PIXIE Science at Aerospace

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A primary focus of research at Aerospace over the last year using PIXIE (and other ISTP data) has developed with the advent of an 80% duty cycle in the front chamber in September, 1998, allowing detailed examination of the global distribution of auroral X-ray emissions during the extended periods required to investigate the nature of geomagnetic storms. In *Anderson et al.* [2000a], we examined a 10-hour period of intense auroral activity during the main phase of a geomagnetic storm using both PIXIE and UVI images along with numerous other space and ground-based observations. It was shown that during storms, the majority of observed X-ray emissions were produced in the morning sector and were associated with electrons driven Earthward and around the morningside by enhanced magnetospheric convection. The nature of the PIXIE energy response is such that the efficiency of producing X rays detectable by PIXIE increases rapidly with the increasing energy (>2 keV) of the electrons producing the X rays *via* impact with the atmosphere. Thus PIXIE tends to see emissions primarily in the morning sector where the distributions are inclined to be harder, with high energy tails. It has been shown [e.g., *Christon et al.*, 1991] that the precipitating electron spectra in the morningside resemble relatively low energy Maxwellian distributions with high energy tails best fit by a kappa distribution. PIXIE is responding to the X rays produced by electrons in this high energy tail. This was discussed in some detail in *Anderson et al.* [1998], where the measured X-ray distributions were compared with measured electron distributions. Intense emissions seen in the premidnight sector are associated with substorms and the strongly accelerated distributions associated with the substorm surge. These emissions are more transient than the intense morningside emissions associated with strong stormtime magnetospheric convection. *Anderson et al.* [2000a] showed a period of over 5 hours during a storm main phase during which B_z was strongly southward, magnetospheric convection was very strong, and there were significant morningside X-ray and UV emissions and auroral currents, in the absence of substorm associated premidnight auroral emissions, currents, or geosynchronous injections.

PIXIE's energy response and global view over extended periods of time allows it to clearly differentiate the signatures of storms and substorms. *Anderson et al.* [2000b] demonstrated this with observations from a series of three storms. A number of impulsive events were observed during the storms that showed signatures that were inconsistent with substorm activity. These events, termed convection enhancements, often occurred shortly after substantial increases in the cross-polar-cap potential drop, associated with the magnetospheric convection strength, and showed significant X-ray emissions in the morning sector with little activity in the premidnight sector, and no geosynchronous substorm injection signature. This paper was featured on the *GRL* cover.

The results of the previous research led to a study in which we examined the statistical distributions of X-ray and UV emission patterns and compared them with statistical distributions from precipitating electron measurements [*Anderson et al.,* 2001]. Such distributions are generally derived using the simplistic, but easily obtained, *Kp* index. We found in general good agreement, with the differences being consistent with the known instrument energy responses, the motion of magnetospheric particles in the inner magnetosphere, and the spectral characteristics of the auroral particles. We observed little change in the auroral distributions with increasing *Kp,* other than an increase in the auroral oval width and intensity. However, the X-ray distributions changed dramatically with decreasing *Dst*. The X-ray emissions, on average, were more intense in the evening sector for *Dst* > 0, associated with isolated substorm activity and substorm injections, and in the morning sector for *Dst* < 0, associated with geomagnetic storm activity and strong magnetospheric convection. There were also indications that such was true of the UV distributions, and it was suggested that future statistical studies bin the measurements by indices other than *Kp* such as *Dst*, Δ*Dst*, the magnetospheric electric field strength, or the asymmetric indices proposed by other researchers. This paper will appear the special *JGR* issue on *Polar* science in March, 2001.

In *Anderson et al.* [2000c], we presented the first continuous observations of X rays associated with high-energy polar rain, during a period of low solar wind density in which the Earth's bow shock was extended to twice its usual distance and solar wind electrons had direct access to the northern polar cap. Energetic precipitating electron measurements showed multi-component spectra that matched well with measurements by the *Wind* spacecraft upstream of the bow shock. The PIXIE measurements, taken over a continuous 11-hour period during which the solar wind density reached its lowest value, showed modulations in emission intensity that matched well with the energetic particle measurements and were associated with changes in the energy and flux of the high-energy component of the electron distributions. We concluded that this high-energy component and the emission modulation observed by PIXIE were associated with electrons accelerated in solar flares or coronal flare-like events. This paper was published in one of the special *GRL* issues on the event and a PIXIE image from this event was featured on the *GRL* cover. There was not enough room in the *GRL* paper to present all of our findings; we are following it with a detailed report in *JGR*.

