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DETERMINING THE SOLAR-FLARE PHOTOSPHERIC SCALE HEIGHT
FROM SMM GAMMA-RAY MEASUREMENTS

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We have developed a connected series of Monte Carlo programs to make systematic calculations of the energy, temporal and angular dependences of the gamma-ray line and neutron emission resulting from such accelerated ion interactions. Comparing the results of these calculations with the SMM/GRS measurements of gamma-ray line and neutron fluxes, we have determined the total number and energy spectrum of the flare-accelerated ions trapped on magnetic loops at the Sun (Hua and Lingenfelter 1987a) and constrained the angular distribution, pitch angle scattering and mirroring of the ions on loop fields (Hua and Lingenfelter 1987b; Ramaty, Miller, Hua and Lingenfelter 1988, 1990; Hua, Ramaty and Lingenfelter 1989). Comparing the calculations with measurements of the time dependence of the neutron capture line emission, we have also made a determination of the ^{3}He/H ratio in the photosphere (Hua and Lingenfelter 1987c).

We have now extended the diagnostic capabilities of the SMM/GRS measurements by developing a new technique to directly determine the effective photospheric scale height in solar flares from the neutron capture gamma-ray line measurements, and critically test current atmospheric models in the flare region. Although the photosphere is not a simple exponential atmosphere with a single scale height, an effective scale height can nonetheless be determined at any depth. We show (Lingenfelter and Hua 1991a,b) that a direct measurement of the photospheric scale height in the region of solar flares can be made from existing SMM/GRS measurements of the time-dependent flux of the 2.223 MeV gamma-ray line from neutron capture in photospheric hydrogen and the excess flux at energies just below the line, resulting from Compton scattering of the line photons in the overlying atmosphere. The solar flare 2.223 MeV line flux, observed after the impulsive phase of a flare decreases with a capture time constant that is roughly, inversely proportional to the mean photospheric hydrogen density in the capture region; and the ratio of the flux in the line to that in the Compton scattered excess just below the line is inversely proportional to the mean column depth along the line of sight through the atmosphere above the capture region. Thus, from such a pair of measurements we can determine the mean density and the mean column depth to that density, and from their ratio we can directly determine the scale height above that density. Furthermore, the time constant of the capture line increases gradually with time and the relative intensity

of the Compton scattered excess below the line gradually decreases with time, as the observed capture region moves up to lower densities because the neutrons in the deeper, denser regions are capture more quickly than those above. Therefore such measurements as a function of time can measure the effective scale height over a range of depths within the photosphere, providing even more sensitive tests of the atmospheric models.

The effective scale heights in the upper several hundred kilometers of the photosphere, determined from current models of sunspots, differ from one another by as much as factor of two, ranging from around 50 km to about 100 km in the models of Avrett (1981), Beebe, Baggett and Yun (1982), Lites and Skumanich (1982), and Matlby et al. (1986). And the effective scale height in the surrounding photosphere, assumed in the quiet sun models, is twice that, running about 150 km (Vernazza, Avrett and Loeser 1981, Matlby et al. 1986). Such scale height differences can be easily distinguished by neutron capture gamma-ray line measurements, thus allowing us to test the models to find out which one best describes the photosphere in the flare region. Thus we have calculated the time dependence of both the 2.223 MeV line emission and the Compton scattered excess at energies below the line for various atmospheric models with differing photospheric scale heights, using the Monte Carlo programs that we have previously developed (Hua and Lingenfelter 1987a, Hua, Ramaty and Lingenfelter 1989). These calculations can now be compared (Lingenfelter and Hua 1991b) with the SMM/GRS measurements (e.g. Prince et al. 1982, Vestrand 1990) of the 3 June 1982 and other flares to directly determine the effective atmospheric scale height and critically test the atmospheric models.

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