Modeling and Development of Soft Gamma-Ray Channeling

SPIE. ASTRONOMICAL TELESCOPES + INSTRUMENTATION

Farzane Shirazi, Peter F. Bloser, James E. Krzanowski, Jason S. Legere, and Mark L. McConnell
University of New Hampshire, Durham, NH 03824, USA

University of New Hampshire

Abstract

We have investigated the use of multilayer thin film structures for channeling and concentrating soft gamma rays with energies greater than 100 keV. Here we briefly describe the properties of W/Si multilayers produced by Magnetron Sputtering technique with the required thicknesses and smoothness. We also have developed a flexible set of computer modeling tools to compute the optical properties of multilayer structures, predict the channeling efficiency for a given lens configuration and aid in the optimization of potential concentrator-based telescope designs. This technology offers the potential for soft gamma-ray telescopes with focal lengths of less than 10 m, removing the need for formation flying spacecraft and providing greatly increased sensitivity for modest cost and complexity and opening the field up to balloon-borne instruments.

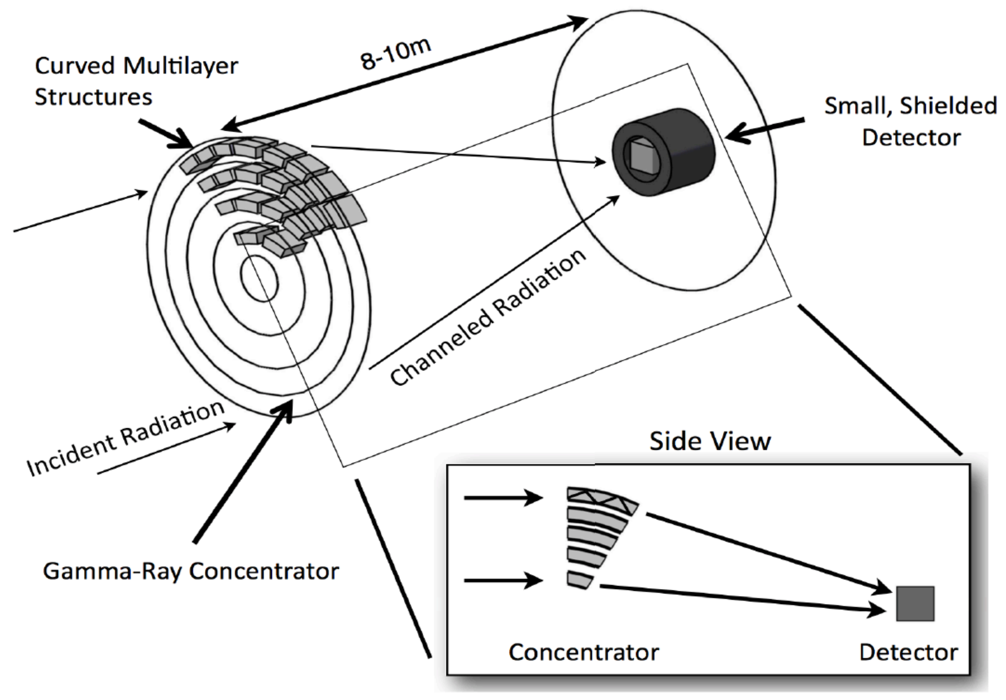
W/Si Multilayer Coating

We have grown prototype W/Si multilayers to determine appropriate parameters for minimizing roughness/stress and increasing the deposition rate. The coating processes have been done in the UNH Material Science Program's magnetron sputter facility, using AJA, International, Inc. system as explained in detail in Shirazi, F. et al [2017].

