The miniaturized High-Energy-Resolution relativistic electron Telescope (HERT): High-Energy-Resolution Electron Flux Measurements of Earth's Radiation Belt. S. Krantz[1], H. Zhao[2], L. W. Blum[3], and X. Li[3], [1]Department of Aerospace Engineering, Auburn University, Auburn, AL, 36849 (shk0008@auburn.edu), [2]Department of Physics, Auburn University, Auburn, AL 36849, [3] LASP, University of Colorado Boulder, Boulder, CO, 80303.

Introduction: Earth's outer radiation belt is filled with relativistic and ultrarelativistic electrons in the MeV energy range and above. These highly energetic electrons pose significant threats to avionics and humans in space, and understanding their dynamics has been an urgent need. In the post Van Allen Probes era, measurements of radiation belt populations heavily rely on small missions such as CubeSats or SmallSats. The miniaturized High-Energy-Resolution relativistic electron Telescope (HERT) is a compact (<3U) telescope designed for a CubeSat mission in a geosynchronous transfer orbit (GTO). HERT's main objective is to provide high-energy-resolution measurements of outer belt electrons to help differentiate various acceleration mechanisms and solve the long-standing question of how electrons in the Earth's radiation belts are accelerated to relativistic and ultrarelativistic energies. HERT uses a stack of solid-state silicon detectors in a telescope configuration to gather 1-7 MeV electron measurements with an energy resolution (dE/E) < 10%. Geant4 simulations are conducted to characterize the instrument responses and aid in the design of HERT. With a compact configuration and much higher energy resolution in comparison to previous telescope type instruments (e.g., Relativistic Electron Proton Telescope (REPT) on the Van Allen Probes [1,2]), HERT will significantly contribute to the quantitative understanding of the radiation belt electron dynamics.

Objectives, Requirements, and Projected Performance: HERT's specific science objectives are to understand the energy-dependent acceleration of relativistic and ultrarelativistic electrons in the entire outer radiation belt and to quantify the contribution of radial diffusion to the energy-dependent acceleration of outer belt electron core populations. To achieve these science objectives, observations of 1-7 MeV electron flux oscillations and radial flux profiles throughout the outer radiation belt are required. HERT will measure the electron count rates of energies 1-7 MeV with high energy resolution of dE/E < 10%, with the projected energy resolution dE/E < 5% at 2-4 MeV and dE/E < 10% at 1-2 MeV and 4-7 MeV. Since electrons with different pitch angles drift at different speeds, HERT requires a Field-Of-View (FOV) of 20° - 40° to focus on a relatively narrow range of pitch angles while retaining enough counting statistics. The measurement cadence is required to be <1 min, while we project it to be much faster (1s). A range of measurable fluxes is required and projected to be 10-10^7 #/cm2/s/sr/MeV according to seven years' measurements of the Van Allen Probes. HERT requires the accuracy of electron count rates within 30%, and accelerator beam tests will be conducted to ensure this. To fit into a future CubeSat/SmallSat mission to GTO, HERT will have a volume/mass/power less than 3U/4kg/6W.

Instrument Design: Building upon the heritage from the REPT instrument and the Relativistic Electron Proton Telescope integrated little experiment instrument (REPTile) on the Colorado Student Space Weather Experiment [3], HERT is comprised of a stack of nine solid-state silicon detectors in a telescope configuration with a beryllium window to block lower energy electrons, and a tantalum collimator to enforce the required FOV. Sensor shielding with high-Z materials surrounds the instrument to reduce the amount of radiation exposure at GTO. The final detector in the stack would be used to filter out penetrating particles. A design choice being studied is to separate the first eight detectors into an "inner ring" and "outer ring" of detectors instead of a single detector. The "outer ring" of detectors would be used to filter out side-penetrating particles and scattering electrons. This is later shown as the "inner/outer" configuration. The "whole" configuration refers to all nine detectors being single detectors. Figure 1 shows HERT's geometry in the "inner/outer" configuration from a Geant4 cross section.

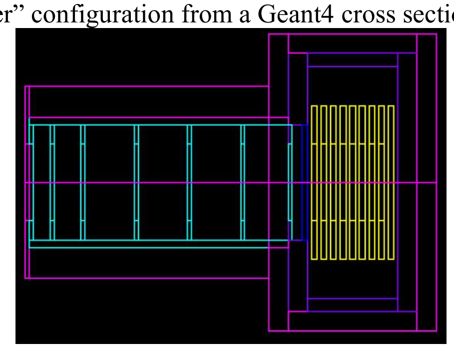

Figure 1- Cross section of the HERT Instrument in the Geant4 Simulation. Materials marked in magenta is aluminum, purple is tungsten, cyan is tantalum, blue is beryllium, and yellow is the silicon detectors.

