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A COSMIC and SOLAR X-RAY and GAMMA-RAY INSTRUMENT for a SCOUT LAUNCH

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Abstract

We present an overview for a set of simple and robust X-Ray and Gamma-Ray instruments which have both cosmic and solar objectives. The primary solar scientific objective is the study of the beaming of energetic electrons and ions in solar flares. The instrument will measure spectra and polarization of flare emissions up to 10 MeV. At X-Ray energies both the directly emitted flux and the reflected albedo flux will be measured with a complement of six X-Ray sensors. Each of these detectors will have a different high Z filter selected to optimize both the energy resolution and high rate capabilities in the energy band 10-300 keV. At energies >100 keV seven 7.6x7.6 cm NaI and a set of 30 concentric plastic scattering detectors will record the spectra and polarization of electron bremsstrahlung and nuclear gamma-rays. All of the components of the instrument are in existence and have passed flight tests for earlier space missions. The instrument will use a spinning solar orientated Scout spacecraft. The NaI detectors will act as a self-modulating gamma-ray detector for cosmic sources in a broad angular band which lies at 90° to the sun-earth vector and hence will scan the entire sky in 6 months.

Solar Objectives

There is growing evidence that particle streams, both electrons and ions, exist in solar flares. Vestrand et al. (1987) showed that solar flares detected on GRS/SMM at energies >300 keV had a strong excess near the solar limb. The spectral shape of the electron bremsstrahlung in these flares also had a clear dependence on the flare position. More recently Bai (1988) used both HXRBS and GRS data to show that the brightness ratio of X-rays at >300 keV to 25 keV was more than 10 time larger for limb flares as compared to disk center flares. This anisotropic X-ray emission can only be explained by electron beams (Dermer and Ramaty, 1986). One of the objectives of the MAX'91 program should be observations which can quantify particle beams in solar flares (Dennis et al., 1988).

Observable Predictions of Particle Beams

Electron Bremsstrahlung Emission

<u>Albedo X-ray Component</u>
Early statistical tests of the positional brightness of solar flares at energies near 25 keV failed to detect evidence for electron beams (Datlowe et al., 1977). One of the reasons for this is due to the fact the reflected or albedo x-rays from the photosphere almost exactly compensates for the changing brightness of the directly emitted x-ray emission (Bai and

Ramaty, 1978; Langer and Petrosian, 1977, Vestrand et al., 1987). It is important to note, however, that the spectral shape of these two components are quite different in the energy band 10 - 150 keV (Santangelo et al.,1973). Instrumentation which can spectroscopically separate these two components will be sensitive to electron beaming.

Polarization
Numerous calculations have shown that x-rays produced by electron beams will be polarized (Bai and Ramaty, 1978; Langer and Petrosian, 1977; Emslie and Brown, 1980). The current experimental status and prospects for polarization measurements of solar flares at energies up to 150 keV have been recently reviewed (Chanan et Al., 1988). This study points out the desirability of extending the measurements to much higher energies. Earlier polarimeters were only designed to cover the energy band up to 150 keV.

Nuclear Line Emission

Doppler Shifts and Line Shapes
The measurement of the Doppler energy shift of gamma-ray lines is a historical way of measuring ion beams. The application of this technique to solar flares has been reviewed (Ramaty and Crannel, 1976). More recently Werntz and Lang (1988) have extended this type of observation to show that line structure and line splitting from nuclear de-excitation of ^{12}C and ^{16}O can also be used to determine ion beaming.

Polarization of Nuclear Lines
Sawa (1987) recently pointed out that nuclear line emission is also polarized if it is produced by ion beams. He showed that the degree of polarization for the ^{12}C and ^{16}O lines can be much larger than 50%. He also pointed out that unlike Doppler Shift measurements, polarization observations can reveal the full particle geometry rather than just the line-of-sight component.

The above shows that polarization observations, particularly if made in conjunction with other observations, has the potential of addressing beaming of both electrons and ions.

