Modeling galactic cosmic rays (GCRs) in Roman's Wide Field Instrument using the HAZARD simulator

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Motivation

At the Sun-Earth L2 Lagrange point, Roman will be exposed to the space environment without the protection of the Earth's magnetic field, with an expected rate of order 100 events/detector/second (Kruk 2016). This affects image quality, as each event will have associate pixels that must be flagged, masked, and potentially interpolated over.

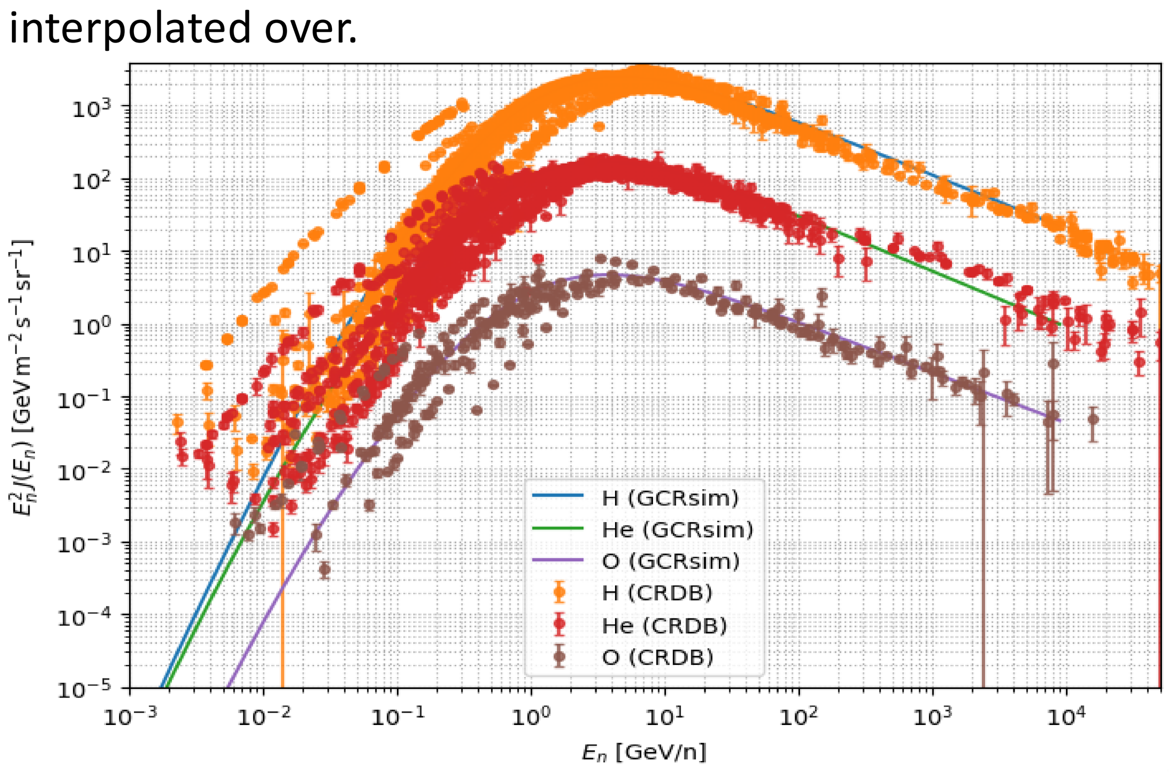


Fig. 1 (Above): The High Atomic Z Astrophysical Radiation Dynamics (HAZARD) simulator's GCR flux model compared against data from the Cosmic Ray Database.

Fig. 2 (Below): GCR and ejected electron mean population distribution as a function of their energy.

