ANTIMATTER ON THE MOON; **Thomas L. Wilson. NASA Johnson Space Center, Houston, Texas 77058.**

One of the most puzzling problems in astrophysics and cosmology today is the question of antimatter in the Universe, an issue which is intimately tied to the elemental abundances and how matter originated as the world expanded and cooled from the hot big bang which is believed to have created the Universe. The question is one of symmetry, namely that there should have been a great deal of antimatter created by the big bang - so why do we not see it today? The subject has been addressed by a number of experimental investigations that have established limits on some astrophysically occurring forms of antimatter - a topic which has been reviewed in several places [1-3]. These include antinuclei [4-6], antiprotons $\bar{p}$ [7-10], and positrons e^+ [11-12] in cosmic rays studied primarily from balloon-borne spectrometer experiments on Earth. There is presently a proposal underway for maintaining a long-duration antimatter spectrometer (AMS) in low Earth orbit (LEO) using the Shuttle and International Space Station [13], making the search for antimatter in cosmic radiation a promising subject of current interest.

Compounding the above question of matter/antimatter symmetry in the Universe, which is actually an argument of the baryon-asymmetric versus baryon-symmetric Universe [e.g., 14], is the fact that supersymmetric (SUSY) dark matter candidates for the galactic halo likewise produce antimatter. Unless the SUSY dark matter magically cancels out the antimatter during the evolution of the Universe, there is even yet another universe of missing matter - the SUSY matter or "supermatter" predicted by the grand unified theories (GUT's). A consequence of SUSY GUT's is also the prediction that the $\bar{p}/p$ flux will exhibit a distinctive drop around the neutralino mass, say 10 GeV [15-16]. This has resulted in the proposal that NASA's candidate payload MAX (matter-antimatter experiment) [17] be taken to the Moon and placed in lunar orbit or on the surface as a Lunar MAX (or LMAX) [18-19] to look for this effect. Clearly, MAX-type antimatter experiments are becoming increasingly important in our search for 90% of the Universe which we have never seen.

That the Moon and lunar exploration could have a role in resolving some of this puzzle follows from a very interesting line of reasoning and needs to be discussed further. This is related to the possibility that the Moon might be a better place than the Earth for conducting certain fundamental experiments in physics and astrophysics, which was a central theme of NASA's Stanford Workshop in 1989 [20] where the subject of lunar-based measurements of cosmic ray antimatter was first presented [21-22]. The Moon, which has no appreciable atmosphere and a very low intrinsic magnetic field, has several distinct advantages over LEO for antimatter investigations because it orbits at 60 Earth-radii, placing it outside the Earth's radiation belts, and is usually outside the Earth's magnetosphere. The result is lower background constraints, similar to the argument for proton decay experiments made by Pati and Salam [20].

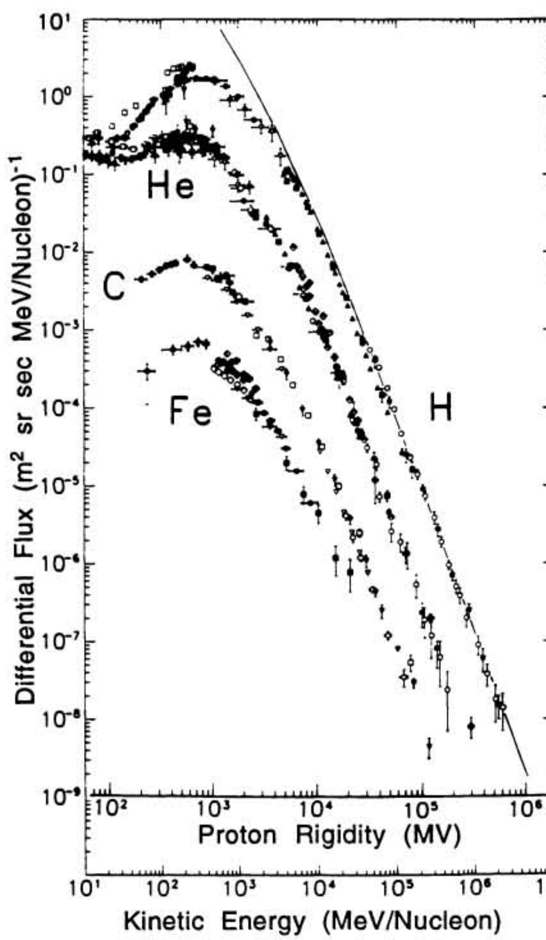
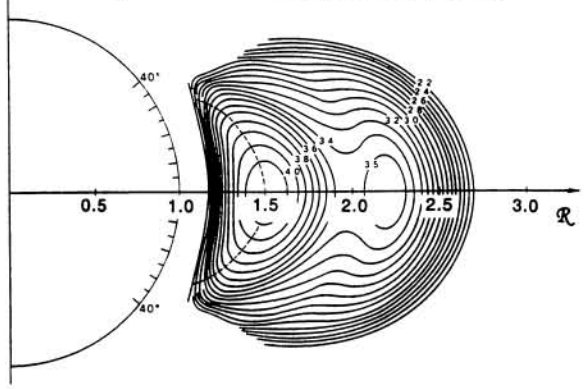


