Design and feasibility study of hard X-ray scattering polarimeter for small satellites

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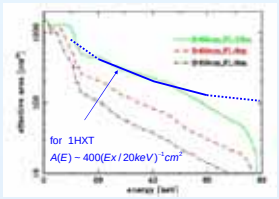
Hard X-ray Polarimetry

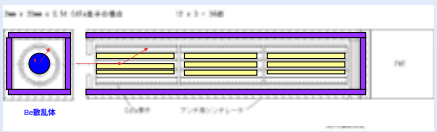
We have studied design and feasibility of hard X-ray polarimeters for small satellite experiments. We first started the study for the next generation Japanese X-ray satellite, NeXT, which will employ super-mirrors, which collect X-rays from 10-80keV (see the right panel). Hard X-ray polarimetry is not only un-exploited field, but also we expect larger polarization degree due to non-thermal nature of the emission.

Although the focal-plane polarimeter is not included in the current design of NeXT, we are now considering possibility of a small satellite for hard X-ray polarimetry.

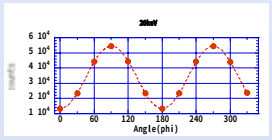


Scattering Polarimeter (non-imaging)

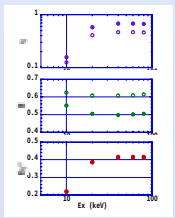
The sensitivity of a polarimeter is scaled with $\mathbf{M}\eta^{1/2}$,where M is the modulation against 100% polarized X-ray incidence, and h is the detection efficiency. We easily get $\mathbf{M}\eta^{1/2}$=0.4 with scattering polarimeters, while photo-electron tracking polarimeter achieve 0.07 according to simulation. Therefore, we first consider a scattering polarimeter with Be target as shown below. We can make the design compact, if it is placed on the focal plane of hard X-ray mirror.



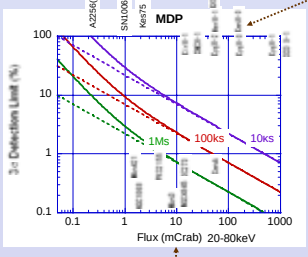
Be is 4mm diameter and 60mm length, surrounded by 12x3set=36 CdTe detectors of rectangular (2mmx20mm) shape.



(Left)We determine the polarization direction and degree by counting rates of each 30deg.
(Right) M,η,$M\eta^{1/2}$derived from simulation



Clusters and SNRs are very important, but dim in hard X-rays, except for the Crab. Need 1Ms to get a few% polarization.

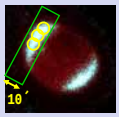


10ks observations of bright BH,NS binaries will detect polarization degree of 2%. 100ks is enough for fainter ones.

100ks observations of bright AGN detect severl % polarization.

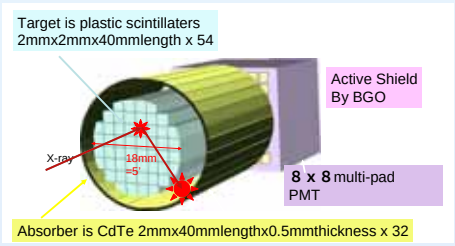
Minimum Detectable Polarization degree expected for Be scattering polarimters on the focal plane of 4 telescopes of NeXT. MDP is defined for 3 σ detection.

However,this type of scattering polarimeters need multi-pointings to cover extended sources.

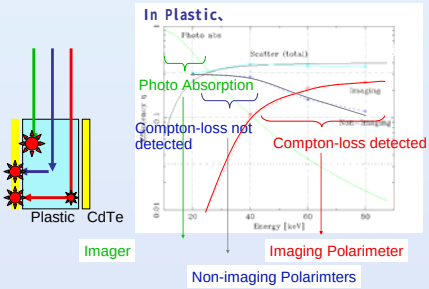


Scattering Polarimeter (Imaging)

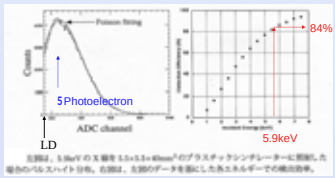
Be scattering polarimeter with a single target is not capable of imaging. On the contrary, using number of plastic scintillaters as target, Compton-loss is detected, which makes imaging type polarimter (Gunji et al., 2003).



If scattering is occurred in plastic scintillaer, Compton-loss signal is detected position sensitive PMT. Scattered photons are detected with CdTe.



Detection efficiency η of three kinds of events. The function of the detector/polarimter depends on incident X-ray energy.



Experiment: Lower limit of the signal detected with plastic scintillater and PMT.Compton-loss of Eo<40keV X-ray incidence is difficult to be detected at present.

Incident X-ray energy(E_0)and Compton-loss (ΔE_{90})

E_0	ΔE_{90}
30	1.7
40	2.9
60	6.3
80	10.8

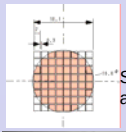
Summary of simulation for the imaging type polarimter. We assume the focal plane of 4 NeXT telescope is available as for the left non-imaging type case. 3 σ MDP is for 100ks,10mCrab source. Above 20keV, MDP is almost the same as for Be non-imaging type polarimeter, though energy threshold is higher than that. The polarimter functions as imaging type only above 40keV. If a new type of PMT (prizm photo-electron surface) is available, huge improvement is expected.

	η	M	$M\eta^{1/2}$	E(keV)	3 σ MDP
Point Source	0.4	0.55	0.35	20-80	2.7%
Diffuse Source over FOV					
as non-imaging type	0.4	0.28	0.18	20-80	5.3%
as imaging type	0.2	0.55	0.25	40-80	15.9%
with Prizm PMT (expected)	0.2	0.55	0.25	20-80	3.8%

Current Status and Plan

A proto-type detector of imaging type scattering polarimter was already used in a balloon experiment on Septetember 2003. In addition, we are doing r&d to reduce detection limit of Compton-loss signal on the ground.

Balloon Experiment Module 2003/Sep



Plastic Scintillater assembled

Rectangular CdTe

Either type of the focal plane polarimeter presented here is not included in the current design of the NeXT satellite. Even when the collective mirror is not available, we think the imaging type scattering polarimter is useful with collimator.

If we use scintillater detectors instead of CdTe, as we did for proto-type, effective area of 20cm^2 is attainable. 10 of such unit on a small satellite will provide about 1/10 area of the case we considered for NeXT. However even with 200cm^2 , with 100ks observations of binary sources will yield MPD of 2%. Tens of targets is expected for such a hard-xray polarimetry satellite. The polarization detected in hard X-rays must be very much different from that in soft X-rays, reflecting the non-thermal nature of hard X-rays.