Chapter 3

Solar Energetic Particles

Objective: To study the transport, acceleration, and interactions of solar energetic particles.

Note: The Principal Investigator was also involved in all of these subprojects.

3.1 Fitting SEP data: January 20, 2005 event

- Researcher: Alejandro Sáiz (Mahidol U.)
- Type of work: Computation, data analysis
- Key Points: Largest relativistic solar particle event in 50 years. Explanation of the January 20, 2005 ground level enhancement in terms of nonlinear transport of relativistic solar particles and/or a magnetic bottleneck configuration beyond Earth.
- Status: Paper in preparation
- Output: 5, 7, 9, 10, 15

Despite the decline in the solar cycle, the Sun produced a giant ground level enhancement (GLE) of relativistic solar particles on January 20, 2005. This was a huge event, the largest GLE in 50 years! (Oddly, this event did not excite much interest among the popular press.)

We have been invited to help analyze the data from polar neutron monitors - in Antarctica, Australia, Greenland, Canada, and Russia - maintained by the Bartol Research Institute and collaborators. In addition to the directional distribution of cosmic rays, there are data from a bare monitor (similar to our MicroMonitor) maintained at that time by Bartol at the South Pole, which provide spectral information.

Interestingly, on January 20, 2005, the data exhibit an unusual second spike superimposed on the decay of the first. This is corroborated by a spectral feature (possibly indicating energy dispersion) in the bare counter to neutron monitor ratio. Remarkably, the second peak has a lower anisotropy than the first, indicating a change in interplanetary transport conditions after 10 minutes! We show that this can be explained by 1) a manifestation of self-amplified waves, in which the first particles lose some of their energy to wave generation that resonantly scatters the following particles, or 2) a magnetic bottleneck configuration due to a previous coronal mass ejection then located beyond Earth.

In our most recent fits to the data, the bottleneck hypothesis provides a better fit. At present, we are working toward preparing 2 journal articles about our results for this event. The PI has prepared a draft of the first paper (to be led by Prof. Bieber), and several collaborators have provided figures.

3.2 Fitting SEP data: August 14, 1982 event

- Researchers: Alejandro Sáiz (Mahidol U.), Pornsak Sommart
- Type of work: Computation, data analysis
- Key Points: Our modeling and fitting techniques are also applied to fit data on relativistic electrons from a solar storm.
- Status: Ongoing

In this work, we apply similar analysis techniques to study the remarkable solar electron event of August 14, 1982 as observed by the MEH instrument on the ISEE-3 spacecraft. A qualitative analysis was published by Kane et al. (1985). With its remarkable intensity and anisotropy of relativistic electrons, this event should be particularly amenable to a quantitative analysis, and our collaborator Prof. Paul Evenson of U. Delaware recommended that we use our techniques to do so. This work is largely being carried out by an M.Sc. student, Pornsak Sommart.

3.3 Transport of GLE particles to Mars and Jupiter

- Researchers: Alejandro Sáiz (Mahidol U.)
- Type of work: Computation
- Key Point: Examining the radial dependence of SEP profiles, including the distances of Mars and Jupiter, with regard to radiation hazards for astronauts. Performed the first SEP transport simulations to include the radial dependence of the mean free path from *ab initio* turbulence models.
- Status: Ongoing
- Output: 12, 13, 16, 26, 43

This work was suggested by Prof. John Bieber at U. Delaware, USA. John submitted a grant proposal to NASA, with David and Alejandro as co-investigators, to examine the radial dependence of SEP profiles, including the distances of Mars and Jupiter. This is of interest to NASA's manned space program, with regard to future human exploration of Mars, for which solar energetic particles represent an important and unpredictable radiation hazard. With regard to radiation hazards, ions in the energy range detected by neutron monitors at Earth, i.e., ~500 MeV to 5 GeV, are particularly important. Although astronauts in present-day missions are still protected by Earth's magnetosphere (and humans at ground level are very well protected by Earth's atmosphere), there is no good plan for protecting astronauts from SEP and GCR above 500 MeV, and the flux of such particles can increase by more than ten-fold during a major solar event.

In some sense, this is something we in Thailand can already study, using the simulation programs and procedures developed here (Ruffolo 1995, Nutaro et al. 2001). In collaboration with Bieber and others at U. Delaware, we have fit neutron monitor data from several solar events (Bieber et al. 2002, 2004, 2005, Ruffolo et al. 2006; see also Section 3.1), so we could use the fit parameters for such an event to compute the expected time-intensity profiles at greater distances, including the orbits of Mars and Jupiter.

A potential weak point in such work is the lack of observational data concerning the mean free path of solar energetic particles as a function of radius (distance) from the Sun. A valuable suggestion by John Bieber is to incorporate a state-of-the-art theoretical estimation by his group at U. Delaware, using an *ab initio* model incorporating a model of the radial evolution of solar wind turbulence. They find that the mean free path varies as $r^{-0.5}$, so we have compared models with a mean free path that is constant (the standard assumption) or varying as $r^{-0.5}$. For the example of the injection function and transport parameters inferred for the event of Jan. 20, 2005 (see 3.1), we have determined inferred time-intensity profiles at the orbits of Mercury, Venus, Earth, Mars, Ceres, and Jupiter.

3.4 Particle acceleration at a coronal mass ejection

- Researcher: Chanruangrit Channok (Ubon Rajathanee U.)
- Type of Work: Theory, computation, data analysis
- Key Point: Aim to explain time-intensity profiles of energetic storm particles.
- Status: On hold

This line of work was begun after Chanruangrit Channok finished his Ph.D. thesis work with our group and returned to Ubon Rajathanee University. For a while he would occasionally visit us in Bangkok, especially after he obtained a Young Researcher Grant from TRF.

Our idea is to investigate a recent observation that the presence of two coronal mass ejections (CMEs) in space leads to greatly enhanced particle acceleration. We plan to model the particle acceleration at a "broad-brush" level, using a diffusion convection equation, instead of a pitch angle transport equation as in our fitting work. We will also need to take into account the generation of waves (and turbulence) by the particle acceleration. We think the secret to understanding the enhanced particle acceleration is the reflection of waves and particles in the space between the two CME-driven shocks. We developed this idea in part because one of the events studied by Chanruangrit in his thesis work (Channok et al. 2005) had a constant particle intensity in between the two shocks, as if particles were trapped there, which might possibly cause more wave generation and concentration.

As a step toward the modeling of pairs of CMEs, we aim to first explain in better detail the acceleration at a single CME, in conjunction with Mihir Desai at Southwest Research Institute in the US. We have achieved some theoretical understanding of time profiles observed by the ACE spacecraft, which in some sense correspond to spatial distributions of particles near the shock structure as it moves past the Earth. The work was aiming toward a quantitative comparison with observed time profiles, but is now on hold as Dr. Chanruangrith Channok apparently does not have time to do it.