STARDUST@HOME: A MASSIVELY DISTRIBUTED PUBLIC SEARCH FOR INTERSTELLAR DUST IN THE STARDUST INTERSTELLAR DUST COLLECTOR.
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In January 2006, the Stardust mission will return the first samples from a solid solar-system body beyond the Moon. Stardust was in the news in January 2004, when it encountered comet Wild2 and captured a sample of cometary dust. But Stardust carries an equally important payload: the first samples of contemporary interstellar dust ever collected. Although it is known that interstellar (IS) dust penetrates into the inner solar system [2, 3], **to date not even a single contemporary interstellar dust particle has been captured and analyzed in the laboratory.** Stardust uses aerogel collectors to capture dust samples. Identification of interstellar dust impacts in the Stardust Interstellar Dust Collector probably cannot be automated, but will require the expertise of the human eye. However, the labor required for visual scanning of the entire collector would exceed the resources of any reasonably-sized research group. We are developing a project to recruit the public in the search for interstellar dust, based in part on the wildly popular SETI@home project, which has five million subscribers. We call the project Stardust@home.

Using sophisticated chemical separation techniques, certain types of refractory ancient IS particles (so-called presolar grains) have been isolated from primitive meteorites (e.g., [4]). Recently, pre-solar grains have been identified in Interplanetary Dust Particles[6]. Because these grains are not isolated chemically, but are recognized only by their unusual isotopic compositions, they are probably less biased than presolar grains isolated from meteorites. However, it is entirely possible that the typical interstellar dust particle is isotopically solar in composition. The Stardust collection of interstellar dust will be the first truly unbiased one.

The Stardust Interstellar Dust Collector

Stardust uses aerogel collectors to capture dust samples. Particles with speeds of a few km $\sec^{-1}$ or greater typically produce characteristic carrot-shaped tracks when they stop in aerogel collectors. The Stardust Interstellar Dust Collector consists of 130 aerogel tiles, with dimensions 42mm $\times$ 21mm on the collecting face, 30mm thickness, and density in a gradient from $\sim$10 mg cm^{-3} at the collecting surface to $\sim$20 mg cm^{-3} at the bottom of the collector. The SIDC was exposed to the interstellar dust stream twice during the pre-encounter cruise phase of the Stardust mission. Landgraf [1] has estimated that Stardust will collect $\sim$40 interstellar dust particles of size 1μm or greater.

Automated microscopic scanning of the Stardust Interstellar Dust Collector

The first aerogel collectors were scanned manually in optical microscopes to locate captured hypervelocity particles. This process was laborious, and suffered from poor, unknown, and probably variable efficiency. Several years ago we developed a fully-automated scanning optical microscope for the analysis of nuclear track-etch detectors used in high-energy nuclear astrophysics instruments and experiments[7]. Practically without modification, we were able to adopt it to the automatic scanning of aerogel collectors to identify deep hypervelocity particle impacts. The system is ideal for the identification of relatively large, deeply-penetrating particles, and is sufficiently sensitive to detect impacts of submicron particles[5].

After recovery of Stardust, the SIDC will be automatically scanned at the JSC Curatorial Facility. This scanning system will be essentially a duplicate of an existing automated microscope now at the Space Sciences Laboratory at UCB. The data will be acquired at 1μm spatial resolution or better. For each field of view, sequences of images will be collected at increasing focus depths, separated by 2μm in depth. When complete, approximately six months after the start of data collection, the entire three-dimensional image dataset will be archived and will be available indefinitely for future generations of researchers. As the high-resolution image data are acquired, short "focus movie" clips will be generated automatically and provided to the Stardust@home server. At the end of the data acquisition, 1.6 million focus movies will have been generated.

Automated identification of interstellar dust impacts is not practical

But because the system cannot automatically distinguish between impacts and background (cracks, large inclusions, out-of-focus surface objects), the efficiency of the technique is strongly dependent on the quality and cleanliness of the aerogel collector. The SIDC aerogel collectors will probably be reasonably clean, but we anticipate significant and ubiquitous surface cracking due to the integration of the collectors into the carrier. In order to locate interstellar dust particle impacts, an automated system would have to scan very near the surface, at $\sim$ 20μm depth. We anticipate that in such a scan an automated scanning system would be overwhelmed with triggers, and would not be practical. We have consulted with one of the world's experts in computer-based object recognition, Prof. Jitendra Malik in the Computer Science department at U. C. Berkeley, on the possibility that the tracks of interstellar dust grains could be identified automatically, given the enormous progress that has been made recently in this field[8]. The conclusion of the discussion is that **it is unlikely that an algorithm could be developed that could reliably identify hypervelocity impacts against the anticipated background.**

Identification of interstellar dust impacts by amateur volunteers

However, for a human microscopist, identification of impacts is straightforward. A person scanning an aerogel collector by eye, using only an ordinary optical microscope, would identify impact events by repeatedly moving up and down in focus. **We will emulate this scanning mode using a downloadable software tool that we call the "Stardust@home software microscope."** In a manner similar to SETI@home, the software microscope (SSM) will automatically connect to a server and download a dataset for scanning. The amateur operator, or "microscopist", will then use the SSM to examine each field of view, using a slider to move focus up and down. The microscopist will identify an impact candidate by clicking on it. The SSM will ask for confirmation, then will send the coordinates and index of the field of view back to the Stardust@home server. Although there will be default settings, we plan to build controllable settings into the SSM. The microscopist will be able to control contrast and brightness, and will be able to use some image processing tools such as false-color gradients.