Initial Results on the Instrument Performance: Initial work focused on calculating the efficiency and the geometric factor of the instrument. HERT's geometric factor was calculated using two different methods: theoretical [4] and Geant4 simulation [5]. The theoretical geometric factor was determined by simplifying the telescope geometry to several circular symmetric discs. For the “whole” configuration, the collimator alone is the limiting factor and leads to the theoretical geometric factor being a constant with respect to incident energy. For the “inner/outer” configuration, the geometric factor has a negative gradient as higher energy electrons must travel through more detectors in the stack to be counted. Geant4 simulations were conducted with electrons having incident energy from 1 MeV to 7 MeV with two million particles simulated for each energy level. Figure 2 shows the comparison between the simulated and theoretical geometric factors for the two configurations.

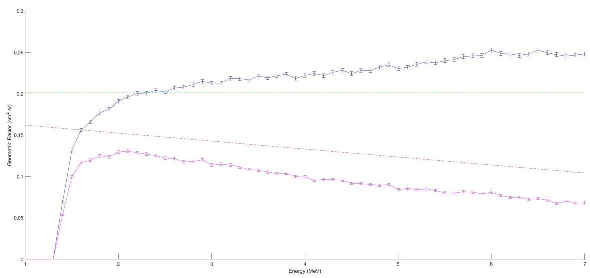

Figure 2- Simulated vs. Theoretical Geometric Factors. The green and red dashed lines are for the theoretical geometric factors of whole and inner/outer configurations, respectively. The blue and magenta curves are for simulated geometric factors of whole and inner/outer configurations, respectively.

To determine the incident energy at a high-resolution, a total of thirty-two energy channels from 1 – 7 MeV are used. The geometric factor for each energy channel can be plotted as a function of incident energy. In Figure 3 and Figure 4, the results for the “inner/outer” and “whole” configurations can be seen respectively.

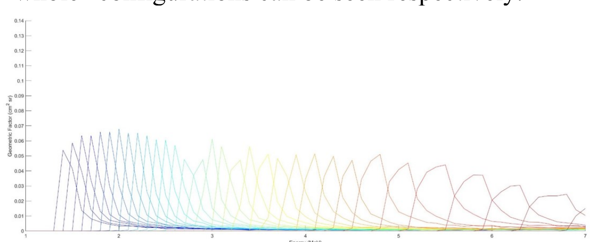

Figure 3- Geometric Factor by 32 Energy Channels (1-7 MeV) in Inner/Outer Configuration

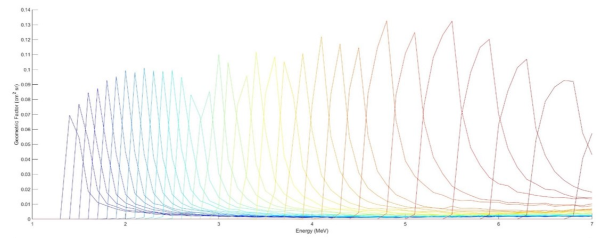

Figure 4- Geometric Factor by 32 Energy Channels (1-7 MeV) in Whole Configuration

Future Work:

Future work for HERT is to estimate count rates for each energy channel using the geometric factors and bow-tie analysis, and optimize the energy channel ranges. The estimated count rates will be critical for the design of the detector electronics.

Acknowledgments: HERT is supported through NASA grant 80NSSC21K1041.

S. Krantz would like to thank Dr. Hirabayashi of Auburn University for his research mentorship.

References:

[1] Baker, D. N., Kanekal, S. G., Hoxie, V. C., Batiste, S., Bolton, M., Li, X., et al. (2012). The Relativistic Electron-Proton Telescope (REPT) instrument on board the Radiation Belt Storm Probes (RBSP) spacecraft: Characterization of Earth’s radiation belt high-energy particle populations. Space Science Reviews, 179(1-4), 337–381. [2] Baker, D. N., Kanekal, S. G., Hoxie, V., Li, X., Jaynes, A. N., Zhao, H., et al. (2021). The Relativistic Electron-Proton Telescope (REPT) Investigation: Design, Operational Properties, and Science Highlights. Space Sci Rev 217, 68. [3] Li, X., et al. (2013), First results from CSSWE CubeSat: Characteristics of relativistic electrons in the near-Earth environment during the October 2012 magnetic storms, J. Geophys. Res. Space Physics, 118. [4] J.D. Sullivan, Geometric factor and directional response of single and multi-element particle telescopes, Nuclear Instruments and Methods,Volume 95, Issue 1,1971, Pages 5-11, ISSN 0029-554X, [5] Yando, K., Millan, R. M., Green, J. C., and Evans, D. S. (2011), A Monte Carlo simulation of the NOAA POES Medium Energy Proton and Electron Detector instrument, J. Geophys. Res., 116, A10231,