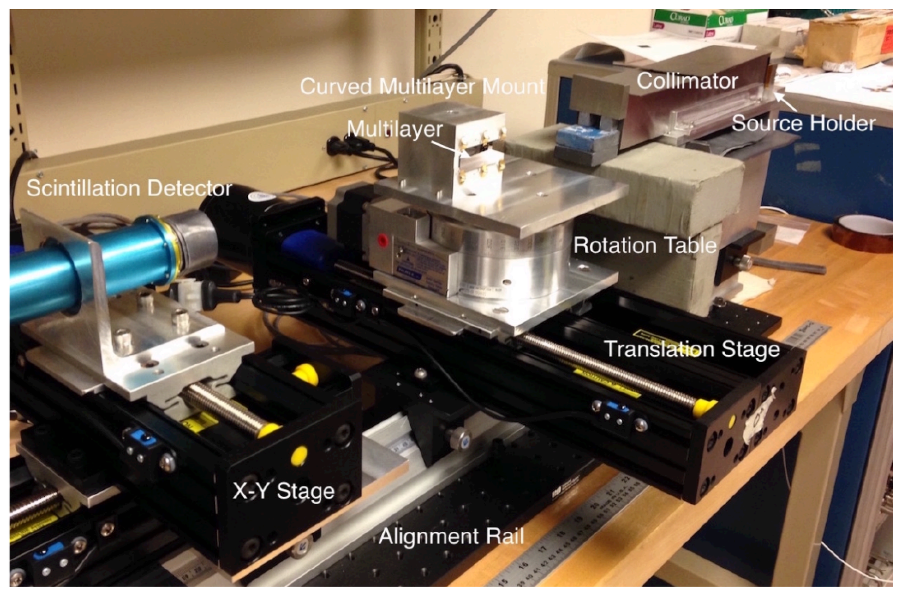
Number of bilayers	N = 30
Si average thickness	t_{si} = 150 nm
W average thickness	t_W = 30 nm
Total thickness	t_{tot} = 5.4 μm
Si average deposition rate	DR_{Si} = 0.113 nm/s (22 min)
W average deposition rate	DR_{Ir} = 0.062 nm/s (8 min)
Average roughness (at 1 μm)	R_a = 1.86 nm , R_q = 1.92 nm

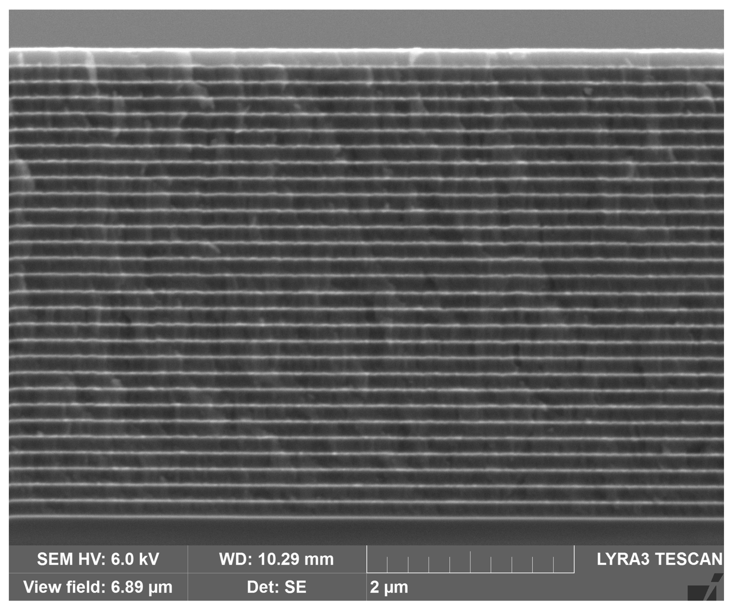
Gamma-Ray Concentrator

A suitable arrangement of bent multilayer structures of alternating low and high-density materials will channel soft gamma-ray photons via total external reflection and then concentrate the incident radiation to a point [Bloser, P. et al, 2015].

