POsitron Electron Magnet Spectrometer (POEMS)
for the Eos Mission

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ABSTRACT

The P0sitron Electron Magnet Spectrometer (POEMS) has been selected to enter definition phase study for flight on one of the Earth Observing System (EOS) polar platforms. Following launch, which could come as early as 1997, POEMS will measure the critical positron and electron components of the cosmic radiation and utilize this information to trace processes occurring within our geospace environment, in solar flares, in the solar wind, and elsewhere in the galaxy. In addition, POEMS will measure heavier charged particles to complement the electron/positron measurements. With POEMS data we will investigate the origin (primary or secondary) of galactic positrons, study the charge sign dependence of solar modulation over a large fraction of a solar cycle, measure positron and neutral particle emission from solar flares, and monitor the temporal variations of the charged particle intensities and energy spectra in the EOS orbit. Two orthogonal charged particle telescopes are used, each terminating in a shared bismuth germanate (BGO) detector array that also serves as a calorimeter for neutral particles, specifically neutrons and gamma-rays from solar flares.

INTRODUCTION At the present time the particle astrophysics community is concerned with development of the generation of spacecraft instruments that will carry research into the next century. One key element of this program will be Astromag, a large magnetic spectrometer that will take advantage of observing opportunities presented by the manned Space Station. However Astromag alone will not be able to answer all important physics questions. In a low inclination orbit, the manned Space Station will be at a high rigidity geomagnetic cutoff precluding study of low energy particles. Some important data can be obtained from balloon platforms, but these are limited by weight capability, launch location, flight duration, and atmospheric background. Valuable data will also be provided by such missions as WIND, CRIE, ACE, SAMPEX, and HNC. A critical link between these other missions, measurement of low energy (5 MeV to 5 GeV) positrons, will be provided by the POEMS investigation, selected for definition for flight on the first NASA/Eos polar platform, scheduled for launch in 1997. The positron spectrum itself and its time variation are quite important scientifically. Combined with simultaneous measurement of elec-
trons, protons, alpha particles and higher-Z elements systematic measurement of the positron component will provide a potent tool for understanding a number of the most important problems in cosmic, solar and heliospheric physics. In this report we briefly summarize the scientific objectives of POEMS and sketch the design and performance of the instrument.

**PRIMARY POSITRONS** A gamma-ray line at 0.511 MeV from $e^+ \rightarrow e^-$ annihilation has been observed from a variety of astrophysical sites — the galactic center region, the interstellar medium, gamma-ray bursters and solar flares. Production of positrons in some sources of the 0.511 MeV gamma radiation is calculated to exceed the production rate of secondary positrons in cosmic ray interactions by nearly two orders of magnitude (Ramaty and Lingenfelter, 1979). There are several possible sources of astrophysical positrons. First, positrons result from interactions of accelerated particles (Kozlovsky, Lingenfelter, and Ramaty, 1987). This is the source of the secondary positrons formed by cosmic ray interactions in the interstellar medium (Protheroe, 1982), but it is also likely that high energy particles exist in energetic compact objects such as Cyg X-3, Her X-1 or pulsars. Second, positrons result from the decay of nucleosynthesis products (such as $^{56}$Co) that power the light curves of supernova like the recent SN1987A. Radionuclides $^{60}$Co, $^{44}$Ti, $^{22}$Na and $^{26}$Al, produced in Type I and Type II supernova explosions, are expected to be important sources of positrons. Finally, positrons may come from direct pair production in a high energy environment such as pulsars (Harding and Ramaty, 1987).

**PARTICLE CONFINEMENT IN THE GALAXY** Electrons and positrons are unique tracers of the confinement and transport of cosmic rays due to their low rest mass and electromagnetic interaction with the interstellar medium (Webber, 1983). Other widely used tracers of particle “history” involve secondary to primary ratios such as $\bar{p}/p$, $^2$H/$^4$He, $^3$He/$^4$He, B/C, F/Ne, sub-Fe/Fe ($21 \leq Z \leq 25$)/($Z = 26$), V/Fe or Sc/Fe. The numerator in these ratios is a secondary particle produced by nuclear interactions of primary nuclei (such as the denominator). These ratios, therefore, measure the propagation history of different components in the cosmic radiation. Both positrons and electrons are produced as secondary particles in nuclear interactions (primarily by $\pi^\pm \rightarrow \mu^\pm \rightarrow e^\pm$ but for $e^-$ there are also primary sources (Cummins, Stone and Vogt, 1973). POEMS data may confirm the secondary nature of all positrons, or they may define an energy range in which secondaries dominate. Stephens and Golden (1987) and Webber (1987) have summarized the data and have shown that a propagation model can be developed that predicts both the anti-proton flux and an $e^+$ fraction consistent with the low energy results. However, this new prediction falls well above the measured positron fraction around 1 GeV, so that there is currently no satisfactory model which explains all of the data.