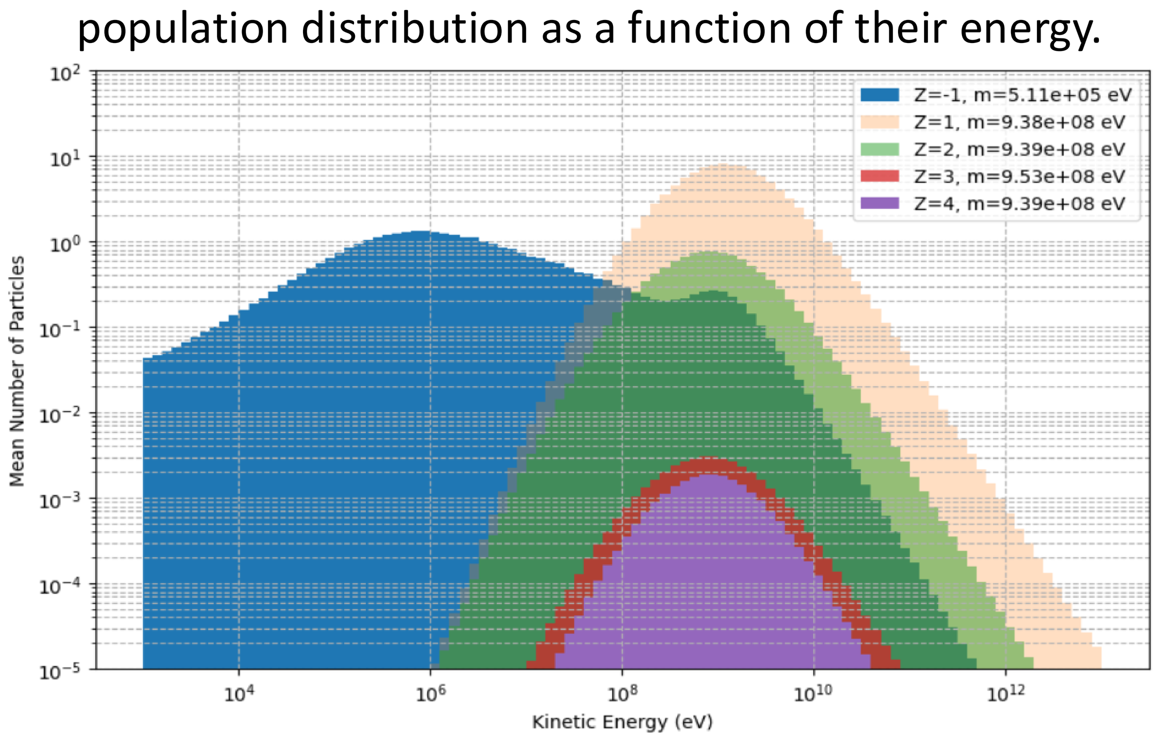