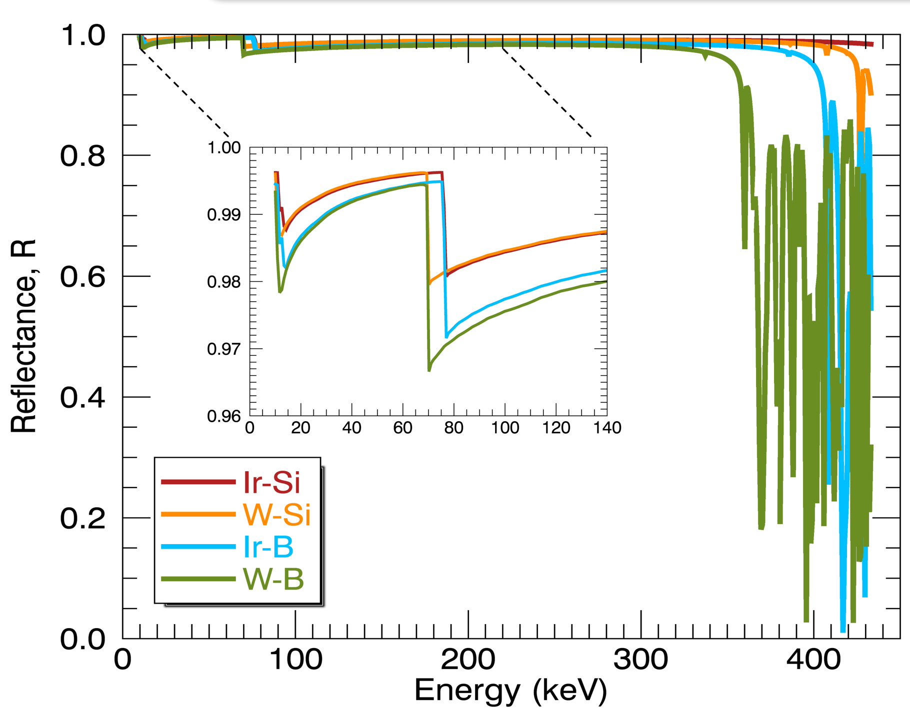


We have constructed a precision test setup to demonstrate the channeling of 122 keV gamma-ray photons from a ^{57}Co source over a bending angle of 1°-2° using the produced multilayer structures [Bloser, P. et al, 2016].

