to be unnecessary.

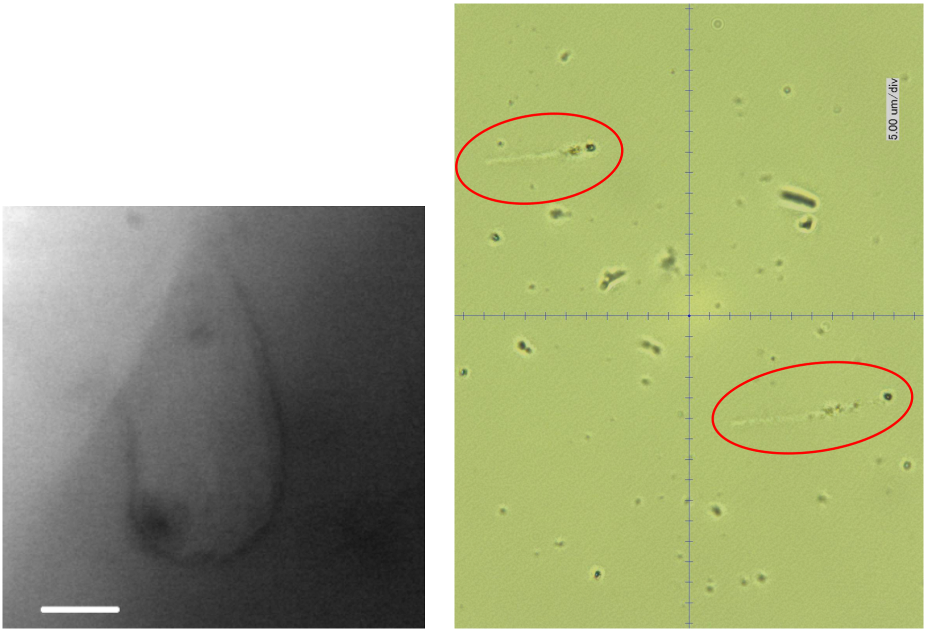

Figure 6: Bulbous track morphologies (upper panel) occur at high impact velocities >15 km per second and initially served as template for calibrations (scale bar is 2 micrometer). During later phases of the citizen science search campaign it was realised that extremely narrow "whisker" tracks better reflect the – unexpected – low speed impacts of interstellar grains. Lower panel shows 2 faint whisker tracks in upper left and lower right corner caused by particles with about 10 km/sec impact velocity. Using these "whisker" tracks as new calibration templates substantially improved the efficiency of stardust@home searchers.

The use of calibrations enables us to measure individual and ensemble-wide detection efficiencies, but it has other advantages. It enables us to generate individual scores, so that the project becomes a kind of competitive game. This is highly motivating for some of the volunteer "dusters" on Stardust@home. It also solves the attention-deficit problem that is common in "manual", long-term searches for very rare objects.

4 Results and perspectives

By the end of the Stardust interstellar dust preliminary examination phase, 69 tracks were identified in aerogel, and 3 of them turned out to be interstellar dust candidates sensu strictu. For one of these candidates ("Sorok"), only a bulbous track was leftover from the high speed capture (Fig. 7). For two other tracks, terminal particles - called Orion and Hylabrook - could be identified (Fig. 7). They consisted of a high fraction of crystalline material, a high fraction of oxides and multiple iron bearing phases which was somewhat surprising because astronomical observations indicated interstellar dust as being mostly amorphous and mostly of silicate composition.

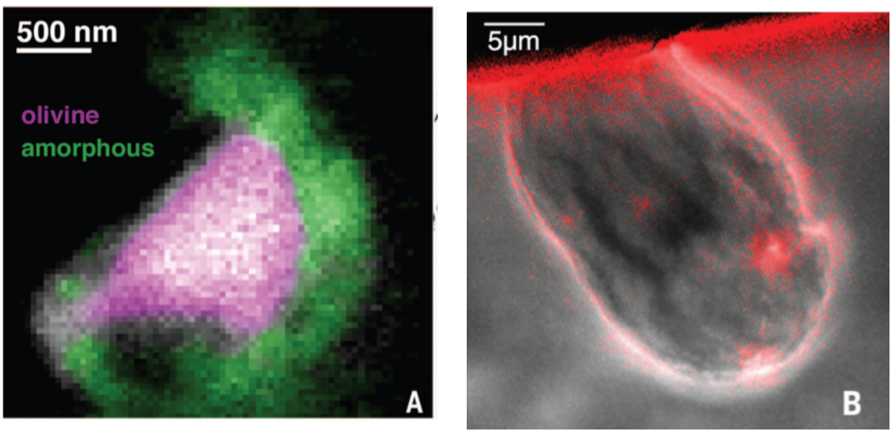

Figure 6: Interstellar dust candidate particles Sorok and Hylabrook. 30714 amateurs taking part in this citizen Science project were co-authors of the publication reporting their discovery in Science magazine [3].

Stardust@home has inspired other citizen science projects, such as Galaxy-Zoo. Recently, working with collaborators at Cornell University and the Human Computation Institute, we developed a project to carry out the analysis of fluorescence micrographs of blood flow in Alzheimer's mouse-model brains using the Stardust@home virtual microscope. This holds the promise of dramatically accelerating Alzheimer's research at Cornell, by eliminating a bottleneck in the experimental protocol of the Schafer/Nishimura lab. This project is called EyesOnAlz, and was recently featured along with Stardust@home on The Crowd and the Cloud, a documentary series on "citizen science" funded by the US National Science Foundation.

Stardust@home has been successful in enlisting amateurs as collaborators in a real science project. Although it has a public outreach component, this is entirely serendipitous: we took this approach only because it was the only practical one that we could see. And indeed, the amateur volunteers are real collaborators in the project. >30,000 volunteers were co-authors in the Science paper [3] announcing the discovery of seven particles of probable interstellar origin in 2014.

References

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List of individual stardust@home dusters is at
http://stardustathome.ssl.berkeley.edu/sciencedusters/

About the Authors

Andrew J. Westphal is a Research Physicist at the Space Sciences Laboratory at the University of California at Berkeley. He obtained his PhD in high-energy particle astrophysics. His current research interests lie in the elucidation of the earliest history of the Solar System, using clues contained in the most primitive extraterrestrial samples. He and his research group use infrared, x-ray and electron microscopy to carry out laboratory analyses of extraterrestrial materials.

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