INSTRUMENT

This Scout Gamma-Ray Instrument is based on a design first presented by Morfill and Pieper (1973). They showed that a self-modulateing or "active anti-collimator" detection system, based on a rotating detector array, can have a 20-50 times higher sensitivity per unit mass that a conventional well-shaped detector-shield system at energies greater than a few hundred keV.

Their basic design has been modified by the addition of plastic scintillator scattering detectors. This gives the instrument good polarization sensitivities for solar emission without compromising its self-modulateing cosmic capabilities. The NaI portion of the instrument will operate as a gamma-ray spectrometer with the same basic spectral capabilities as the GRS on SMM.

Six NaI X-ray detectors, each with a different high-Z filter, will provide good energy resolution and high rate capabilities in the solar X-ray albedo energy band.

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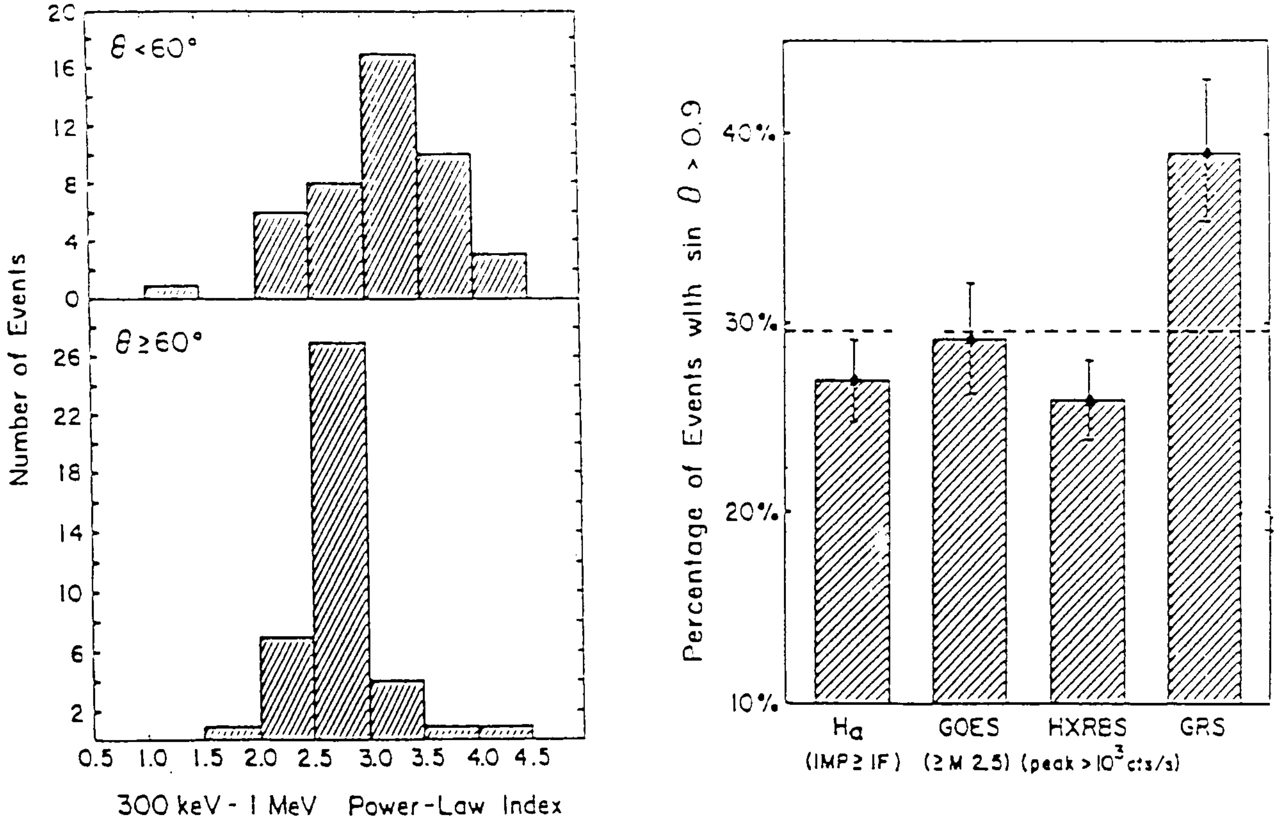
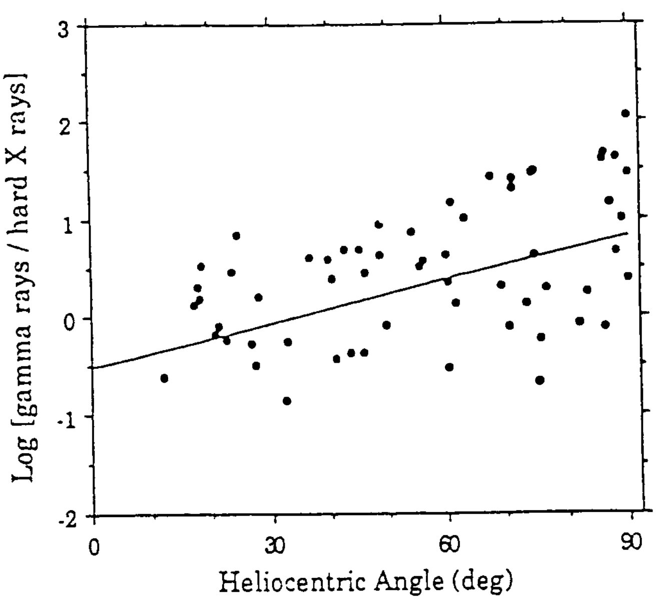
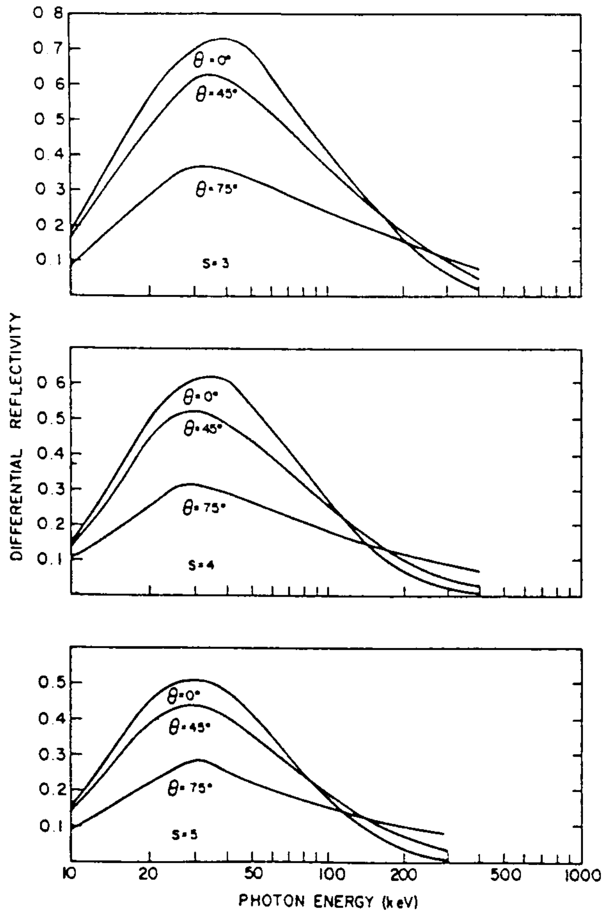


