
The Milky Way

# Monte Carlo Radiation Transport Simulations for Astrophysics and Space Science

**Lawrence S. Pinsky [UH] / Thomas L. Wilson [NASA-JSC] / Victor Andersen [UH]**

This project in astrophysics and space science, which provides Monte Carlo radiation transport simulations, has continued to build on the effort of earlier years in two areas: (1) writing and validating computer codes to assist scientists and engineers in simulating space radiation in a wide range of environments, and (2) collaborating with scientists on specific problems where expertise with radiation transport calculations are an important component of the scientific analysis.

In all cases discussed in this report, the Monte Carlo simulation package used is the radiation transport code FLUKA,[1,2] which is one of the most complete and sophisticated radiation transport codes available today. The data analysis package is ROOT,[3] an object-oriented physics analysis package being developed at the European Organization of Nuclear Research (CERN).

**Software Development**

As part of previous ISSO work, we had developed codes to generate lists of particles suitable for input to FLUKA, based on model energy spectra and spatial distributions of energetic particles from sources such as galactic cosmic rays and solar energetic particle events. In the past year, we have further enhanced the capabilities of these codes, allowing the user to select from a larger number of both spectral and spatial models.

The spectra of galactic cosmic rays observed at Earth varies with time, due to energy losses as the particles travel inward against the outward flowing solar wind, and solar magnetic field embedded within. The solar magnetic field does not stay constant with time, but, instead, varies over a 22-year cycle; since the solar magnetic field is the prime agent of cosmic ray modulation, the modulation level of cosmic rays varies over this 22-year cycle as well. Therefore, in order to generate cosmic ray spectra for a given time period, the level of cosmic ray modulation must be known, as well as the spectrum of cosmic rays entering the heliosphere from interstellar space. In the past year, we have developed codes to meet these needs that allow the user to determine the level of modulation, and apply this level of modulation to a spectrum of his or her choice, based upon standard existing models of the modulation process. An example of the results of these modulation codes is shown in Fig. 1.

**RADIATION—Dr. Lawrence Pinsky, Professor and Chair, Department of Physics, is a specialist in the effects of radiation in space. Humans will find themselves affected by radiation in space during flights and while engaged in laboratory research in transport vehicles or in the International Space Station. The present task is to simulate radiation effects in a wide range of environments. The research is vital for future travel in space.**

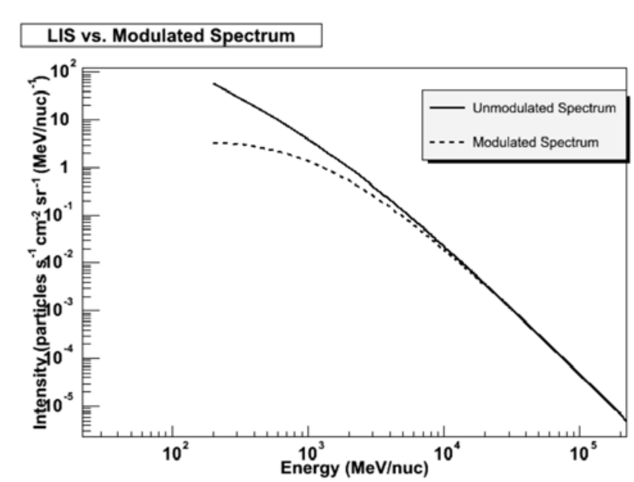



**Figure 1. Example Calculation of the Result of Modulation within the Heliosphere of Galactic Cosmic Rays Observed at Earth**

**Atmospheric Precipitation of Outer Belt Electrons**

The outer Van Allen belt of Earth contains large numbers of energetic electrons, which are trapped on closed lines of Earth's magnetic field. These electrons bounce back and forth from the northern to southern hemisphere following the magnetic field lines. The altitude at which the bounce, or mirror, occurs depends on how much of the electrons' velocity is directed along the magnetic field line on which they are trapped: the more the velocity is aligned with the field, the lower the altitude at which the electron will mirror. Electrons that mirror at low enough altitudes can suffer large numbers of energy-losing collisions with air molecules, and thus be precipitated into the Earth's upper atmosphere. The Earth's magnetic field is reasonably well approximated by a dipole field, but a dipole that is tipped with respect to Earth's rotation axis and offset slightly from the center of the earth. This means that a particular electron will mirror at different altitudes in the northern and southern hemisphere, with the altitudes being lower in the southern hemisphere.