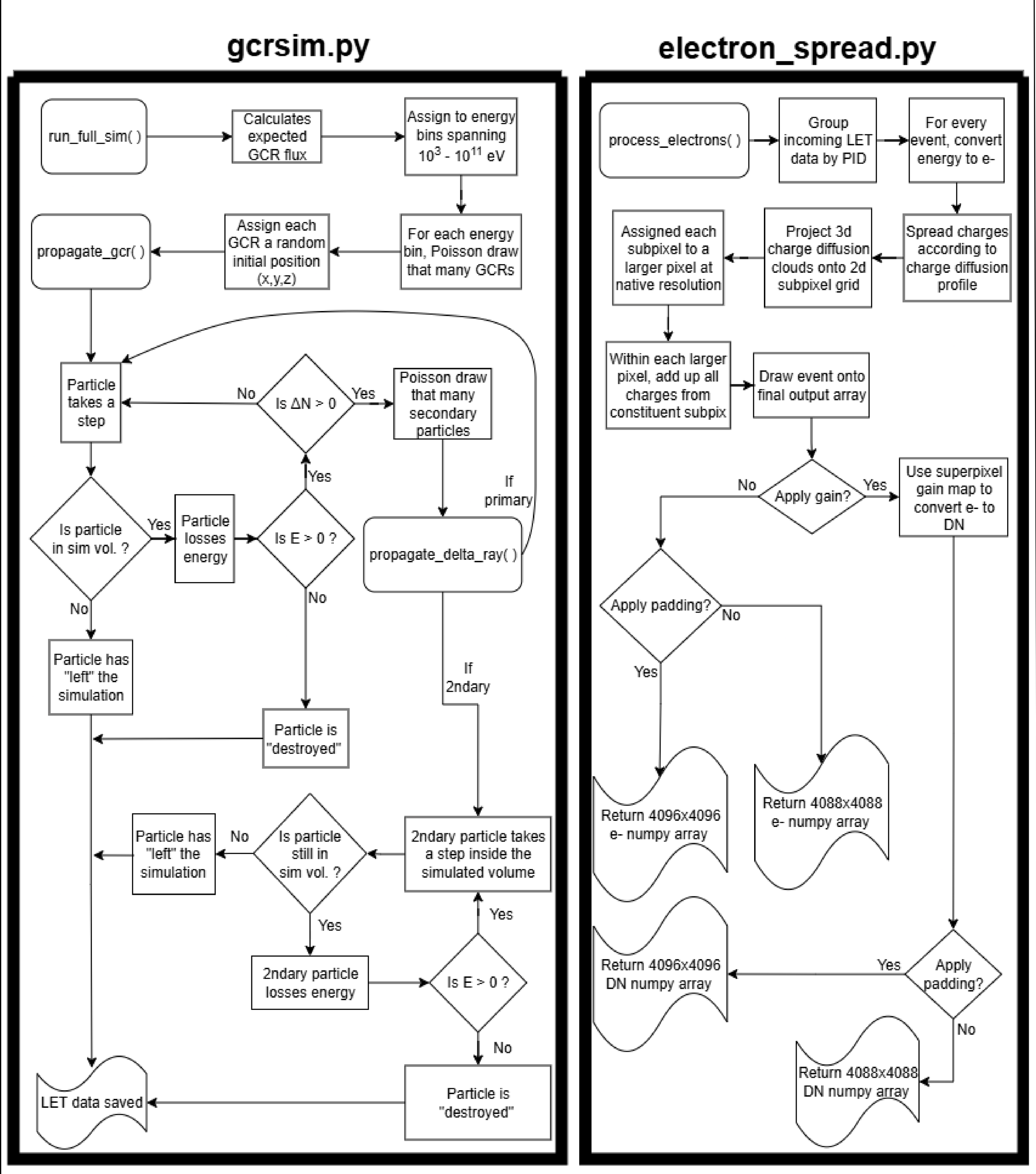


