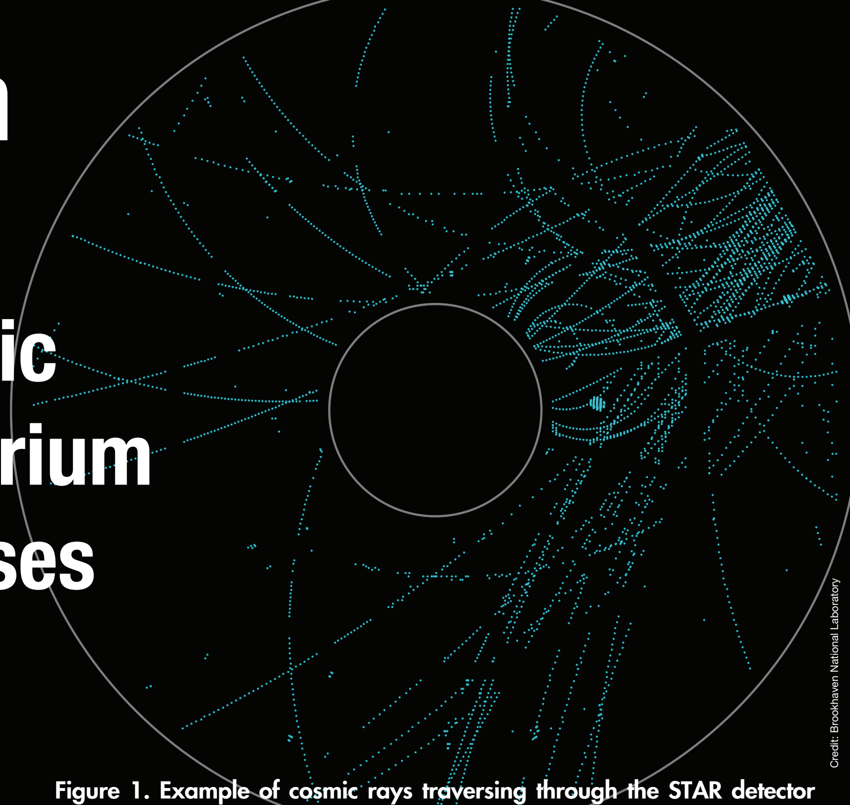
Detectors in space:

Analyzing cosmic ray tracks in barium phosphate glasses with unknown environmental information



Credit: Brookhaven National Laboratory

Figure 1. Example of cosmic rays traversing through the STAR detector in the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. The straighter paths indicate faster moving particles while the curved paths indicate slower moving particles. This information allows researchers to determine particle charge information.

By Nicholas J. Tostanoski, Darren Stohr, and S. K. Sundaram

While traveling to distant star systems in a reasonable time period is currently beyond our capabilities, there are other ways for us to learn about faraway stars and planets.

Cosmic rays are heavily ionized particles from outside our solar system that travel through space at nearly the speed of light (Figure 1). Analyzing the composition of cosmic rays can provide a rich source of information on the chemical evolution of the universe.

Track-etch detectors allow for precise identification of cosmic rays. These detectors consist of glasses that are marked when cosmic rays pass through them. These cone-shaped marks, or "tracks," trace the trajectory that the particles took through the glass and are revealed via chemical etching.[1]

Interest in tracking cosmic rays in glass dates back to the late 1980s. Price et al.[2,3] identified phosphate glasses as good materials for track-etch detectors because of their increased sensitivity due to low bond strength. Wang et al.[3] performed a systematic study of phosphate glasses free of uranium and identified BP-1, a barium phosphate glass with composition $58P_2O_5$–$21BaO$–$11SiO_2$–$10Na_2O$ mol%,[1] as the best choice for the application.

In the 1990s, the U.S.-Russian collaborative TREK cosmic ray experiment used BP-1 on the external surface of the Russian Mir space station to help identify and quantify the elemental abundance of ultra-heavy nuclei and isotopes in galactic cosmic radiation.[4] However, currently, literature related to examination of the TREK track-etch detectors is inadequate, due in part to lack of knowledge about the environment during the experiment.

Temperature and pressure during irradiation exposure in long-term space missions play a critical role in determining the charge resolution of the glass.[5] Unfortunately, no information is known about the temperature and pressure of the local BP-1 environment before, during, or after the TREK experiment. Additionally, after the experiment, the samples were placed in storage with unknown environmental conditions. These unknowns affect the ability of researchers to analyze tracks multiple decades after the conclusion of the TREK experiment.

Our study shows how one might examine tracks in a detector glass plate for which detailed environmental provenance is unknown.

Experimental procedure

In theory, and limitedly reported in literature, glass track-etch detectors can be analyzed using optical and electron microscopy techniques, where hydrofluoric acid (HF) reveals tracks in the glass.