One of the important drivers of chemical reactions in the upper atmosphere—such as the destruction of ozone—is the deposition of energy in the atmosphere. In most places in Earth's upper atmosphere, the dominant source of energy deposition is the absorption of solar x-ray and ultra-violet photons. At a restricted range of longitudes in the southern hemisphere however, the low altitude which outer belt electrons reach means that they can actually dominate the heating and, thus, drive the chemistry.

Dr. William Sheldon (Professor Emeritus of physics at the University of Houston) has actively been studying the process of electron precipitation. In the past year, we have begun a collaboration with Dr. Sheldon in order to model the energy deposition process using FLUKA. There are a number of important questions we hope to be able to address with these simulations. First, calculations of electron precipitation until this time have assumed that electrons were entering the atmosphere vertically. However, electrons from the outer belt are following the magnetic field lines, and thus enter the upper atmosphere at latitudes near -80° close to horizontally. The results of a FLUKA simulation demonstrating the difference in energy deposition (and thus atmospheric ionization) in the horizontal versus the vertical case is shown in Fig. 2, showing that horizontally moving electrons deposit energy preferentially at higher altitudes than vertically moving electrons. Additionally, the simulations show that about half of the horizontally entering electrons are scattered enough by interactions in the atmosphere to enter layers of the atmosphere above 100 kilometers: these layers are observed to have populations of energetic electrons, a source for which may be electrons from the outer belt that have been backscattered to higher altitudes. Figure 3 shows a comparison of the energy spectrum of electrons entering the atmosphere from the outer belt at 100 kilometers, and the spectrum of back scattered electrons at this same altitude, moving outward.

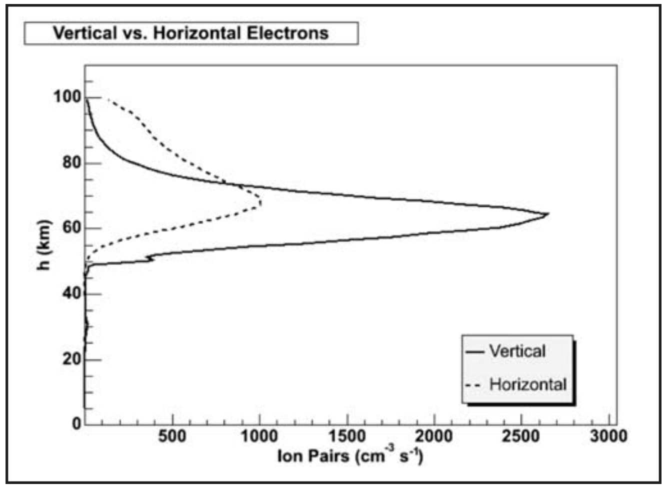



**Figure 2. Ion Production Profile for Energetic Electrons from the Outer Van Allen Belts Entering the Upper Atmosphere Vertically and Horizontally**

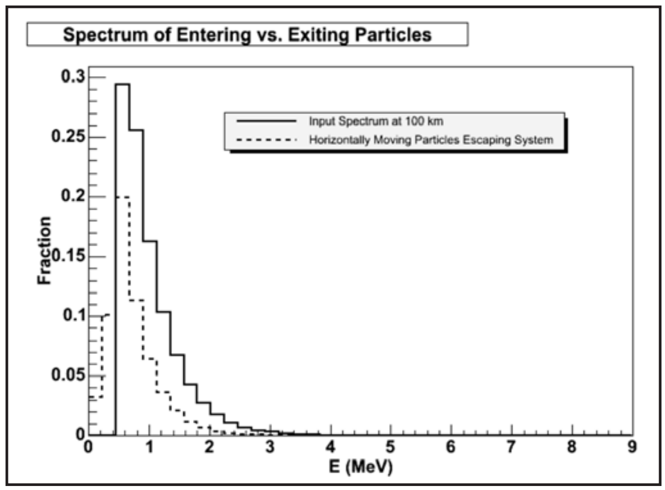



**Figure 3. Comparison of Spectra of Horizontally Moving Electrons Entering the Upper Atmosphere and Leaving the Upper Atmosphere at an Altitude of 100 km**

**Summary**

A wide range of problems in astrophysics and space science involves energetic particles. Sophisticated radiation transport codes such as FLUKA provide a valuable resource in analyzing these problems, but the major disadvantage in using the codes is the lack of interfaces and tools appropriate to space science and the steep learning curve involved in using the codes and interpreting their output. Our ongoing effort in this project is to develop codes to assist space scientists and engineers in using these sophisticated tools.