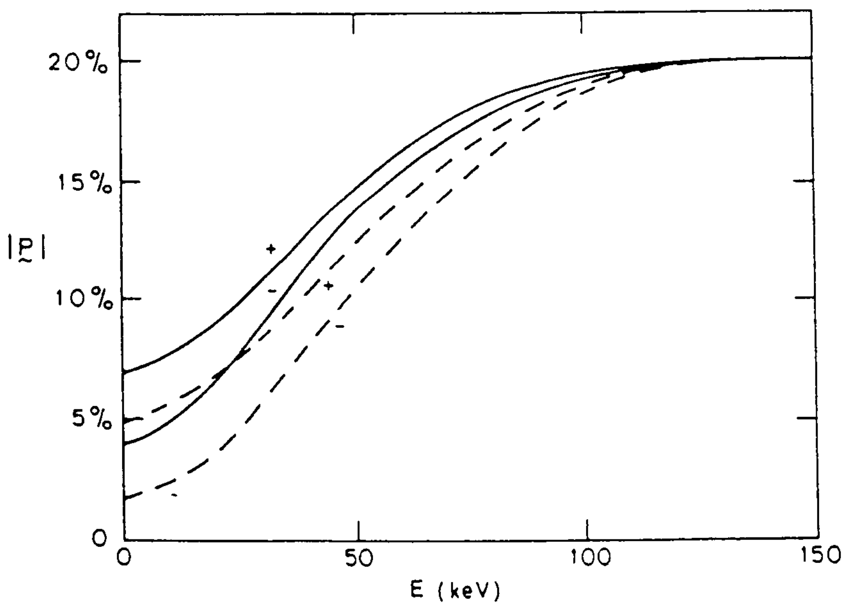
Display 1. These two figures show a) the distribution of the fitted power law index within the energy band 0.3-1.0 MeV for flares with heliocentric angles <60° and > 60°; and b) the fraction of detected events >300 keV near the solar limb as compared to three other flare emissions which are expected to be isotropic (Vestrand et al.,1987).



Display 2. The distribution of SMM flares showing the relative gamma-ray to x-ray brightness as a function of the flare heliocentric angle (Bai, 1988).



Display 3. The calculated X-ray albedo from solar flares given as a fraction of the "direct" X-ray emission for three different "direct" emission power laws and three different flare positions. These calculations assume the "direct" emission is isotropic (Bai and Ramaty, 1978).



Display 4. A model dependent calculation of the polarization fraction as a function of energy. Some of the decrease at low energies is caused by thermal emission and some by the unpolarized albedo flux (Emslie and Brown, 1980).