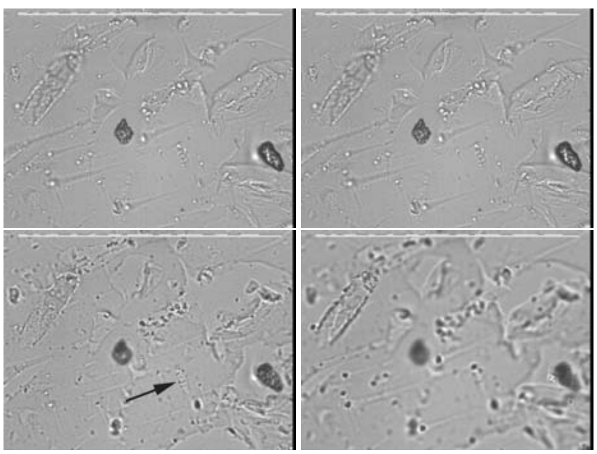

Fig. 1: Frames from a "focus movie" of a randomly-selected field of view of an aerogel tile from the ODCE collector, which was deployed on the Russian space station *Mir*, starting 20μm above the surface (upper left) to $\sim 50\mu$m below the surface. This field is much more crowded with impacts than the SIDC is expected to be: the vast majority of fields in the SIDC image dataset will have no impacts. However, the surface cracking in this sample may be typical for the SIDC. There are 12 impacts in the field of view. An impact that may be similar to an interstellar dust impact is indicated by the arrow. While it is not easy to identify impacts in these still images extracted from the focus movies, even an relatively untrained microscopist can readily identify impacts in the focus movie. These movies can be viewed at http://ultraman.berkeley.edu/baypac/focusmovies.html.

Stardust@home: Mode of operation

• Features that have been identified by at least three volunteers will be automatically identified and fed back into the datastream so that they will be examined by at least 20 volunteers. This will be done without informing the microscopists that these images have already been previously flagged to avoid bias. If some threshold number (order of half) of these microscopists also identify the impact, then these images will pass on to the next level of candidacy.

• Information about the candidate impacts are then sent to expert microscopists, who will confirm the preliminary identification, again using the SSM and archived focus movies.

• The candidate locations are then sent to the curator at JSC, who performs a technical analysis to confirm the identification in the actual collector.

• The impacts will then be extracted, possibly in aerogel "picokeystones", for detailed chemical and isotopic analysis.

Recruitment of microscopists

Astronomy is one of the few fields in science in which volunteers make a genuinely valuable contribution. Stardust@home is another example of this. **Because of the enormous volume of data, the participation of amateur volunteers is critical to the scientific success of the project to recover first contemporary interstellar grains ever collected.** The strong E/PO component of this project is entirely serendipitous.

We will recruit volunteers through the Stardust mission webpage, through a link from the SETI@home project, which has five million subscribers who are interested in space, hoping to be the first to discover Extraterrestrial Intelligence, through the existing partnerships between Berkeley and Amateur Astronomers (AAVSO and ASP), and educators, and through articles in amateur magazines (e.g., Sky and Telescope, Astronomy, Space Science News, and Science Education Online). We will actively seek "advanced recruits" through the astronomy undergraduate classes at UC Berkeley and the University of Washington, for preliminary verification of the data, which will be then turned over to the science team for final selection.

References

[1] Landgraf M, Muller M, Grun E. (1999) *Planet. & SS* **47**, 1029

[2] Grün, E. *et al.*, (2000) *J. Geophys. Res.* **105**, 10403

[3] Taylor, A. D., Baggaley, W. J., Steel, D. I. (1996).*Nature* **380**, 323

[4] Amari, S., Zinner, E. (1997) *Nucl. Phys.* **A621**, 99c .

[5] Westphal, A. J. *et al.*, *M&PS* (2003).

[6] Messenger, S. *et al. Science* **300**, 105 (2003).

[7] Westphal, A. J. et al., *Nature* **396**, 50 (1998).

[8] Belongie, S., Malik, J. and Puzicha, J., *IEEE Trans. on Pattern Analysis and Machine Inteligence*, **24(4)**, 509-522, (2002); Jitendra Malik, Serge Belongie, Thomas Leung and Jianbo Shi, *International Journal of Computer Vision*, **43(1)**, 7-27, (2001).