

## CAWSES II, Task Group 3

### Item 7: Substorm Variability and Radiation Belts

Bruce T. Tsurutani

A prime focus on the topic of substorms and radiation belts has been substorms that have occurred during high speed solar wind streams (HSSs) emanating from coronal holes. Relativistic electrons are accelerated out of the substorm-injected 10-100 keV electron population to  $\sim$  MeV energies during HSS events. Besides being a fundamental plasma physics wave-particle interaction problem, the relativistic electrons present a hazard for orbiting spacecraft.

Over the last 5 years (2009 to present), the science community has produced an enormous body of work on various facets of this topic. Much of the work now focuses on chorus, an electromagnetic whistler mode wave generated by the substorm (and convection) energetic electron temperature anisotropy/loss cone instability. Chorus is now thought to be the main acceleration mechanism for relativistic electrons (but magnetosonic mode waves have not been ruled out). Chorus secondary (parasitic) interactions with the high energy tail ( $\sim$ 100 keV) of the electron distribution function can produce MeV electrons in one or two days, consistent with observations. Studies of the loss mechanisms/rates by off-axis chorus, by electromagnetic ion cyclotron (EMIC) waves and other wave modes have been pursued. As of this date, the dominant loss mechanism has not been agreed upon.

It is now well accepted that radial diffusion of relativistic electrons are driven by ULF waves, the latter of which have been shown to be present during intervals of prolonged substorm/convection activity. However for  $E_e > 6$  MeV, a combination of chorus acceleration and transport from a source region inside geostationary orbit are required to explain observations.

Progress on the details of chorus (important for wave-particle modeling), such as mechanisms for rising tones, falling tones and direction of propagation has been made. A new feature of chorus was brought to light during this study interval, the coherency of the emission at the generation region. Rapid pitch angle transport was theoretically predicted. The high temporal (20-30 ms) variations in optical measurements of a pulsating aurora may be a consequence of this. Most wave-particle models have yet to take this new development into account. Most wave-particle interaction codes have assumed quasilinear theory. The nonlinear aspects of wave-particle interactions also need to be taken into account.

Chorus and relativistic electrons (without substorms?) have been studied at other planets, such as Jupiter and Saturn. At Jupiter, relativistic electrons pose an even bigger problem than those at Earth. Satellite lifetimes are extremely shortened by the presence of the electrons. Presently designs such as either very heavy spacecraft shielding (making the launch weight high) or highly elliptical orbits, are employed. Knowledge from Earth-based wave-particle interactions could possibly help design techniques that would reduce the relativistic electron fluxes at Jupiter and Earth. This would allow close orbiting spacecraft at Jupiter and longer lifetime satellites at Earth.

A topic not well covered in the last 5 years is whether there are other important phenomena that occur in the magnetosphere during HSSs. Certainly substorms occur, but other “convection” events occur as well. The importance of the latter for the radiation belts is unknown.

If one focusses only on the topic of chorus and relativistic electrons, the scientific community has written 200+ articles. The following bibliography contains only articles related to either of these two topics. There are certainly more that have been missed by accident. Part of the upsurge of interest in this area have been a workshop (First International Workshop on Electromagnetic Chorus Plasma Waves, 2009), a Chapman Conference (Dynamics of the Earth’s Radiation Belts and Inner Magnetosphere, 2011), the NASA Van Allen Probes (2012) and the upcoming Japanese ERG (2015) mission. But there is also a general upsurge in interest in the related plasma physics and space weather applications as well.

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