Fig. 3 (Below): Flowcharts of the HAZARD simulator's two main scripts, gcrsim.py and electron_spread.py. Generation and propagation of initial GCR and secondary ejected particles is handled by gcrsim.py. The resulting linear energy transfer (LET) data is fed to electron_spread.py to convert into electric charges within an empirically determined charge diffusion envelope (Macbeth 2026).



Model

To test the effectiveness and residual statistical effects of cosmic ray rejection, we wanted a model of cosmic rays that goes beyond general shape, average density, and average signal. We developed HAZARD to account for the stochastic nature of ionization, given that most track segments have less than mean ionization.

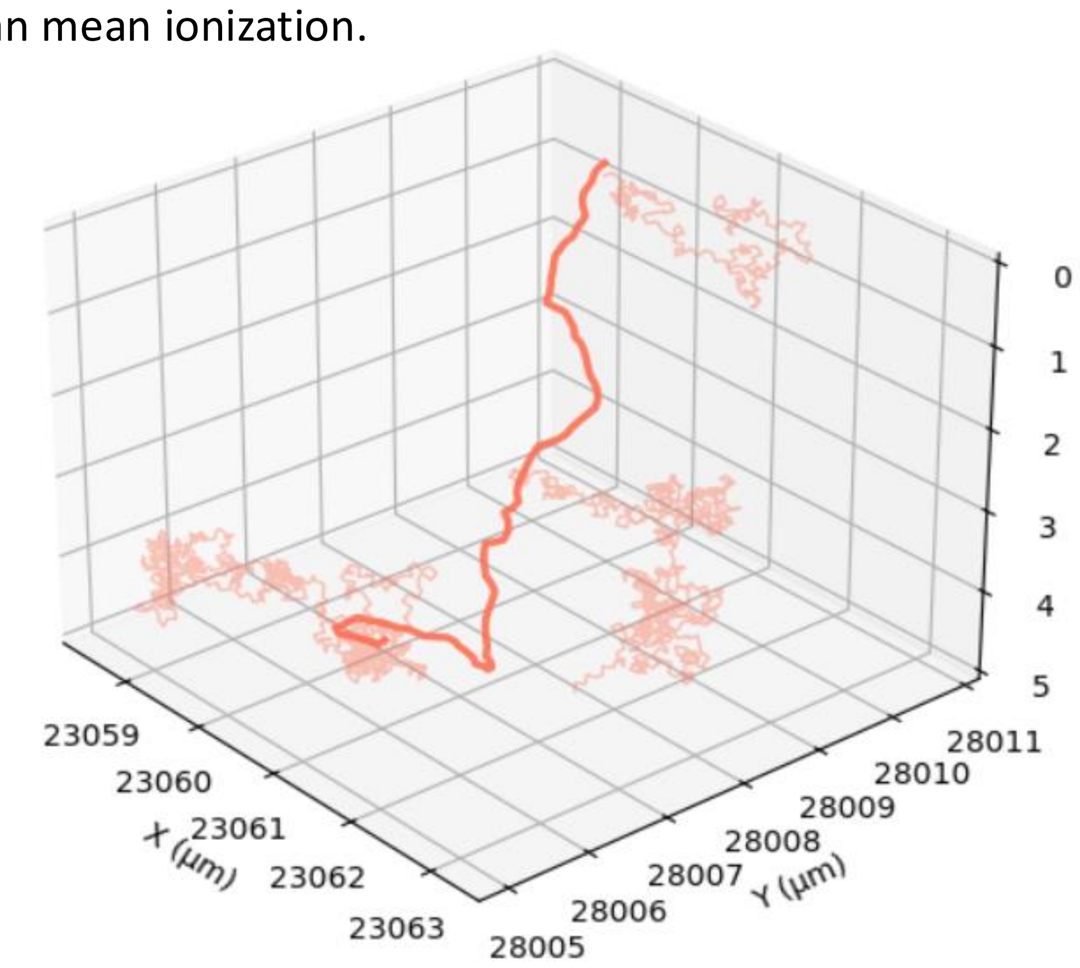


Fig. 4 (Above): A **simulated** low-energy electron, seen in bolded orange, enters a portion of the simulated volume and generates delta rays, three of which can be seen in orange going about their random walk as they diffuse in the material, extending away from the original particle that created them.