We are currently working on a study involving PIXIE observations during pressure pulses. On September 24, 1998, a pressure pulse associated with a CME encountered the Earth's magnetopause near 23:40 UT. Shortly after, within less than 3 minutes, almost the entire auroral oval lit up in X rays, with emissions extending past noon in the afternoon sector, something rarely seen in PIXIE images. The dayside emissions lasted for only a few minutes before dying away with the inception of substorm activity in the premidnight sector. Magnetometer measurements, measurements at the IRIS riometer array, and PIXIE measurements all show a different timing associated with the pressure pulse. We are analyzing the energy distribution of the precipitating particles as inferred from PIXIE and the temporal evolution of the global emission patterns in an effort to understand the particle energization and injection mechanisms associated with pressure pulses. We would note that this is during a period when both chambers of the instrument were operating at maximum duty cycle, thus providing better determination of the precipitating electron distributions [c.f., *Cummer et al*., 2000; *Ostgaard et al.,* 2000; 2001].

The PIXIE X-ray spectra provide the capability of characterizing the energy flux and average energy of auroral electrons incident upon the atmosphere on a global scale. We are working on comparisons of these parameters derived with PIXIE with parameters derived with UVI and using ground-based instrumentation. A paper describing our results entitled "Spectral Analysis of Auroral Emissions on January 14, 1999" by McKenzie *et al.* will soon be submitted to JGR. Validation of the PIXIE results in this manner is important because PIXIE's large field of view will allow the instrument to continue to image the entire auroral oval as the line of apsides of the

Polar orbit continues to precess toward the equator. Eventually PIXIE will be able to image both full ovals (but, of course, not simultaneously) so long as *Polar*'s propellant supply allows it to maintain an orbit-normal spin-axis orientation. The *Polar* imaging teams (PIXIE , UVI, and VIS) have published a number of studies involving multi-spectral imaging [e.g., *Anderson et al.,* 2000a; 2000b; *Cummer et al.,* 2000; *Ostgaard et al*., 1999; 2001]; Phil Anderson will be giving an invited talk on multi-spectral imaging results using results from all three *Polar* imagers at the 2001 Spring AGU special session "Space-Based Auroral Remote Sensing".

We also continue our work in magnetic storms with an investigation of a number of storms and the occurrence of substorms within those storms. This is an issue at the forefront of the space physics field. The old idea that a storm is just a collection of substorms (as suggested by *Chapman* [1962]) and that by understanding the dynamics of individual substorm energy injection, one can understand the entire storm process, has recently been disproved. We are studying the relationship of storms and substorms and the energetic electron populations in the inner magnetosphere using three different approaches as laid out in our extended mission proposal:

1. A suggested in *Anderson et al.* [2001], we are using an extended statistical database (PIXIE data from September, 1998 to the present), to derive statistical relationships between the auroral emission patterns and various geomagnetic activity indices, including Kp, AE, Dst, AL, AO, AU, ASYM, ΔAE, and ΔDst. We hope to expand this study to include UVI data and particle data from *DMSP* and *TIROS*.

2. We have selected a number of stormtime periods and periods of substorm activity that are being examined and compared on a case-by-case basis. We are particularly interested in the occurrence of substorms during storm main phase and the efficacy of storms and substorms in injecting ring-current particles. The cross-polar-cap potential drops derived from the *DMSP* ion drift measurements and the AMIE model are being used to infer the strength of the inner magnetospheric convection as part of the study.

3. We are comparing stormtime simulations of the diffuse aurora using the model of *Chen and Schulz* [2001] with stormtime PIXIE measurements. Preliminary results for a generic model storm suggested that an MLT-dependent pitch-angle scattering rate, leading to a transition between weak and strong pitch-angle diffusion at $L \sim 6$, agrees better with the PIXIE data than does a model that assumes strong pitch-angle diffusion everywhere [*Anderson et al*., 2000a]. A full simulation of the 19 October 1998 storm (using *DMSP*- and AMIE-derived cross-polar-cap potentials) is being performed, and the resulting electron precipitation characteristics (*e.g.*, timing, morphology, characteristic energy, and energy flux) will be compared with PIXIE data from this event, especially for the morning sector.

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