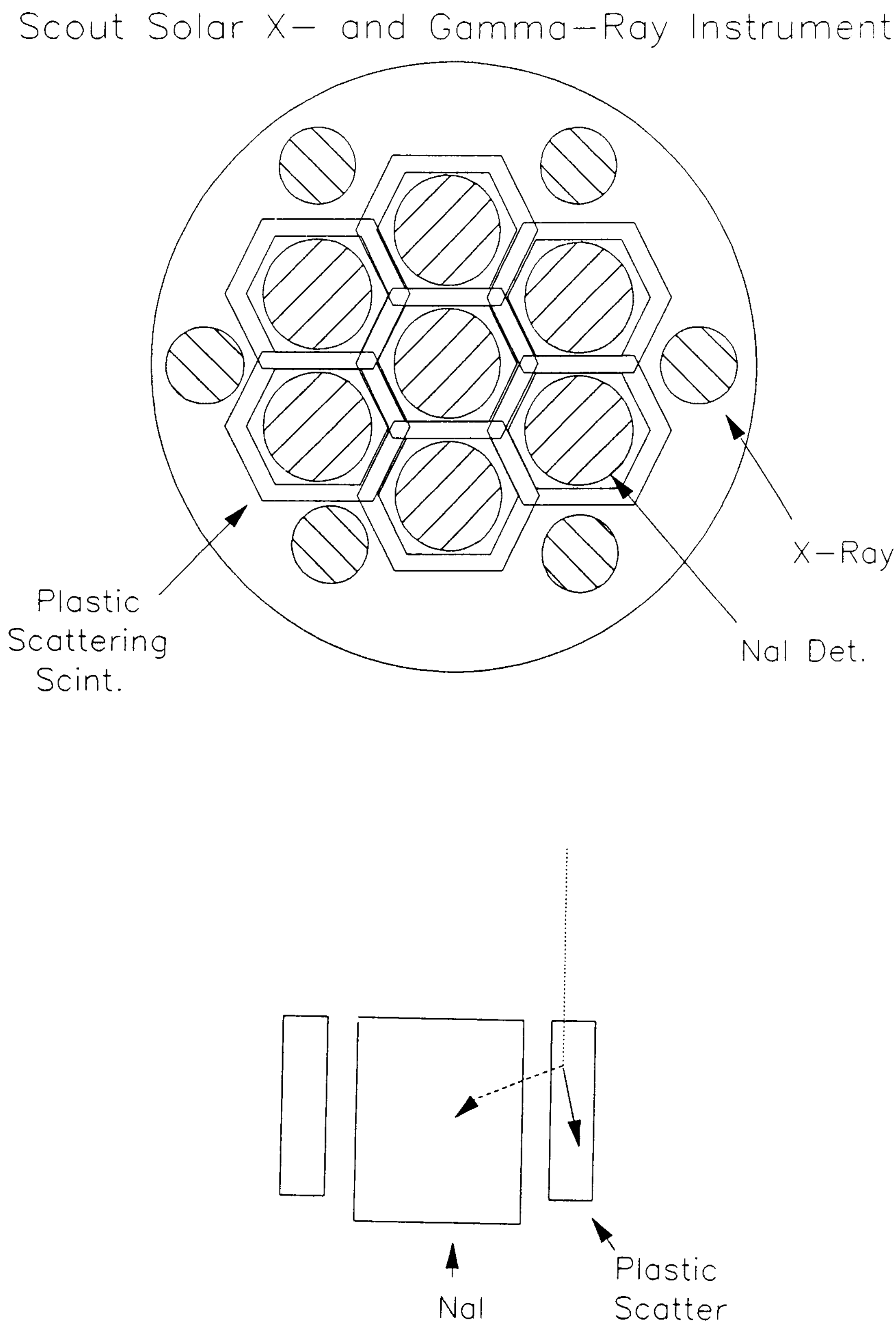
TABLE I

Projected linear polarization amplitudes $P(\theta)$ of 4.43 MeV $^{12}C^*$ and 6.13 MeV $^{16}O^*$ gamma-rays assuming gaussian substates distributions $P(j, m)$ of width σ

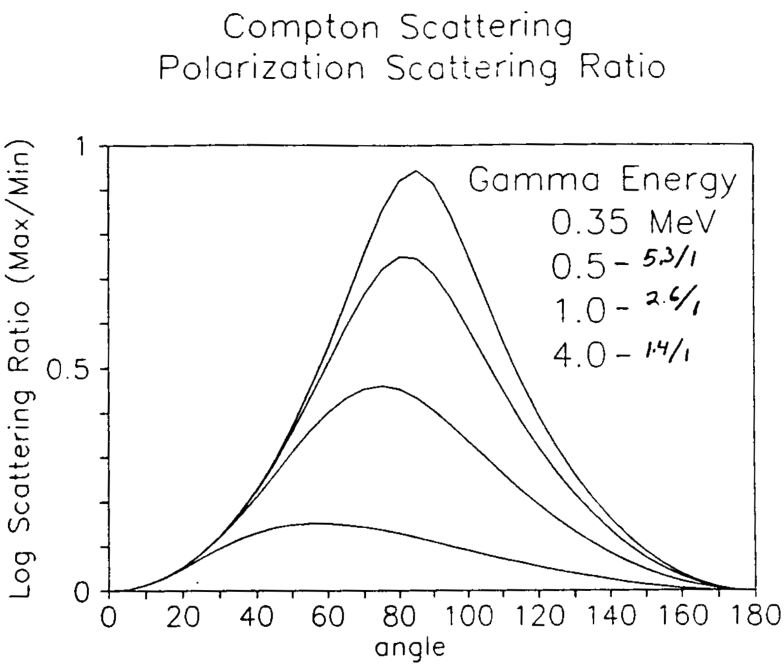
θ (°)	4.43 MeV $^{12}C^*$		6.13 MeV $^{16}O^*$	
	$\sigma = 0.95$	$\sigma = 1.5$	$\sigma = 1.0$	$\sigma = 1.5$
0	0	0	0	0
10	0.06	0.02	0.07	0.03
20	0.11	0.07	0.20	0.09
30	0.21	0.14	0.36	0.17
40	0.32	0.22	0.52	0.27
50	0.43	0.31	0.65	0.37
60	0.53	0.39	0.75	0.46
70	0.62	0.45	0.81	0.51
80	0.69	0.50	0.82	0.53
90	0.72	0.52	0.82	0.54

