SEARCH FOR CONTEMPORARY INTERSTELLAR DUST IN THE STARDUST COLLECTOR. Andrew J. Westphal[1], Ronald K. Bastien[2], Anna L. Butterworth[1], Josh Von Korff[1], David Anderson[1], Bryan Mendez[1], Rastika Prasad[1], Nicole Kelley[1], David Frank[1], Robert Lettieri[1], Zack Gainsforth[1], Christopher J. Snead[1], Jack L. Warren[2], Michael E. Zolensky[2], 20064 Stardust@home "dusters"[3] , [1] *Space Sciences Laboratory, University of California at Berkeley, Berkeley CA 94720, USA* [2] *KT NASA Johnson Space Center, Houston, TX 77058, USA* [3] *Stardust@home volunteers located world-wide*.

Introduction

In January 2006, the Stardust return capsule returned to earth bearing the first samples of contemporary interstellar dust. Several dozen interstellar dust particles near 1 μm in diameter are estimated [1] to have been captured in the ~ 1000 cm^2 aerogel collector. Before they can be analyzed, these particles must be identified. Here we describe the effort to find these interstellar particles (ISP). This project consists of two distinct parts: the collection of high-magnification digital images of the collector, and a massive distributed web-based search for the ISP tracks in the aerogel collectors called Stardust@home.

Digital high-magnification imaging of the SIDC

The Stardust Interstellar Dust Collector (SIDC) consists of 132 aerogel tiles and 240 aluminum foils. The SIDC is under curation in the Cosmic Dust Laboratory at Johnson Space Center. We modified an automated scanning microscope to accommodate the SIDC. This microscope was developed several years ago at Berkeley for experimental nuclear astrophysics work. The automated microscope consists of a Leitz metallographic microscope with computer-controlled stage and focus. Imaging is done with a 1024×768 CCD camera with Firewire interface. A Mac mini computer controls the stage and acquires images from the CCD using Astro IIDC software (Aupperle Services and Contracting). We scan one aerogel tile at a time using a 10× objective, which results in a 480μm $\times$ 340μm field of view in the digital images. First, we measure altitudes of the surface of the tile on a coarse grid. We then generate a unix script using MATLAB that implements automated scanning of the tile. The MATLAB code interpolates between points on the coarse "focus map" to determine surface heights. In each field of view, we collect a stack of 43 images spanning $\sim 200\mu$m in focus depth, descending from just above the aerogel surface. Because of surface roughness, especially near the edges of the tiles, this interpolation fails approximately 20% of the time. The movies are collected at full resolution as ∼25MB QuickTime movies. These movies are archived under JSC curation. Movies are then shipped to Berkeley for the next steps in the search. First, the movies are automatically separated into individual frames and compressed. They are then uploaded to Amazon Storage, which has generously donated extensive storage space and web access for this project.

Stardust@home implementation

Here we enlist the help of thousands of amateur collaborators in the search for the tracks of interstellar dust. To implement the Stardust@home project, we wrote a "Virtual Microscope" (VM) in html and javascript that emulates a real microscope. The VM runs on most web browsers and does not require the download of any software. URLs for the stack of images in a single field of view are delivered to the VM by a server at Berkeley. These point to images stored in the distributed Amazon Storage server. The user moves the computer mouse along a slider to focus up and down – behind the scenes, this causes the VM to rapidly slew through the stack of 43 images. The granularity of focussing mechanism is typically imperceptible.

If the user identifies a feature of interest, the user clicks on it. The VM records the position of the click, and asks for confirmation. If no feature is found, the user clicks a "no track" button. If the focus range is inadequate for searching, the user clicks a "bad focus" button. The VM reports the user action and coordinates within the field of view to the server, which records the event in a mysql database.

Each volunteer must go through an online tutorial and pass a test before registering and participating in Stardust@home. As of 12 December 2006, 20064 people had collectively performed more than 30 million searches. Through an online forum hosted on the Stardust@home website, participants have extensive discussions, and have named themselves "dusters." We adopt this terminology here.