**References**


[1]A. Fasso, A. Ferrari, and P. R. Sala. "Electron-Photon Transport in FLUKA: Status," *Proc.*, MonteCarlo 2000 Conference, Lisbon, Oct. 23-26, 2000. Ed. A. Kling, F. Barao, M. Nakagawa, L. Tavora, and P. Vaz. Berlin: Springer-Verlag, 2001. 159-64. (*Invited talk.*)

[2]A. Fasso, A. Ferrari, J. Ranft, and P. R. Sala. FLUKA: Status and Prospective for Hadronic Applications," *Proc.*, MonteCarlo 2000 Conference, Lisbon, Oct. 23-26, 2000. Ed. A. Kling, F. Barao, M. Nakagawa, L. Tavora, and P. Vaz. Berlin: Springer-Verlag, 2001. 955-60. (*Invited talk.*)

[3]R. Brun and F. Rademakers. "ROOT - An Object Oriented Data Analysis Framework," *Proc.*, AIHENP'96 Workshop, Lausanne, Sept. 1996, *Nucl. Inst. & Meth. in Phys. Res. A* 389 (1997): 81-86. See also <http://root.cern.ch/>.


**Publications**


Andersen, V., T. L. Wilson, and L. S. Pinsky. "Helium Production of Prompt Neutrinos on the Moon," 35th Lunar and Planetary Science Conference, 2004. 1870-71.

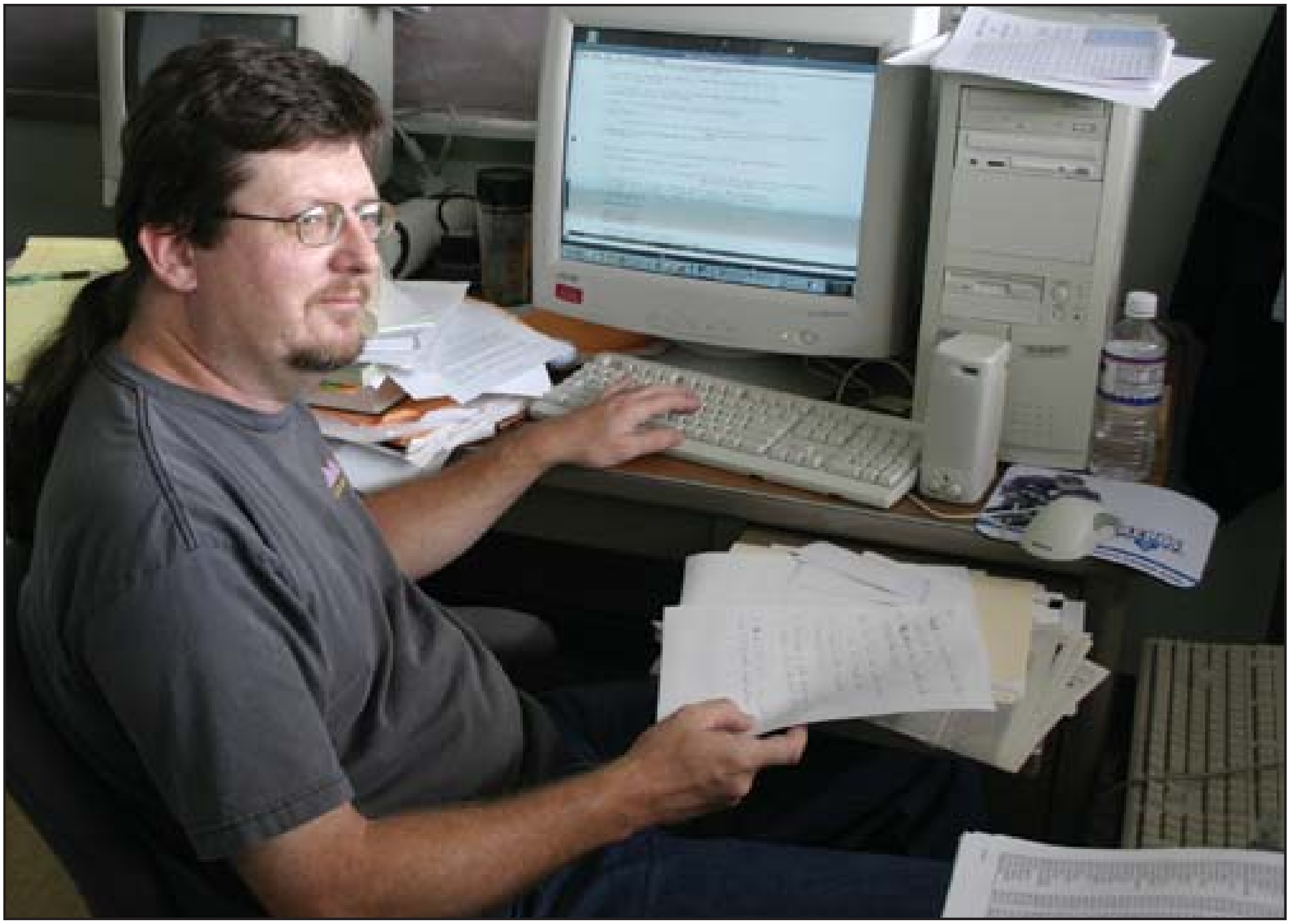
Andersen, V., K. Lee, L. Pinsky, W. Atwell, T. Cleghorn, F. Cucinotta, P. Saganti, R. Turner, and C. Zeitlin. "Monte Carlo Simulation of the Response of the MARIE," *Proc.*, 28th International Cosmic Ray Conference, Tsukuba, Japan, July 31-Aug. 7, 2003. 2113-3116.

