A Compact Solar Hard X-ray Polarimeter

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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. In order to address the scheduled Chinese Academy of Sciences-ESA 2015 joint call, we propose a compact CdTe based hard X-ray polarimeter with spectro-imaging 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 polarimetry in the 100 keV to 1 MeV energy range might be an exceptional breakthrough for solar physics, opening a new window to interpret solar flare dynamics.

Solar X-ray Polarimetry

Herein we propose a compact CdTe based hard X-ray polarimeter with spectro-imaging 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%.

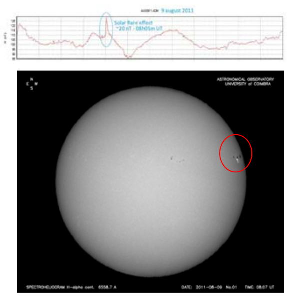


Fig. 1 – August 9th 2011 solar flare: up, earth magnetic field signature; down, Hα sun spectroheliogram (solar flare indicated in red). Source: Geophysical and Astronomical Observatory, University of Coimbra Portugal.

Compton Polarimetry Definitions

The Klein-Nishina cross-section for linearly polarised photons gives us an azimuthal dependency for the scattered photons:

$$\frac{d\sigma}{d\Omega}=\frac{r_0^2}{2}\left(\frac{E'}{E}\right)^2\left[\frac{E'}{E}+\frac{E}{E'}-2\sin^2\theta\cos^2\varphi\right]$$

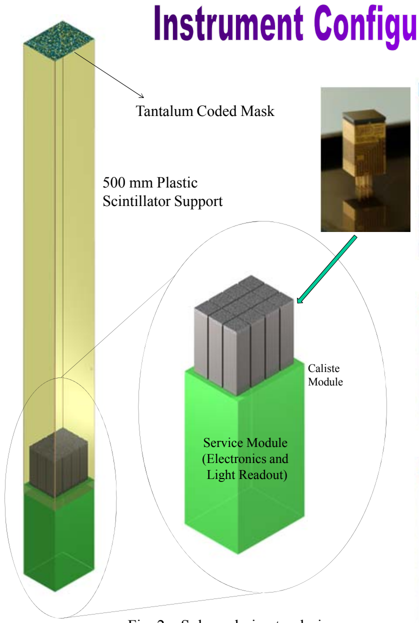
where r_0 is the classical electron radius, E and E' are the energies of the incoming and outgoing photons respectively, θ the angle of the scattered photon and φ is the angle between the scattering plane (defined by the incoming and outgoing photon directions) and incident polarization plane (defined by the polarization vector and the direction of the incoming photon).

The polarimetric performances of an instrument can be evaluated by analysing the double events distribution through the polarimetric modulation factor, Q:

$$Q=\frac{N_x-N_y}{N_y+N_x}$$

Here we obtain Q through the orthogonal directions x- and y-axis directions defined over the detector plane, to a polarised beam whose electric vector points in the y direction. N_x and N_y are the number of counts in each of the orthogonal directions.

Instrument Configuration



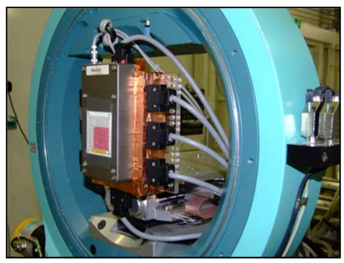
Item	Values
Mask material	Tantalum (16.6 g/cm³, Z=73)
Mask thickness	0.1 mm
Mask element size	1.8x1.8 mm²
Mask size	50x60 mm²
Mask pattern	Optimized random (50% open)
PSD material	CZT (6.0 g/cm³)
PSD pixel pitch	0.6x0.6 mm²
PSD thickness	2 mm
PSD mosaic	3x4 Caliste Modules (10x10 mm²)
PSD sensitive area	30x40 mm² = 1200 mm²
PSD channels/pixels	12x256=3072