**SOLAR MODULATION** Modulation arises due to the flow of the solar wind plasma and trapped magnetic fields outward from the sun (Parker, 1965; Jokipii, 1971). A spherically symmetric model of solar modulation, the “Standard Model”, has been developed (Urch and Gleeson, 1972; Fisk, 1979) which explains the gross features of the modulation process in an equilibrium model which neglects off-diagonal terms in the diffusion tensor, particularly drifts due to the gradient and curvature of the magnetic field, and short time scale variations. The charge sign of a particle charge may affect its modulation by either of two presently known mechanisms: gradient and curvature drift (Jokipii and Levy, 1977) and net magnetic helicity of scattering turbulence (Bieber, Evenson, and Matthaeus, 1987). Both processes are expected will have manifestations in connection with the reversal of solar magnetic polarity at eleven year intervals. For particle drifts and helical scattering, this has the same effect as reversing the charge sign of the particles. Proper comparison requires particles of the same mass but opposite charge, so that the velocity and rigidity are identical. Detailed spectra of $e^+$ and $e^-$ (as a function of level of modulation) combined with simultaneous p and a data will permit the modulation process to be analyzed in detail and the role of particle drifts and/or helical scattering to be determined quantitatively.
SOLAR FLARES Solar flares are an important source of information on the dynamics of the solar atmosphere as well as on the particle acceleration process, which may occur in similar plasma/field environments elsewhere in the galaxy. By correlating observations of solar energetic particles (SEP's) with neutron and gamma-ray measurements, the time dependence of particle acceleration and release can be studied. The large BGO shower counter in POEMS provides a sensitivity to gammas and neutrons comparable to the Solar Maximum Mission (SMM) gamma-ray spectrometer at high energy and about 1/3 the sensitivity of SMM at low energy. POEMS can therefore provide simultaneous charged particle and gamma ray observations over a large portion of a solar cycle.

Flares producing gamma rays tend to be the electron rich. Extending this type of correlation analysis to a larger sample of flares is one of the goals of the POEMS experiment. More interesting, however, is the question of whether such electron rich gamma-ray flares have a detectable positron fraction. Production of neutrons and gammas in these flares shows that SEP's interact in the solar atmosphere. Among the products of such interactions are radioactive nuclei (e.g. $^{11}\text{C}$) which decay by $e^+$ emission (typically producing 0.1-1 MeV positrons). These $e^+$ can be accelerated and emitted into interplanetary space. Low energy positrons (0.1 - 0.5 MeV) may have been seen from the impulsive phase of the 3 June 82 flare (Kirsch, Keppeler and Richter, 1985), but instruments to study higher energy $e^+$ have not been available. If POEMS can detect a significant positron fraction in flares, it would set new constraints on the acceleration time scales, the mixing of material in the "flare regions" and the possible topology of the magnetic field lines.

GEOSPACe STUDIES Data obtained by POEMS can be interpreted to yield valuable information on the Geospace environment. The main POEMS spectrometer will provide a long duration monitor of the geomagnetic trapped electron population at energies above 5 MeV during a wide range of solar conditions, providing information on the time constants for electron enhancements following magnetic storms, as well as resultant energy spectra and pitch angle distributions. POEMS has the unique ability to determine whether there is a significant positron component in the geomagnetic trapped particle population and, if there is, to measure its characteristics over a substantial period of time. Specifically, POEMS will look for evidence that positrons emitted from nuclear reactors are accelerated so as to become a separate belt population. POEMS will also provide a complete, daily, vertical and global map of the input of ionizing radiation into the atmosphere at altitudes below 25 kilometers for use in monitoring hazards to aircraft operation and studies of possible radiation influence on physical and chemical processes in the lower atmosphere.

INSTRUMENT DESIGN SUMMARY Cosmic positrons have eluded precise observation primarily for operational rather than strictly technological reasons. It is in this respect that the EOS mission uniquely provides a perfect opportunity to conduct this investigation. Relatively massive detectors are required to isolate the small fluxes of positrons and electrons from the large flux of cosmic protons and to distinguish the positrons from the electrons. Fundamental physical principles dictate the use of a shower calorimeter and gas Cerenkov detector to separate the electrons and positrons from the protons, and bending in a magnetic field to separate the electrons from the positrons. Approximately half the 125 kg mass of POEMS is devoted to these components. The required mass of the instrument is such that it has been impractical to include such a detector on typical interplanetary spacecraft, however it is of modest size compared to the available EOS polar platform payload. Although this mass is also modest for a balloon payload, atmospheric secondary positrons prevent definitive positron measurements from balloons below approximately 1 GeV.

POEMS, shown schematically in Figure 1, retains four basic design elements of earlier investigations (permanent magnet, trajectory measuring system, gas Cerenkov counter, and shower counter) however each is designed for improved performance. The POEMS magnet is an
POEMS

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Figure 1: Two schematic views of the POEMS sensor. Reference dimensions are given in centimeters, in a coordinate system centered on the permanent magnet.

advanced design using rare-earth materials with virtually no stray field. The trajectory system will be constructed from solid state silicon strip detectors. These detectors will yield excellent position resolution and yet require no consumables. The sealed gas Cerenkov counter will use a non-scintillating gas (ethylene) and photomultipliers which are shielded against accidental triggers using plastic scintillators in anticoincidence. The shower counter will be composed of four layers of Bismuth Germanate (BGO) scintillator, each approximately one radiation length thick. Comparing shower starts in the different layers will allow direct, in flight determinations of the effective interaction cross sections needed to make background corrections.

REFERENCES