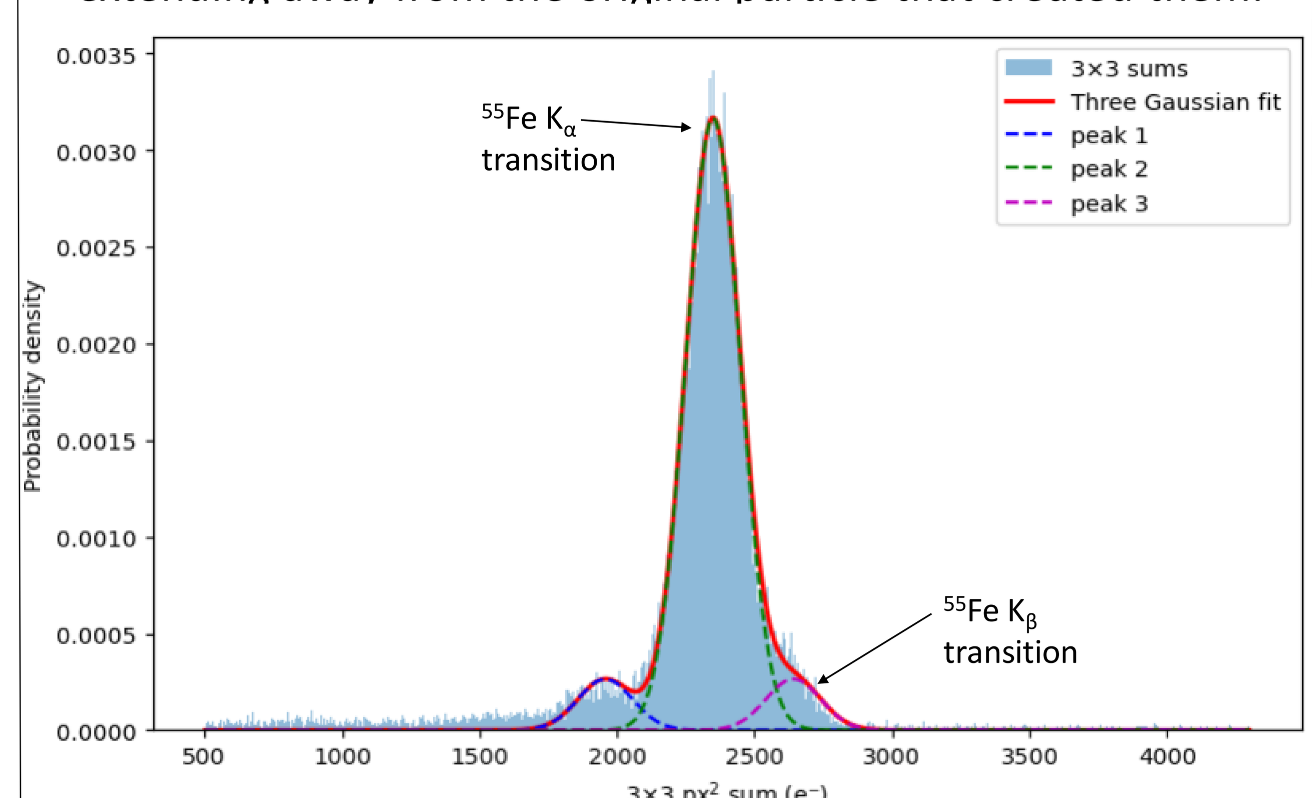
