ECCO: The Extremely Heavy Cosmic Ray Composition Observer

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Abstract

Measurements with unprecedented resolution of GCR abundances of the heaviest elements in the periodic table, made using the Trek detector, are strongly inconsistent with a GCR source of solar-like composition with FIP fractionation. However, the data are consistent with either an origin in gas and dust in the ISM, or with a source dramatically enhanced in r-process material. These models predict very similar abundances in the region of the periodic table between $_{70}$Yb and $_{83}$Bi, but give very different predictions for the abundances of the actinides. The primary goal of ECCO, the Extremely Heavy Cosmic Ray Composition Observer, is to measure the abundances of the individual actinides, both with respect to each other and with respect to the Pt-group, in order to determine the origin of GCR nuclei. ECCO will be a 30 m^2 array of BP-1 glass track-etch detectors which is under development for deployment on the International Space Station. ECCO builds on the heritage of Trek, but employs a novel detector configuration. We describe progress in the development and verification of ECCO.

1 Results from Trek

Trek was a 1.2 m^2 array of BP-1 glass track-etch detectors which was deployed on the outside of *Mir*, and which was designed to measure the abundances of elements with $Z > 70$ in the galactic cosmic rays. With Trek, we achieved a charge resolution of $\sim 0.45e$, which was sufficient to resolve the even-Z elements in this charge region (Westphal, 1998; Weaver, 1998). The measured abundance of Pb with respect to Pt-group elements is dramatically inconsistent with the most widely-held class of models of GCR origin, that is, a solar-like source with FIP-biased preferential acceleration. Our data are consistent, however, with the model of Meyer, Drury and Ellison (Meyer, 1998), in which GCR nuclei originate in gas and dust grains in the ISM; and with the empirical model of Binns *et al.* (Binns, 1989), in which elements with $Z > 60$ are dramatically enhanced in r-process material. Recent data from ancient meteorites, which point to at least two distinct r-processes in Nature, lend plausibility to this idea (Wasserburg, 1996). Unfortunately, these two models give very similar predictions of abundances in Pt-Pb region. However, the abundance of actinides with respect to the Pt-group strongly distinguishes between these models (fig. 2 of (Westphal, 1998)). Trek detected 4-6 actinides during its 3.6-year average exposure; in order to achieve sufficient statistics to make an accurate measurement with the same exposure duration, a much larger detector is required.

2 ECCO primary science goals

ECCO, the Extremely Heavy Cosmic Ray Composition Observer, is a 30 m^2 array of BP-1 glass track-etch detectors, which is intended for deployment on the International Space Station (ISS). **The primary goal of ECCO is to measure the abundances of the actinides (Th, U, Pu, Cm) both with respect to the Pt-group and with respect to each other.** ECCO will collect several hundred actinides, which will be sufficient to reduce the statistical errors on source abundances to negligible levels compared with propagation uncertainties. ECCO will also resolve the individual actinides, with a charge resolution $< 0.40e$, so that their abundances may be used to measure GCR age. In Fig. 1, we show estimated abundances of individual actinides as a function of nucleosynthesis duration in a simple model assuming uniform synthesis, and the most recent ETFSI-Q models of actinide nucleosynthesis of the Mainz group (Pfeiffer, 1998). We also show the predicted U/Th and

