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Improved Analysis of COMPTEL Solar Neutron Data, with Application to the 15 June 1991 Flare

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Abstract. Direct solar flare neutrons are a valuable diagnostic of high-energy ion acceleration in these events, and COMPTEL improves over all previous cosmic neutron detectors in its capacity for neutron energy measurement. Previous studies of COMPTEL neutron data have worked with an incomplete model of the instrumental response, applying energy-by-energy detection efficiencies. Here we employ statistical regularisation techniques with the full (Monte Carlo simulation derived) response matrix to produce improved estimates of neutron numbers and energy distribution. These techniques are applied to data from the well-observed 15 June 1991 flare. Our improved treatment of the instrumental response results in a reduction of 73% in total neutron numbers, compared with previously deduced values. Implications for the picture of primary ion acceleration in this flare are briefly discussed.

1. Solar Flares And Energetic Neutrons

Fast neutrons are a valuable diagnostic of the solar flare accelerated ion distribution, filling the diagnostic gap between the nuclear de-excitation γ-ray lines which tell us about ions at 10-100 MeV/nucleon, and pion decay continuum around 100 MeV photon energy, which carries information on ions ¿ 300 MeV energy. They were first detected by SMM (Chupp et al., 1986), but with no energy discrimination. COMPTEL could perform neutron imaging and spectroscopy in the energy range 10 - 120 MeV (e.g. McConnell, 1994).

2. COMPTEL Neutron Response: Simulation

Work at University of California, Riverside uses the Los Alamos codes LAHET and MCNP to simulate neutron transport in COMPTEL (O'Neill et al., 1993, 1994). The results of these simulations are summarised in an instrumental neutron response matrix, whose elements represent the probability of a neutron incident on COMPTEL with energy E, at angle θ to the instrument, giving the signal in the instrument appropriate to a neutron of energy E', at angle θ'. In practice, flare neutron numbers do not justify a full deconvolution in (energy, angle) space. Instead the Monte Carlo simulations are carried out assuming a point neutron source at the Sun's position, and a detector response matrix H calculated.

Let x_i = no. of neutrons measured in the ith energy bin, f_j be the no. of neutrons incident on the instrument in the jth energy bin, and ϵ be the vector representing data (Poisson) noise. Then

$$\boldsymbol{x} = \boldsymbol{H}\boldsymbol{f} + \boldsymbol{\epsilon} \quad (1)$$

3. GUIPS and Statistical Regularisation

We aim to find an estimator $\hat{f}$ of f. Due to the presence of non-zero ϵ, one is forced to adopt a statistical regularisation approach, in which both smoothing and deconvolution are carried out (Craig and Brown 1986). Here we use the well-known Maximum Entropy (ME) method, in both global and local variants (Thomson and Craig, 1992), as well as so-called Quadratic regularisation, a more computationally straightforward method which gives simiarl results. Poisson noise levels here are significant, so we must be wary of obtaining results that are partly artifacts of the smoothing method, rather than intrinsic to the source. These methods are implemented using the automated Glasgow University Inverse Problem Software (GUIPS) package (Thomson, 1992, Thomson and Craig, 1992).

4. 15 June 1991 Solar Flare

This X12+ flare has been discussed by several authors, in particular Kocharov et al. (1998). Although it produced detectable neutron emission (Kocharov et al., 1994), Compton Observatory was in orbital darkness during the flare's impulsive phase (which peaked at 0820), but it was still producing γ and neutron emissions when spacecraft night ended some 40 minutes later. Kocharov et al. (1998; also Rank, 1995) analysed COMPTEL neutron data from the period 0859 - 0930, deducing the source neutron energy distribution at the Sun. In the absence of a full deconvolution procedure, they applied energy-by-energy detection efficiencies, given by the diagonal elements of the energy response matrix. This procedure clearly underestimates the overall neutron detection efficiency of the instrument; full deconvolution might also significantly revise the form of the energy distribution.

5. Results

- In spite of the low neutron count rates, the form of the neutron energy distribution is broadly consistent across the various methods, and with previous results.