Figure 1

Antimatter on the Moon: Wilson T.L.

Figure 2. Radiation Belts



We will begin an Earth-versus-Moon trade study here by addressing the problem of the Earth's trapped radiation belts and what their absence on the Moon does to the background constraints. The cosmic ray spectrum is shown in Figure 1, modified to show proton rigidity [adapted from 23, 24]. The pertinent quantity is the magnetic shell parameter L introduced by McIlwain [25] for the Earth's magnetic field B, defining the B-L coordinate system used for the inner radiation belts. The (B,L) coordinates can be converted to polar coordinates ($\mathcal{R}$,λ) where $\mathcal{R}$ is an effective radius in Earth-radii and λ is an effective geomagnetic latitude (Fig. 2, illustrating the inner and outer radiation belts) [25]. Beyond L=6 and $\mathcal{R}$=6 (for λ=0), the derivation of L becomes less and less accurate due to external current systems, losing its meaning entirely at $\mathcal{R}$ = 60 near the Moon. The significance of McIlwain's L parameter for background constraints has been reviewed [24,27] and particle cutoff rigidity discussed elsewhere [26,24].

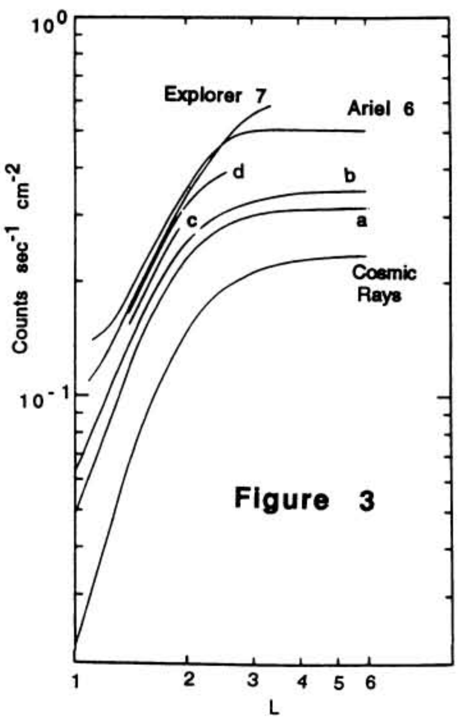


Figure 3

A thorough study of contributions to the raw background rates [27] is shown in Figure 3 detected by Explorer 7 and Ariel 6 for L<6. The cosmic ray (CR) curve follows from Figure 1, taking into account the Earth's magnetic field and the L-dependence is evident in LEO. Curves a-d follow from considering the charged particle (electron) albedo due to CR interactions with the Earth's atmosphere, and are increments to the CR curve itself. Only Curve b includes the effects of photons on the detector walls. Since the Moon has no atmosphere, Curves a, c, and d for electron albedo are not present there, and the detector response converges upon the CR curve incremented only by Curve b. The contributions are all flat for L>6, indicating a disappearance of and independence from McIlwain's magnetic L shell effect.

Thus the Moon is an excellent laboratory for low energy investigations of matter/antimatter in cosmic rays.

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