Stardust@home detector calibration

Large particle physics and particle astrophysics projects often employ large multichannel instruments. Examples are STAR at RHIC[3], AMANDA at the South Pole[5], and the SuperKamiokande in Japan[4]. In some detectors, particularly those employing photomultiplier tubes, noise rates for individual detectors may be up to 100 kilohertz, but by employing multiple coincidence techniques, the noise rate of the entire instrument is negligible.

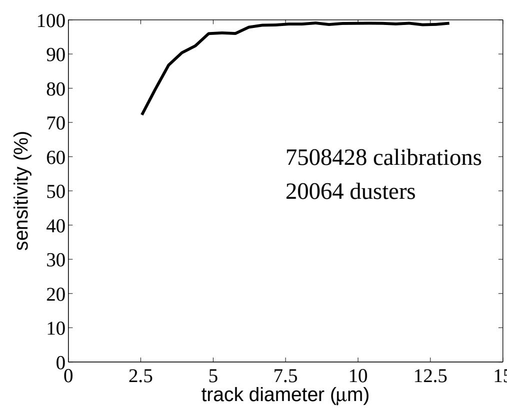

Figure 1: Average individual duster sensitivity as a function of track diameter.

The ensemble of dusters may be thought of as a single, large multichannel instrument. We individually calibrate each detector (duster) using calibration images, which consist of one-fifth of the images in the datastream. The presence of calibration images is known generally to the dusters, but they do not know whether any particular image is a calibration image. These calibration images are either known blanks, or are images in which the image of a single track has been dubbed into the field of view. We used a single image of a submicron carbonyl iron grain that was fired into an aerogel collector using the Heidelberg tandem Van der Graaf dust accelerator at ~ 20 km sec^{-1}. We rotated the image randomly through 2π, and applied a magnification factor between 0.2 to 1.5 in diameter and, independently, in depth to the track image. This enables us to measure sensitivity (efficiency in detecting tracks) as a function of track diameter over a range of 2.5μm to 14μm. These track diameters correspond to particles sizes of $\sim 0.3 - 1.5\mu$m, using the track-to-particle diameter value (~ 9) reported by Burchell *et al.*[2]. (This ratio is likely to be larger for the SIDC since the aerogel densities are lower and the velocities are higher than in the Burchell *et al.* experiments. This will result in even lower particle size thresholds.) Using the blank images, we can also measure the specificity, that is, the efficiency at correctly identifying empty fields. In Figs. 1 and 2, we show the average measured sensitivity as a function of track diameter for the entire ensemble of Stardust@home detectors, and the integral distribution of specificity. These remarkably high efficiencies may be partially due to the testing requirement before participation in the project.

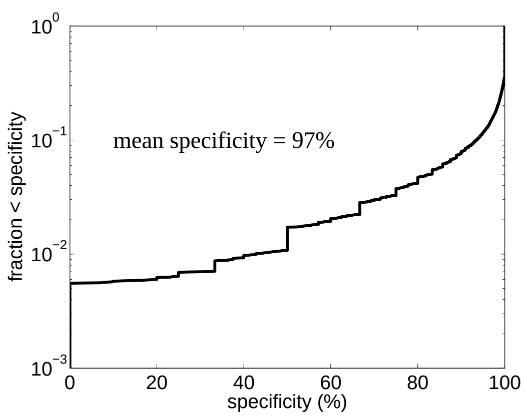

Figure 2: Integral distribution of individual duster specificity.

We emphasize that these are *not* efficiencies for the integrated instrument. The reason is that we use multiple coincidence for triggering. With at least six searches per field-of-view (multiplicity = 6) and a requirement of two-fold coincidence, the efficiency of the instrument will be nearly unity over the entire range of track diameters in the calibration dataset. In practice, the multiplicity up to now is $\gg 100$.

Stardust@home candidates

After promising fields of view have been identified through multiple coincidence, four of us review them at Berkeley. We will then collect images in transmitted light of these candidates, using much higher magnification objectives $25\times$ and $50\times$. This scanning requires unfolding aluminum foils behind the tiles. Testing is currently underway to determine whether foil unfolding compromises the integrity or orientation of the aerogel tiles.

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References

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[4] http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html

[5] http://amanda.uci.edu/