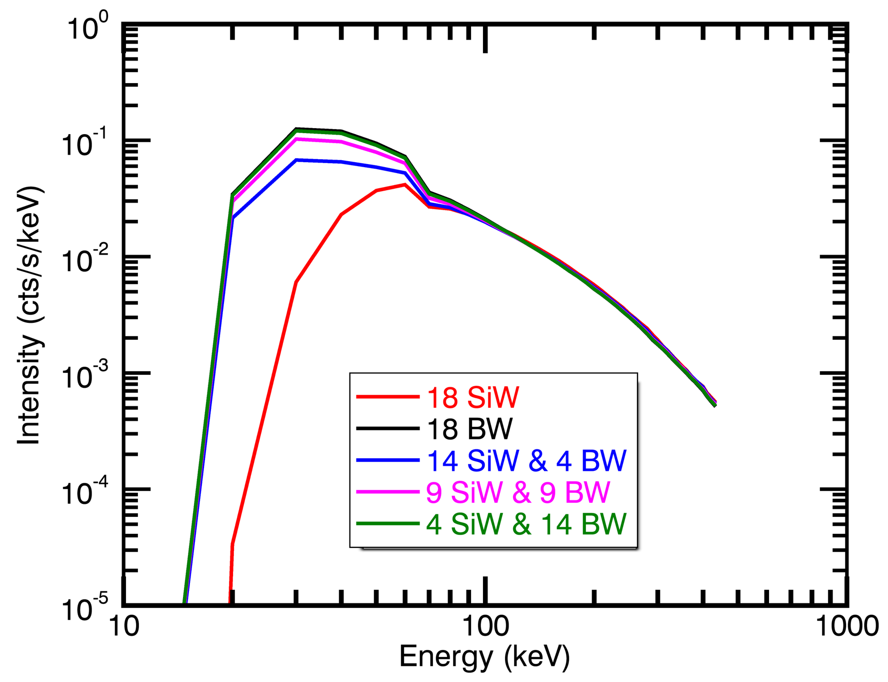




Optical Properties & Lens Geometry



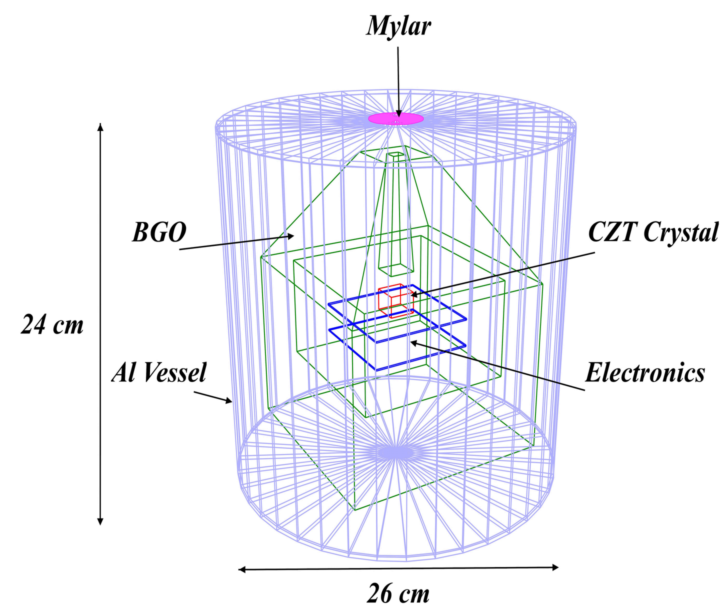
We have studied the gamma-ray's behavior in contact with a reflecting surface by IMD calculation of multilayer optical properties. Here is calculated reflectance for some common material combinations at 0.01 deg incident angle. Coating materials are chosen to achieve maximum reflectivity with a large difference in the atomic number/mass density, not having absorption edges in the energy range of interest and having low interaction probability.