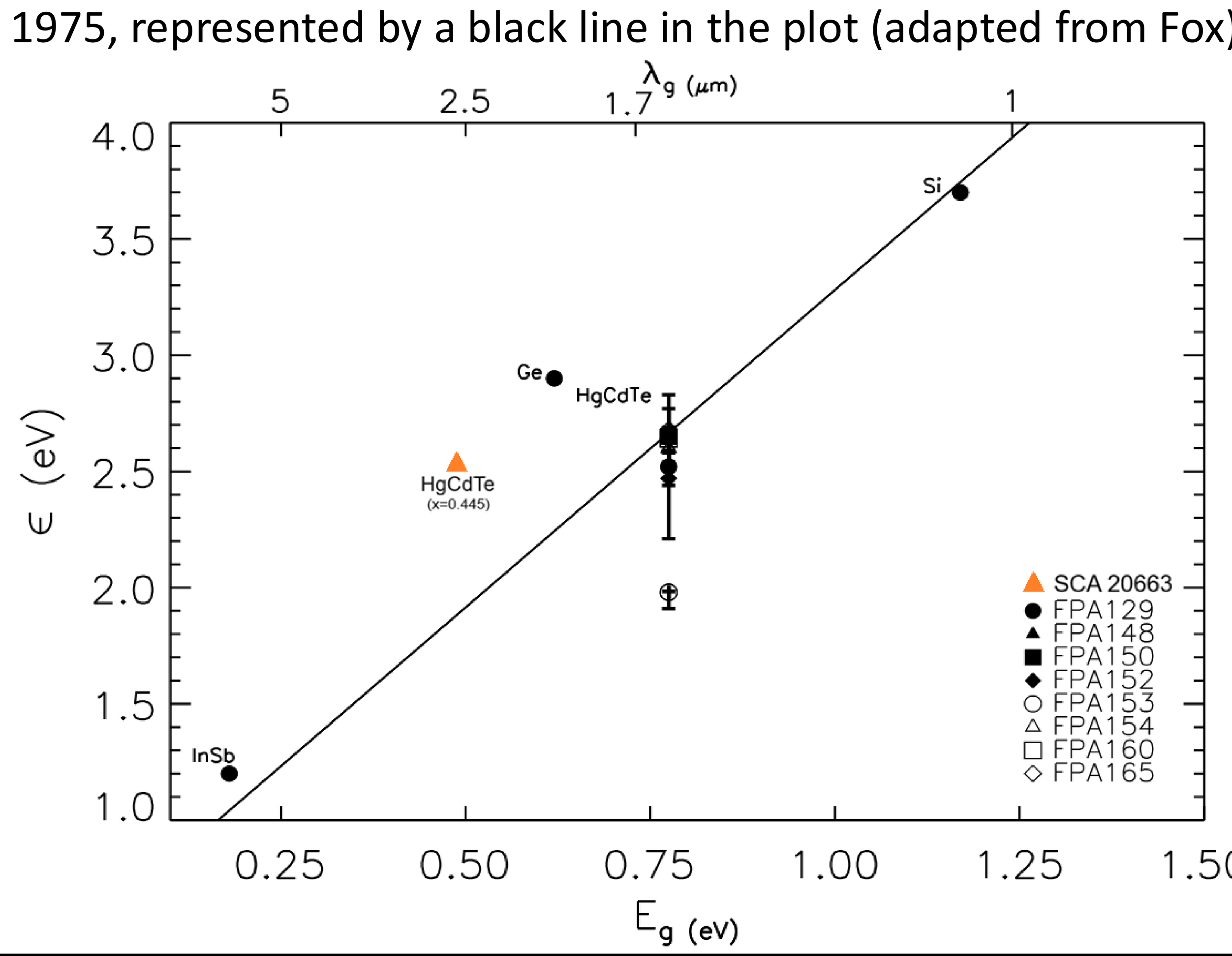