In our study, we used a JEOL JSM-7800F (JEOL, Tokyo, Japan) scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) to analyze the BP-1 in both secondary (SE) and backscattered (BSE) imaging modes, and EDS for elemental analysis. BP-1 was cross-sectioned, ground, and polished.

Samples underwent additional chemical etching using 40–45 vol% HF for two minutes and 49–51 vol% HF for five minutes at room temperature. These ranges were chosen because Price et al.[5] and Randhawa et al.[6] concluded 48 vol% HF was the most suitable etchant to reveal etchpits under SEM.

An electrical conducting gold coating was applied.

Results and discussion

Interaction of cosmic rays with a bulk glass would potentially result in local chemical and structural changes along the narrow, cone-shaped etch trajectory. It is suspected such changes could be viewed using BSE imaging modes, where elemental and compositional changes would be observed and made clear by lack of a specific element along the trajectory.

The BP-1 cross-section was examined using SEM-EDS point, line, and map scans. A line scan was used in the region between the apex of paired etched conical features running through the midpoint, on the border, and within the bulk, as shown in Figure 2.

Analysis resulted in no measurable elemental intensity variations or structural changes. It is suspected that a narrow trajectory connecting the paired etched conical features would be highlighted through additional etching; however, further etching resulted in no visible trajectories or observable changes between etched conical features.

We suspect the BP-1 was initially etched, due to conical features on the as-received sample. We do not see any damage along the trajectory. This observation may be attributed to healing over extended time or removal of the damaged layer during sample preparation.

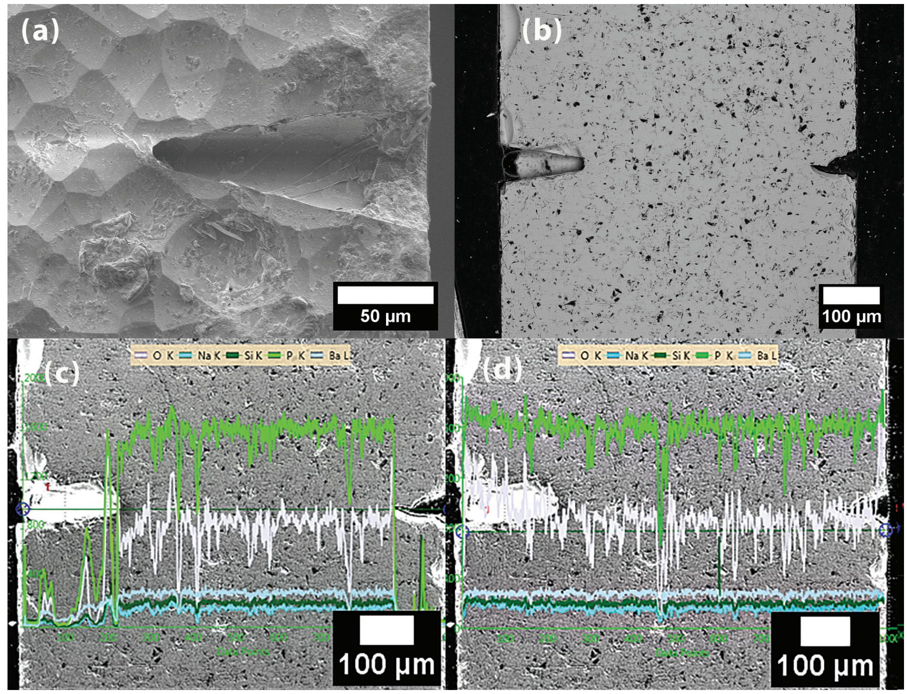


Figure 2. SEM of (a) as-received etched SE image of fracture surface and (b) polished and further etched BSE image featuring paired etched conical features. SEM-EDS line scan (c) between the apex and (d) on the border of the paired etched conical features.

Credit: Tostanoski, Stohr, and Sundaram

Conclusion

Our investigation did not reveal any structural changes or narrow tracks in BP-1, suggesting such compositional changes are beyond the sensitivity of the instrument or perhaps the damage healed with time. Unfortunately, we lack access to new pristine and exposed glasses for comparison.

Our results underline the challenges in determining how cosmic radiation influences glass structure when environmental information before, during, and after the experiment is unknown. However, despite these challenges, it is important to pursue research in this area because understanding and developing means to study glass from track-etch detectors will assist scientists in determining what lies beyond our solar system.

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About the authors

Nicholas J. Tostanoski, Darren Stohr, and S. K. Sundaram are Ph.D. candidate, scanning electron microscopist, and Inamori Professor of Materials Science & Engineering, respectively, in the Inamori School of Engineering at The New York State College of Ceramics, Alfred University, N.Y. Contact Tostanoski at njt2@alfred.edu.

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