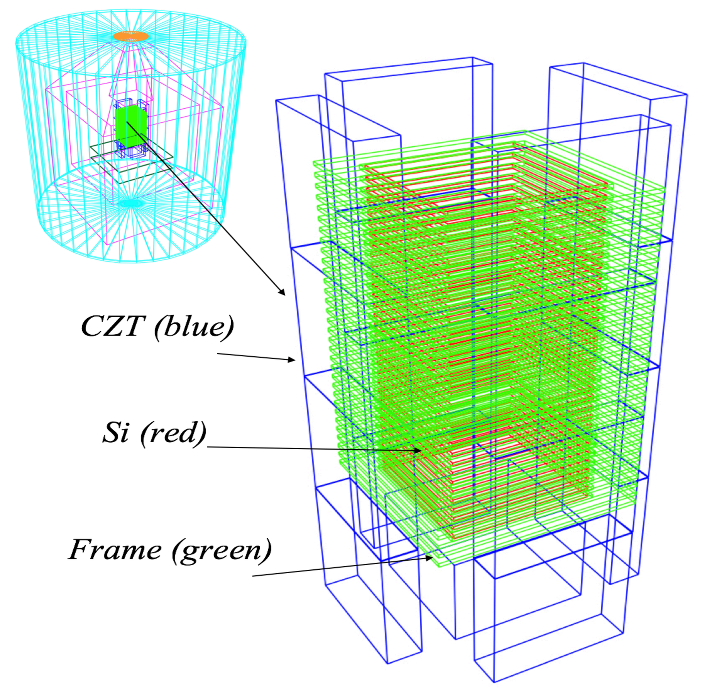


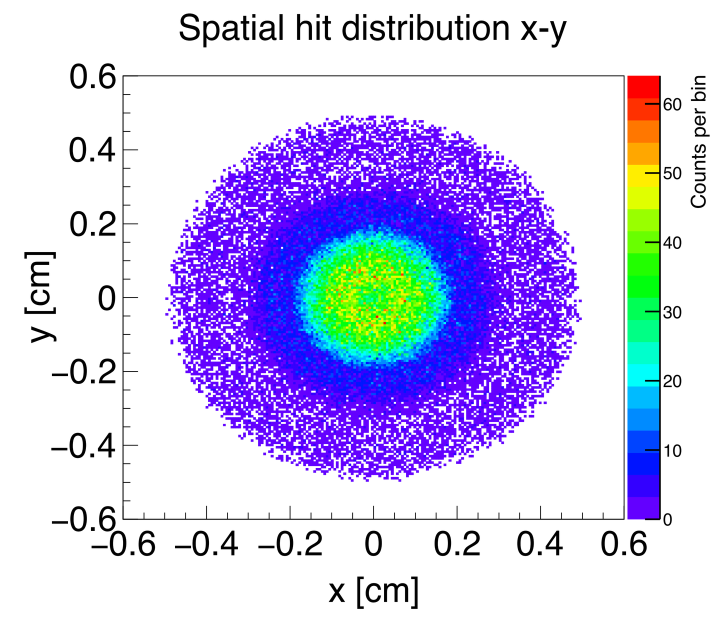
We divided the lens concept into 18 concentric rings starting at an inner radius of 1.5 cm and extending out to 10 cm so that the channeling length may be adjusted based on the required bending angle at each radius. This plot shows energy spectrum of different ring combinations for a Crab-like source by considering the calculated effective areas from our IDL ray-tracing code. A combination of 9 Si/W rings and 9 B/W rings seems to be a good choice to give a higher efficiency.

Geometry and Source for Focal Plane Detector

Two different detectors have been used to simulate the focal plane detector performance, one a single pixel-based CZT for spectroscopy goal and one Silicon tracker+CZT absorber which are capable to detect the polarized radiations. The CZT detector is a 20×20×15 mm^3 (11 by 11 pixel) single crystal with an energy resolution of 1.25% FWHM at 662 keV and a trigger threshold of 10 keV. The Silicon tracker of the second geometry consists of 32 layers of 20×20×0.6 mm^3 double-sided Silicon (10 by 10 pixel). It has one CZT detector at the bottom and four at each side. For the source, a power low spectrum of Crab with a 2.17 power law index, observed by INTEGRAL/SPI was chosen. We modified the input spectrum for the response of concentrator as well as atmospheric absorption for a balloon payload at an atmospheric depth of 3.5 g cm^{-2} and 30º zenith angle . We used near-field linear beam, whose beam profile is given by a radial profile simulated by IDL. For our purposes, an effective observation time of 6 hours has been assumed. We also modeled the dominant background components for the balloon flight and their effect on instrument performance.