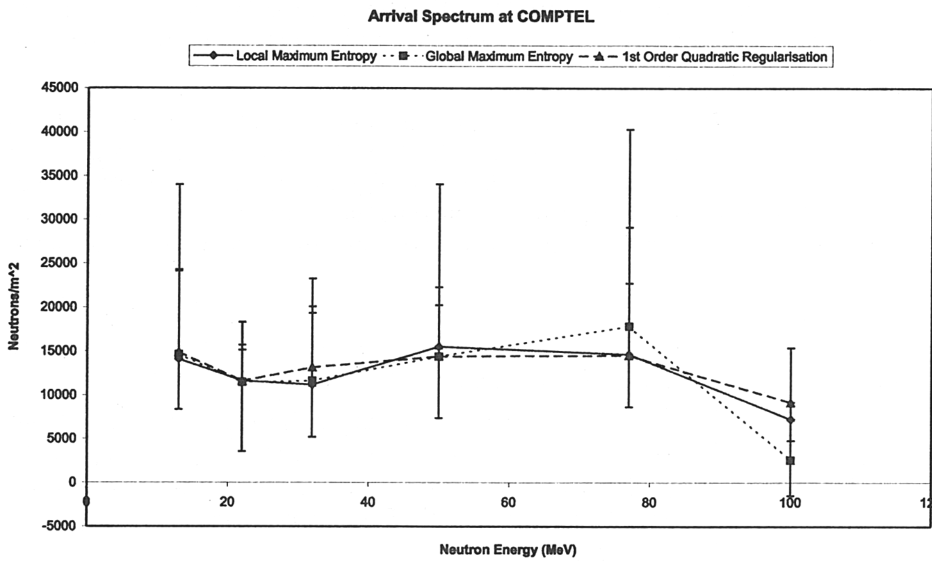

Figure 1. Maximum entropy and quadratic regularised solutions for the energy spectrum of neutrons arriving at the COMPTEL instrument during 15 June 1991 solar flare. Error bars are set at the 66.7% confidence level.

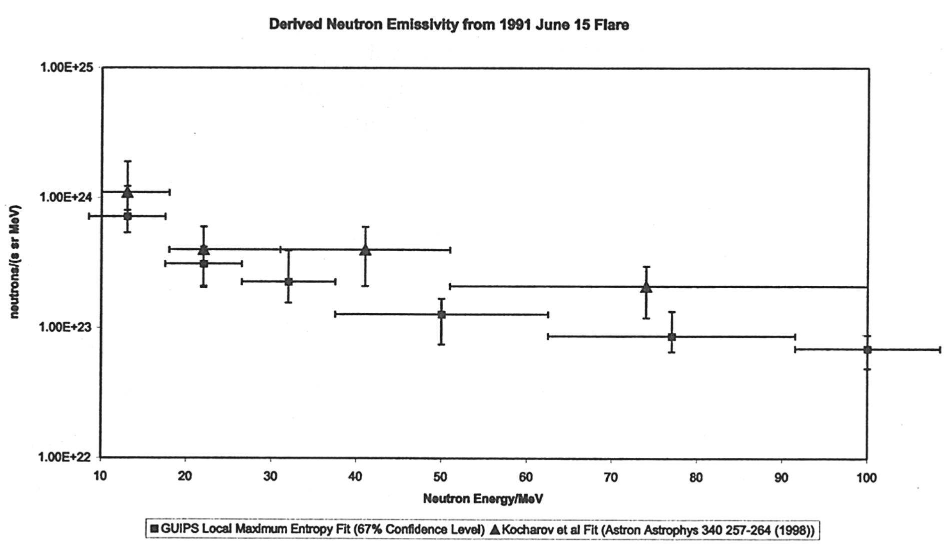

Figure 2. Figure 2. A comparison of a diagonal-elements-only inversion by Kocharov et al (1998) with the full inversion with local maximum entropy smoothing function. Both of these data sets have been converted to source neutron energy distributions at the Sun (after Kocharov et al., 1998).

- In particular, the dip at about 20 MeV, interprable in terms of lower energy neutrons still arriving from the impulsive phase, appear robust - although error bars are large

- Total neutron numbers are revised by this more complete treatment, however, to 73% of the result of Kocharov et al. There was already a problem that the protons needed to explain the high-energy γ continuum should have produced a larger number of neutrons than observed. Our fuller treatment of the instrument response significantly strengthens this conclusion.

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