Sheldon, W. R., V. Andersen, and L. S. Pinsky. "Monte Carlo Study of Secondary Electrons and X Rays Produced by Vertical vs. Horizontal Arrival of Precipitating Electrons at the Top of the Atmosphere," *Eos Trans. AGU, Jt. Assem. Suppl.* 85.17 (2004): Abstract SM33A-18.

Zeitlin, C., V. Andersen, W. Atwell, T. F. Cleghorn, F. A. Cucinotta, K. T. Lee, L. Pinsky, P. Saganti. "MARIE: Current Status and Results from 20 Months of Observations at Mars," 35th Lunar and Planetary Science Conference, 2004. 1954-55.


**Presentations**


Fasso, A., A. Ferrari, S. Roesler, J. Ranft, P. R. Sala, G. Battistoni, M. Campanella, F. Cerutti, L. De Biaggi, E. Gadioli, M. V. Garzelli, F. Ballarini, A. Ottolenghi, D.



**PDAF—Post-Doctoral Aerospace Fellow Dr. Victor Anderson is a member of the UH/NASA-JSC research team in astrophysics and space science engaged in developing Monte Carlo radiation transport simulation designed to discover, understand, and, conceivably, solve the hazards of space travel. The research team has developed codes to measure levels of cosmic ray modulation and the spectrum of cosmic rays entering the heliosphere from interstellar space.**

Scannicchio, M. Carboni, M. Pelliccioni, R. Villari, V. Andersen, A. Empl, K. Lee, L. Pinsky, T. N. Wilson, and N. Zapp. "The FLUKA Code: Present Applications and Future Developments," Computing in High Energy and Nuclear Physics, 2003.

**Funding and proposals**

"Analysis of Data from the Mars '01 MARIE Experiment." NAG9-1347, Aug. 1, 2001-July 31, 2002, $25,894.

"Determining the Radial Dependence of Particle Intensities from Coronal Mass Ejections." ARP, Jan. 1, 2002-Dec. 31, 2003, $103,000.

**Theses or Student Reports Related to the ISSO Research**

Lee, K. Thesis in progress, talks and publications by student listed under "Publications" and "Presentations" above. Mr. Kerry's course of study has seen him pass his Ph.D. qualifying exam and begin his thesis. He began doctoral study on Jan. 16, 2001. Funding Obtained by Student: [See NAG9-1347, above, $25,894].