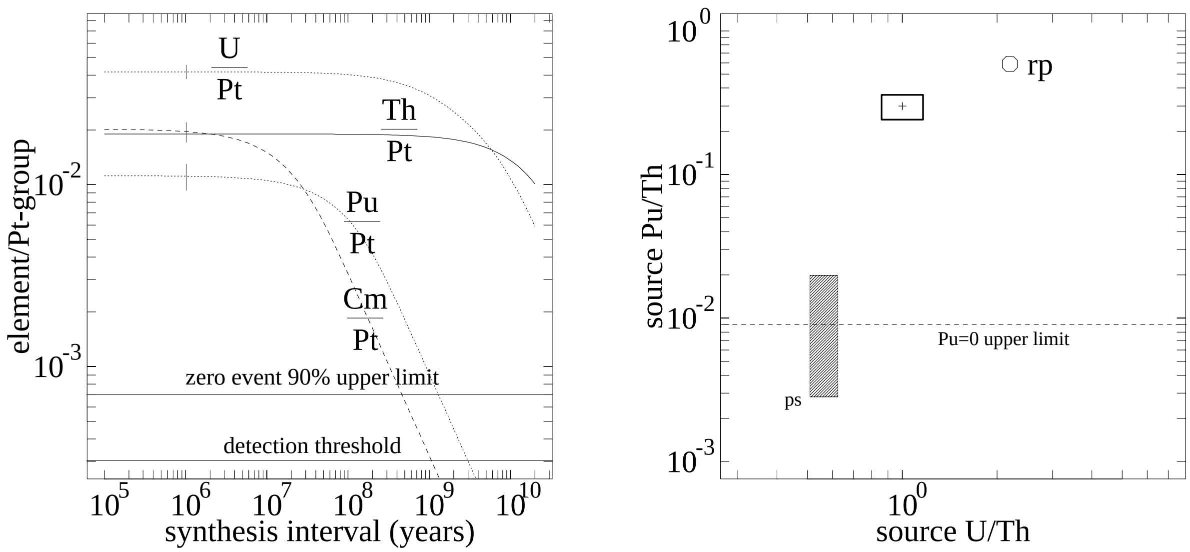

Figure 1: (Left) Individual actinide abundances normalized to the Pt-group as a function of nucleosynthesis interval, assuming uniform synthesis. (Right) Predicted actinide abundance ratios U/Th and Pu/Th for freshly synthesized material ("rp") and for material characteristic of the ISM, assumed here to be similar to protosolar values ("ps"). The range of protosolar Pu abundances is summarized in (Thielemann, 1983). Statistical errors are shown for a hypothetical ECCO measurement marked by "+".

strongly distinguishes between the models. If the GCR nuclei turn out to be relatively young, < 10My, as is expected to be the case in the "superbubble" model of GCR origin of Higdon, Lingenfelter and Ramaty (Higdon, 1998), ECCO would almost certainly detect a large number of ^{244}Pu and ^{247}Cm. If detected, ^{247}Cm would then become the heaviest nucleus ever found in Nature. Much more significantly, *the presence of Cm would indicate that the GCR nuclei are sufficiently young that the observed abundances of the other actinides, Th, U, and Pu, would be virtually identical to their primary nucleosynthetic yields.* These primary yields are important but unmeasured and poorly constrained parameters in cosmochronological models of galactic (not galactic cosmic ray!) age.

3 ECCO secondary science goals

A secondary goal of ECCO is to search, with unprecedented sensitivity, for long-lived superheavy elements. Over many years, there has been a large experimental effort aimed at synthesizing nuclei in the so-called island of stability centered on $Z = 116$. In the laboratory, the experimental challenges are daunting: superheavy nuclei must be synthesized by fusion of lighter isotopes in accelerators. This process produces isotopes which are proton-rich compared to the line of stability, and these isotopes always have very short α-decay half-lives, and are produced only a few nuclei at a time. However, the isotopes with the longest half-lives in the island of stability are expected by lie on the *neutron*-rich side of the line of stability, which is inaccessible by fusion-based synthesis, but which would be accessible to the r-process, the nucleosynthetic process responsible for the actinides, including Th and U. There is therefore a strong motivation to search for long-lived superheavy elements in the most freshly synthesized sample of matter accessible to us, the galactic cosmic rays. ECCO would also carry out the most sensitive search to date for nuggets of strange quark matter in the mass range $10^8 < A < 10^{13}$

4 The ECCO detector

The ECCO detector is designed on the basis of the heritage of the Trek detector, but employs a different detector configuration; since it is a passive detector, it will require minimal or no telemetry, and no external power from the ISS. Trek consisted of stacks of individually polished 1.5mm-thick BP-l glass sheets (Wang, 1988; Weaver, 1998). The central ECCO detectors, however, will be 25mm-thick BP-l glass monoliths, sandwiched between thin BP-1 sheets which serve as hodoscopes. After recovery, the hodoscopes **will be etched** so that tracks of ultraheavy galactic cosmic rays will etch through the glass detector, producing a penetrating hole. The hole is then detected by the ammonia-transfer technique (Keane, 1997). After the trajectory of each ion is determined, the latent track is then removed from the monolith using a water-cooled core drill (fig. 2). The core is then exposed to calibration beams at an accelerator, then diced into wafers. The wafers are individually ground, polished, and etched, and the etch-pits of each GCR ion and surrounding calibration ions are rapidly measured using an automated microscopic scanning system. Using calibration beams at two angles — probably 15” and 40” as in the calibration of the Trek detectors — the absolute location of each wafer within the original monolith can be determined with accuracy better than 10 μm.

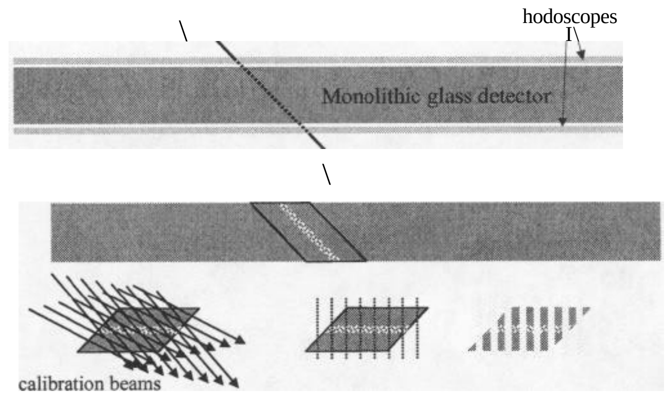

Figure 2: Schematic of operation of ECCO detector.