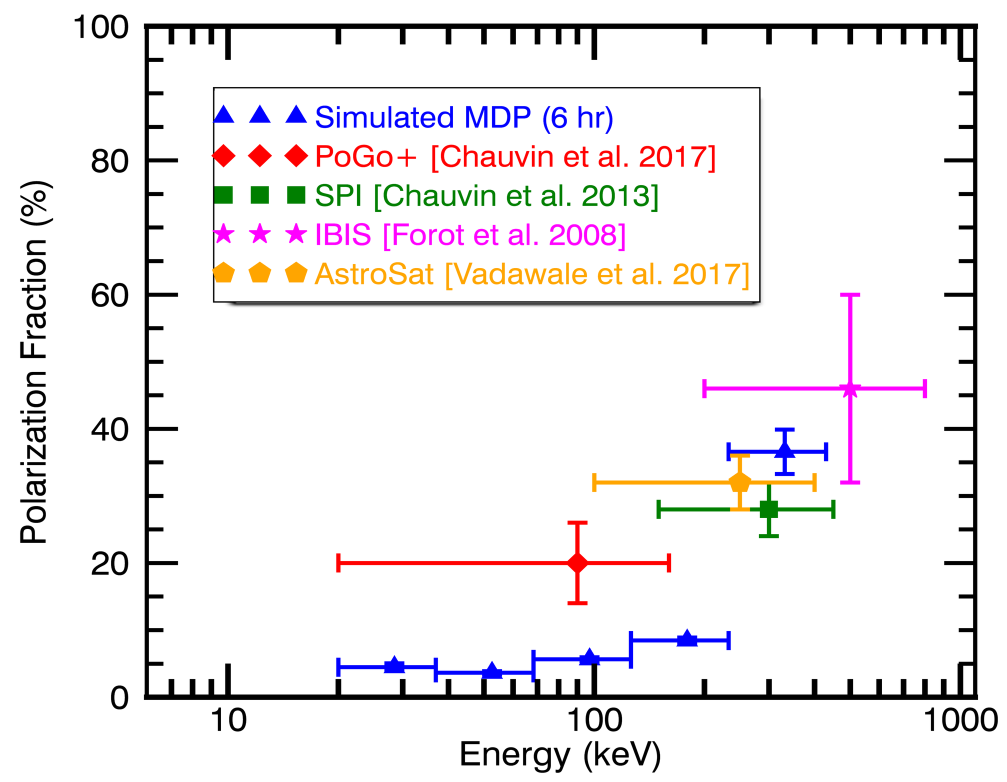


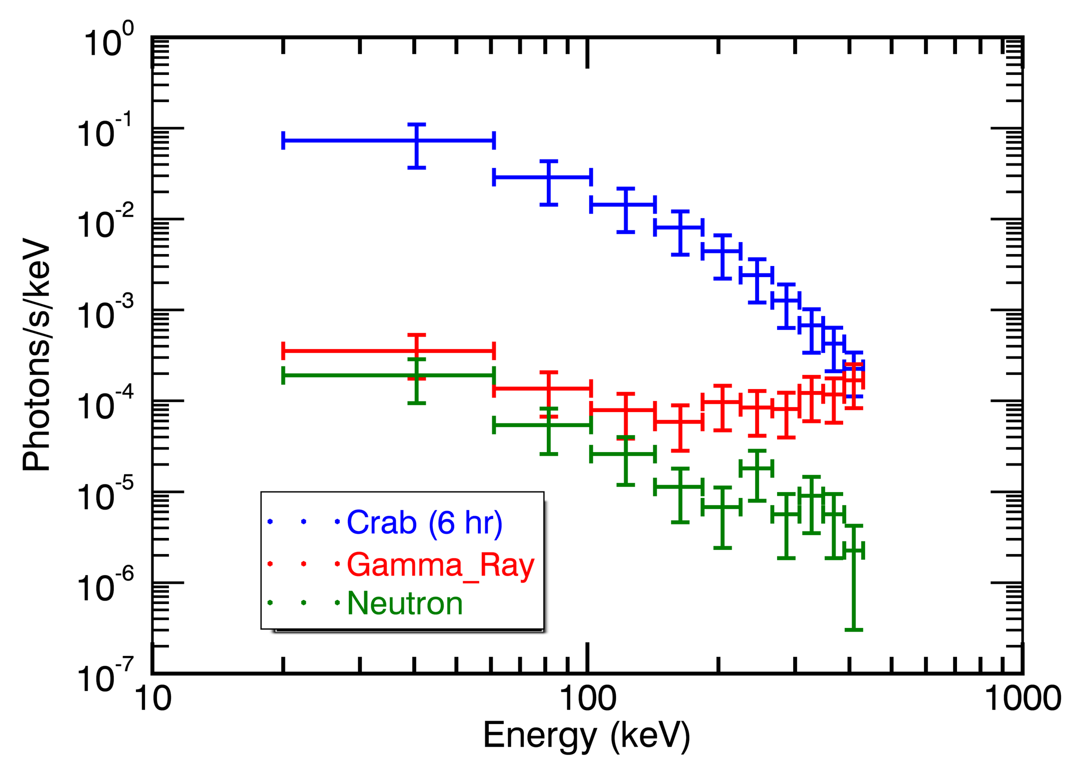




Performance Simulation Result

A comparison between calculated minimum detectable polarization (MDP) of our instrument in the presence of background for a 3σ detection significance (6 hr) with results from other polarimetry studies is shown. Detected spectra of simulated Crab and background also implies good spectroscopy performance for this detector geometry.





For more information, please contact Farzane Shirazi at fs4@wildcats.unh.edu