A Compact Solar Hard X-ray Polarimeter

E. Caroli1, Wei Fei2, R. M. Curado da Silva3,4, O. Limousin5, N. Auricchio1, J. M. Maia3,4, J. B. Stephen1, Nicolas Produt1, Adriana García4, Paulo Ribeiro4, João Fernandes4, Ricardo Patrício9

1IASF - Sezione di Bologna, CNR, Bologna, Italy
2National Space Science Center, CAS, Beijing, China
3Laboratório de Instrumentação e Física Experimental de Partículas, Departamento de Física da Universidade de Coimbra, Portugal
4Center for Space Radiations, Université Catholique de Louvain, Belgium
5CEA/DSM/Irfu/Service d’Astrophysique, F91191, Gif-sur-Yvette, France
6Universidade da Beira Interior, Covilhã, Portugal
7ISDC, University of Geneva, Switzerland
8Observatório Geofísico e Astronômico da Universidade de Coimbra, Portugal
9Active Space Technologies, 3025-307 Coimbra, Portugal

ABSTRACT: The universe has been studied in the hard X-ray domain almost exclusively through spectral and timing variability analysis as well as through imaging techniques. By measuring the polarization angle and the polarization degree of source emissions, the number of observational parameters is increased by two, allowing better discrimination between different models. Herein we propose a compact CdTe based hard X-ray polarimeter with spectroscopic capabilities optimized for solar physics. Measuring the continuum emission polarization will allow establishing important constraints on the emission models. For example, the beaming level of charged particles which produce the Bremsstrahlung radiation could be inferred by polarization measurements. Furthermore, pion decay models are not likely to be compatible with a high degree of polarization measured. Therefore, solar polarity and the new window to interpret solar flare dynamics.

Solar X-ray Polarimetry

Herein we propose a compact CdTe based hard X-ray polarimeter with spectroscopic capabilities optimized for solar physics, merging the solar physics expertise of Chinese partners with the high energy instrumentation experience of European partners for a common goal. Measuring the continuum emission polarization will allow establishing important constraints on the emission models. For example, the beaming level of charged particles which produce the Bremsstrahlung radiation could be probed by polarization. Furthermore, pion decay models are not likely to be compatible with a high degree of polarization measured. A typical solar flare emission lifetime may vary from 20 minutes up to 3 hours. The expected polarization level of the whole solar flare loop stands between 10% and 25%.

Compton Polarimetry Definitions

The Klein-Nishina cross-section for linearly polarized photons gives us an azimuthal dependency for the polarization factors.

\[
\frac{d\sigma}{d\Omega} = \frac{e^2}{2} \frac{(E')^2}{E} \left[ \frac{E}{E'} - 2\sin^2 \theta \cos^2 \phi \right]
\]

where \(r_s\) is the classical electron radius, \(E\) and \(E'\) are the energies of the incoming and outgoing photons respectively, \(\phi\) is the angle between the scattering plane (defined by the incoming and outgoing photon directions) and incident polarization plane (defined by the polarization vector and the direction of the incoming photon).

Monte Carlo and Experimental analysis

Here we obtain \(Q\) through the orthogonal directions \(x\) and \(y\)-axis directions defined over the detector plane, to a polarized beam whose electric vector points in the \(y\) direction. \(N_i\) and \(N_e\) are the number of counts in each of the orthogonal directions.

Estimated Polarimetric Performances

The MDP (minimum detectable polarization) of a space polarimeter in a background free environment with an 8% significance can be expressed by \([53]\):

\[
\text{MDP}(100\%) = \frac{4.29}{A - \phi - \Theta} \left( \frac{1}{\phi} \right)
\]

where \(Q_{\text{min}}\) is the modulation factor for a 100% polarized source, \(\phi\) the double event detection efficiency, \(A\) the polarization detection area in cm², \(\phi\) the source flux (photons/cm²/s), \(R\) is the background flux (count/s) and \(\Theta\) the observation time in seconds.

Conclusion

By both Monte Carlo simulation and prototype experimental testing we showed that a modulation \(Q_{\text{min}}\) factor of about 0.5 is obtained for an instrument configuration similar to the solar CdTe polarimeter herein presented. For a typical solar flare emission whose lifetime may vary from -20 minutes up to -3 hours, minimum detectable polarization of about 25% and \(\leq\,\phi\), respectively, for the same observation times. Therefore, this instrument will potentially allow the measurement of 10 to 25% polarization level estimated for a typical solar flare loop and the breakthrough of new developments in solar physics.