5 ECCO detector verification

Each of the steps in analysis described above has been individually verified.

5.1 Hodoscope verification The ECCO hodoscopes will be 1.5mm-thick BP-l detectors. With this thickness, and the appropriate choice of etching conditions, background — principally due to stopping Fe — is almost entirely eliminated. There is also the additional advantage of “ground truth”: since the individual Trek detectors are also 1.5mm thick, and were exposed in the same orbit and for the same duration as ECCO, the performance and background can be ***measured,*** not just estimated.

5.2 Monolith coring We have demonstrated that BP-l monoliths can be cored, using a 2.5 cm core drill, to at least 70” zenith angle. Core drilling is very rapid, requiring less than ten minutes per core except at the largest zenith angles. Since the drilling is water-cooled, the detector remains essentially at room temperature throughout the process.

5.3 Wafer dicing, grinding, and polishing Dicing the extracted cores into wafers after polishing is straightfoward. We used a water-cooled dicer with multiple blades, so that several wafers are diced simultaneously. The wafers are then ground and polished, using a cold polishing technique.

5.4 Signal magnitude and dispersion measurement We have verified that the monolithic detector performance is excellent. In Fig. 3 we show a scatter plot of matched measurements of etchpits due to 10.6 A GeV Au, delivered by the AGS, using 3 1 wafers taken from a BP- 1 ingot which was diced and polished *after* exposure. The signal and charge resolution, $\sim 0.15e$, are indistinguishable from a BP-l detector which was cut, ground, and polished before exposure, demonstrating experimentally that dicing, grinding, and polishing have negligible effect on latent nuclear tracks. The signal is uncorrected for local variations, indicating that spatial variations in sensitivity, which in any event can be corrected using a calibration beam, are very small.

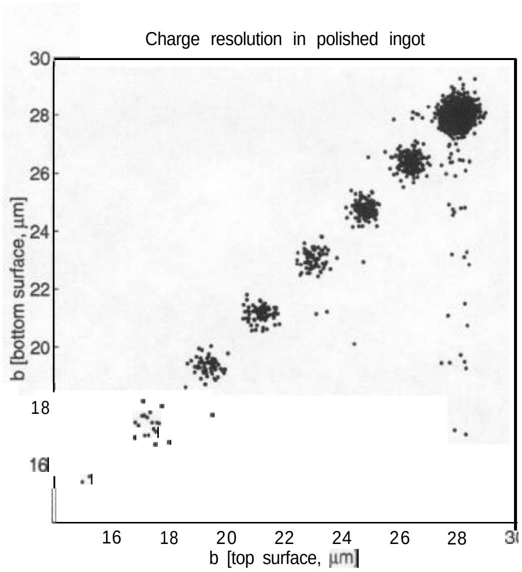

Figure 3: Scatterplot of uncalibrated minor-axes of matched etch-pits taken from adjacent pairs of 3 1 wafers, diced from a BP-l ingot exposed to 10.6 A GeV Au at the AGS.

6 ECCO deployment

We have measured the mechanical strength of BP-1 monoliths, and find that it is easily strong enough to withstand launch loads. We have constructed a mockup ECCO module which is currently undergoing thermal and vibration testing. ECCO, in its strawman design, consists of 21 independent units, each consisting of nine modules (fig. 4), to give the maximum flexibility for transport and deployment on ISS. Each unit will have dataloggers for recording detector temperature during the entire exposure, and will allow for the possibility of thermal regulation using small external solar panels. Each unit will be completely surrounded by a thick thermal blanket. Transport and deployment options for ECCO are currently under study at GSFC and JSC.

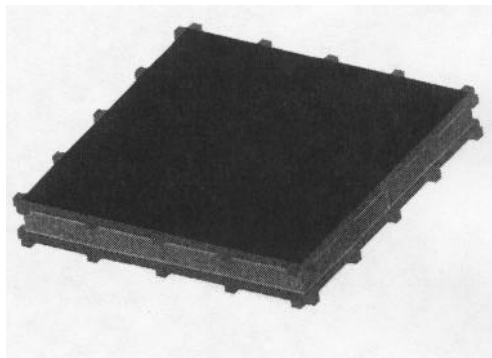

Figure 5: An ECCO module.

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