Fig. 5 (Above): Histogram of normalized X-ray signal from a 2019 experiment. A ^{55}Fe radiative source was used to illuminate one of its transition lines, the K_α line. A Gaussian fit revealed a second peak corresponding to the K_β transition. This tells us about the mean electron-hole pair creation energy.

Fig. 6 (Below): Electron-hole pair creation energies as a function of the material's bandgap energy, with values for Hubble's WFC3 IR channel FPAs in black and white and Roman's WFI SCA 20663 in orange. Our material, with a pair creation energy of ~ 2.5 eV, lies off the empirical relationship derived by Alig and Bloom in 1975, represented by a black line in the plot (adapted from Fox).



Results

HAZARD returns cosmic ray background images by running its Monte Carlo LET data through a charge diffusion model that projects electron diffusion clouds onto a 2d grid, assigning the submicron scale data into bins the size of Roman's native resolution (10 micron pixel pitch).

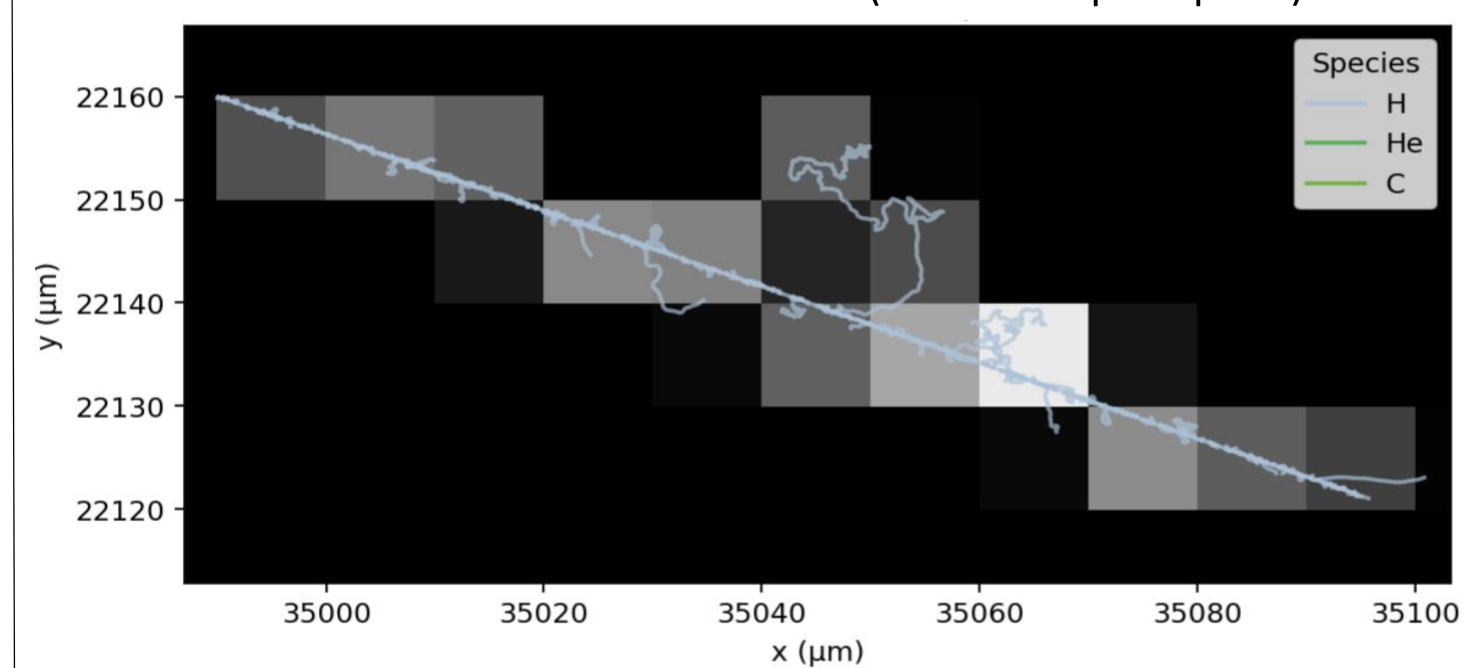


Fig. 7 (Above): A **simulated** proton striking the detector at near grazing incidence, represented by the straight light blue line. The squiggly lines curling around the straight line are delta rays excited by the proton's passage through the simulated volume of the HgCdTe material, with especially long-lived ones extending as far as two pixels away from the proton's path through the material.