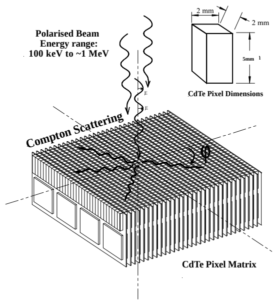
Characteristics	Values
Fully Coded Field Of View (FCFOV)	2° x 2°
Angular resolution	12′
Point source location accuracy (PSLA)	4′/SNR
Operational range	5-400 keV
Imaging energy range	5-50 keV
Polarimetric energy range	150-400 keV
PSD efficiency	~33 % at 200 keV
PSD spectroscopic performance	1% at 60 keV

Resources	Values
Mask-PSD separation	500 mm
Payload Volume	50(L)x60(W)x600(H) mm³
Mask and support Weight	500 g
PSD Weight	200 g
Active Shield (plastic) Weight	1300 g
Active Shield readout Weight	1000 g
Structure Weight	1500 g
DPE Weight	1000 g
PSD AFEE Power	4 Watt
DPE+Active shield Electronics	10 Watt

Fig. 2 – Solar polarimeter design

Monte Carlo and Experimental analysis





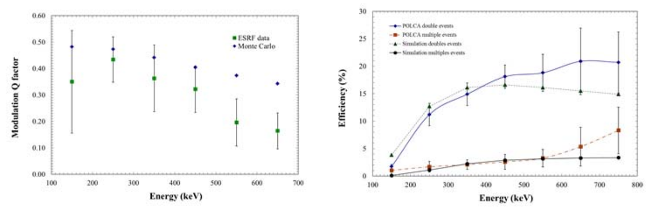


Fig. 3 – Modulation Q factor and double event efficiency obtained by Monte Carlo and ESRF experimental analysis

Estimated Polarimetric Performances

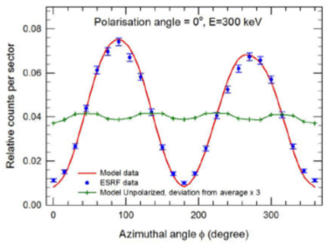


Fig. 4- Modulation of scattered photons distribution for a 300 keV incident beam with a 98 % linear polarization at an angle of 0°, for CdTe Caliste-256. A simulated modulation curve is superimposed to the data. The curve in green is the result of a simulation for a non-polarized irradiation: the fluctuations (with respect to average) are multiplied by 3

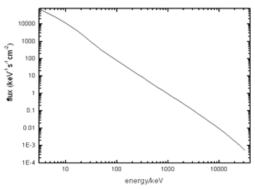


Fig. 5 - Solar flare expected flux emitted by charged particles acceleration.

The **MDP (minimum detectable polarization)** of a space polarimeter in a background noise environment with 3σ *significance can be expressed by [35]:*

$$MDP(100\%)=\frac{4.29}{A\cdot\varepsilon\cdot S_F\cdot Q_{100}}\sqrt{\frac{A\cdot\varepsilon\cdot S_F+B}{T}}$$

where Q_{100} is the modulation factor for a 100 % polarized source, ε the double event detection efficiency, A the polarimeter detection area in cm², S_f the source flux (photons.s⁻¹.cm⁻²), B is the background flux (counts/s) and T the observation time in seconds.

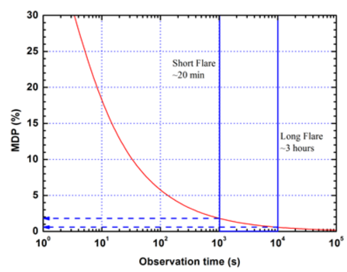


Fig. 6- Estimated minimum detectable polarization (3σ) for a typical solar flare loop in the 100 keV to 1 MeV region.

Conclusion

By both Monte Carlo simulation and prototype experimental testing we showed that a modulation Q_{100} 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 2% and < 1%, 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.