Display 5. A Table of calculated nuclear polarization amplitudes from flare emissions of ^{12}C and 16O (Sawa, 1987).

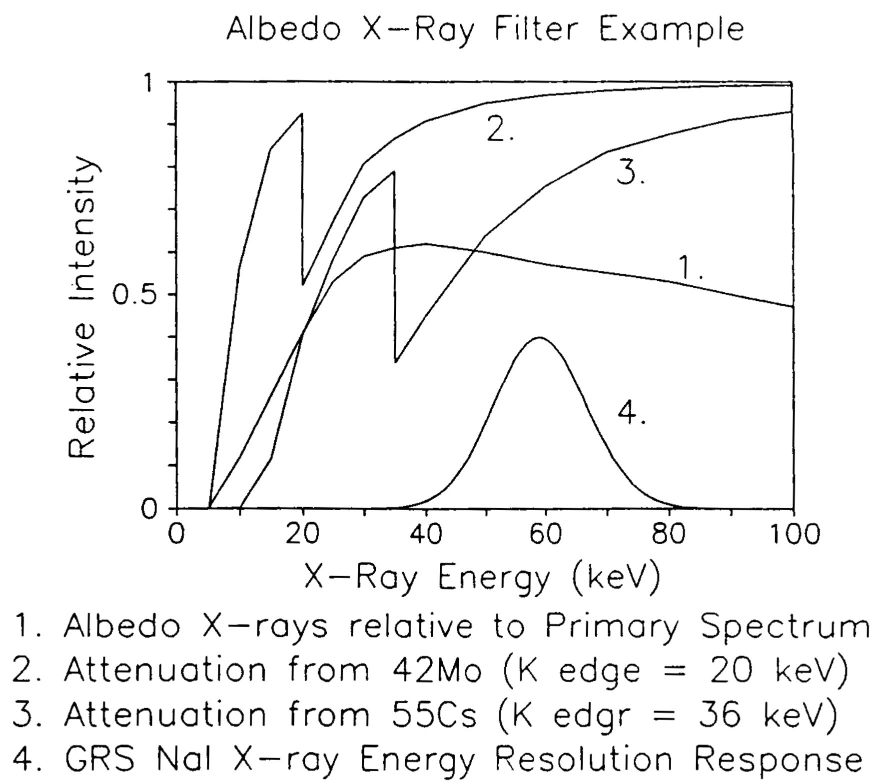
E



Display 6. A top view of the detector array showing the NaI detectors, the 30 plastic scattering detectors and the 6 x-ray detectors. The lower panel shows the scattering geometry between the plastic and NaI detectors for the polarization measurements.



Display 7. A plot of the intrinsic maximum to minimum Compton cross-section polarization scattering ration for 4 energies between 0.35 to 4.0 MeV as a function of the scattering angle (Evans, 1955).



Display 8. This composite figure shows the energy dependent attenuation of two different filter elements. It also shows the characteristic albedo spectrum and a Gaussian peak representing a NaI x-ray detector resolution. High spectral resolution flux measurements are obtained by making spectral observations of the same flare with six different detectors, each having a different energy response because of the different filters.