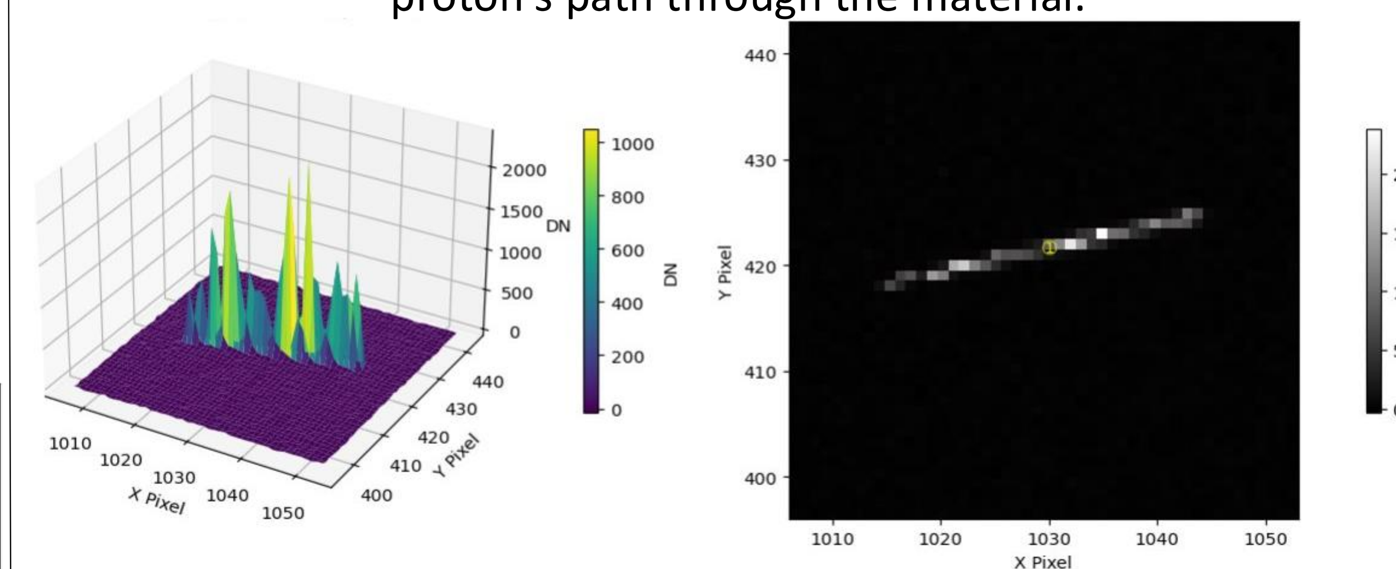


Fig. 8 (Above): An **observed** charged particle, likely a muon, is seen in two panels, one in 3d and the one to its right in 2d, detected during a device characterization experiment conducted at NASA Goddard Space Flight Center.

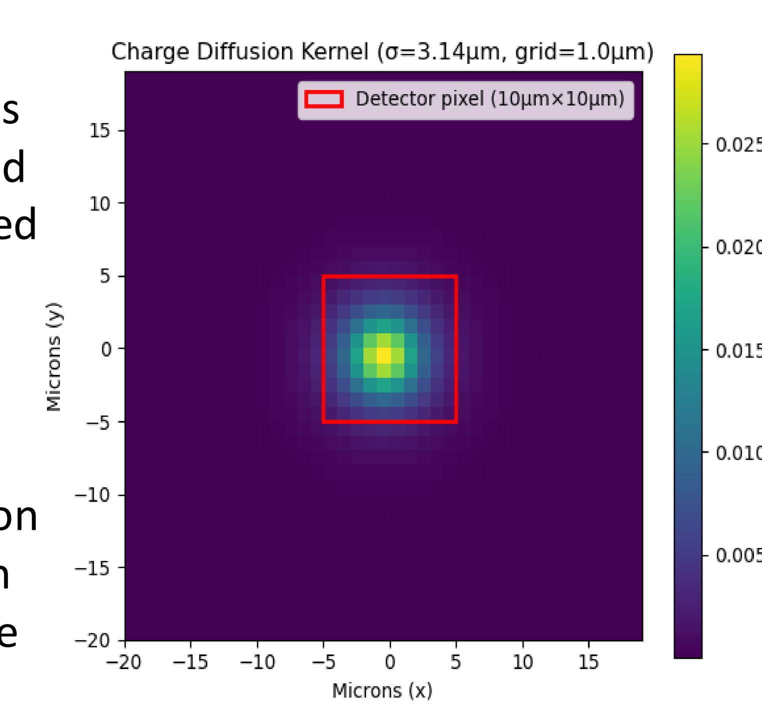


Fig. 9 (Right): The charge diffusion kernel used by HAZARD is shown with a red boundary showing the extents of a Roman WFI pixel.

Verification and next steps

We're developing an analysis framework for measuring and characterizing observed and simulated cosmic ray events, with Goddard's Detector Characterization Laboratory ^{55}Fe X-ray dataset standing in for flight data until launch. The analysis will yield numerical comparisons between reality and our various models.

We plan to make HAZARD an option in the next iteration of the Roman image simulators for users requiring a more “full physics” treatment of cosmic rays, and we will continue to update it based on cosmic rays observed in flight.

Longterm, we're already working on increasing the fidelity of the simulation by upgrading the stopping power and differential production spectrum equations with an improved model for the dielectric function of HgCdTe.

References and acknowledgements

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Special thanks to the Goddard Space Flight Center's Detector Characterization Laboratory for providing access to the 2019 ^{55}Fe X-ray data, which has been invaluable throughout this research.