ASTRO-H Soft Gamma-ray Detector

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Abstract

SGD (Soft Gamma-ray Detector) is one of instruments onboard ASTRO-H which is the next JAXA X-ray satellite to be launched in 2014. SGD is a semiconductor Compton camera with a narrow field of view to achieve very low background, which will improve the sensitivity by an order of magnitude in 40–600 keV band compared with the currently operating instruments in Space. SGD utilizes semiconductor sensors such as Si (silicon) and CdTe (cadmium telluride), and low noise and low power ASIC (application specific integrated circuits) with digitization functionality, which realizes a compact Compton camera with with fine energy resolution. In this presenation, we discuss science drivers for SGD and its development status.

Instrument Concept:

SGD is a Compton camera surrounded by BGO active shield. (see Fig.1) A Compton camera consists of Si and CdTe sensors. We detect photons that is Compton scattered in Si and photo-absorbed in CdTe. The scattering angle, θ, can be calculated from the recoil electron energy (E_1) in Si and the absorbed photon energy (E_2) in CdTe as

$$\cos\theta = 1 + \frac{m_e c^2}{E_1 + E_2} - \frac{m_e c^2}{E_2}$$

θ can also be measured by the incident photon direction constrained by the FOV (field of view) and the interaction positions in Si and CdTe. By requiring consistency between two θ values, we can reject photon backgrounds from radio-activation of detector materials and backgrounds due to random neutron scattering. By employing Si with small atomic number as a scatterer, we can enable Compton scattering below 300 keV and also minimize effects from the finite momentum of the Compton-scattering electrons. By employing CdTe with high atomic number as an absorber, we can maximize the efficiencies at high energies. SGD consists of two units of 4x1 array of Compton cameras to meet requirements described below.

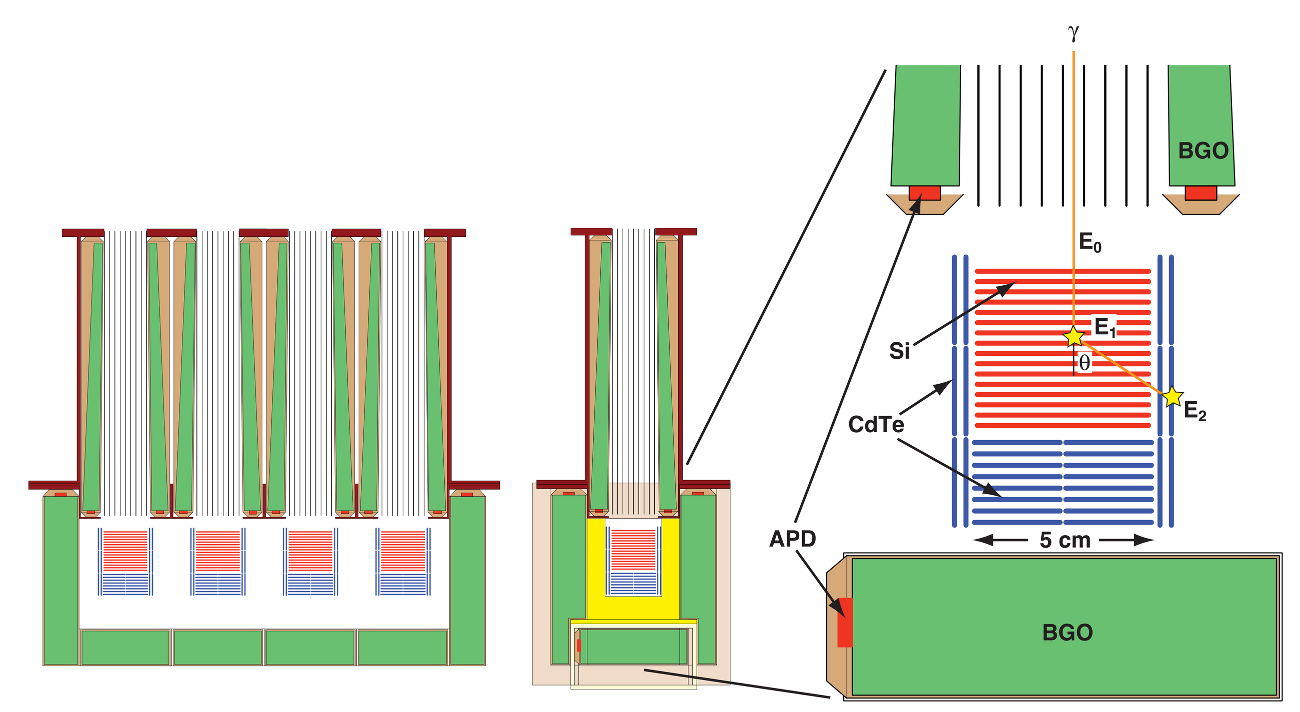

Fig.1 Conceptual drawing of ASTRO-H/SGD

Science Requirements and Drivers:

Main science drivers for SGD include studies of particle acceleration in various sources and associated non-thermal emissions and high-energy cutffs, identification of origin of 511 keV emission from electron-positron annihilation, studies of particle acceleration in GeV band though the observation of non-thermal bremsstrahlung, and observations of polarization. In order to enable studies of above science drivers, SGD needs to be able to measure spectra up to 600 keV for sources with 1/1000 of the Crab brightness (in 2–10 keV) and power law index of 1.7. A simulation results shown in Fig.2 demonstrates that spectral index can be measured within 10% error for such sources. More than 10 AGNs (Active Galactic Nuclei) are known to be brighter than this example, which enables us to probe existence of spectral breaks above 100 keV. Such spectral breaks are expected to play a crucial role to solve the question on the soft gamma-ray emissions in AGN (emission from the accretion disk or relativistic electrons in the jet). We also expect to contribute to understanding of the soft gamma-ray emissions in >10 X-ray pulsars and magnetars. Fig.3 shows simulation results for observation of no-thermal bremsstrahlung from a supernova remnant, Cas-A, which confirms that SGD can determine the magnetic field of Cas-A with a 100 ks observation. By combing this with the results from other wavelength, we can estimate the fluxes and spectra of electrons and protons accelerated in Cas-A. In addition, SGD is sensitive to the polarization in the 50–200 keV band from several Galactic black holes and neutron stars, and some AGNs in flare states. Detection of the gamma-ray polarization from these sources will bring new probes into the gamma-ray emission mechanism. Moreover, the detection of the polarization from sources in the cosmological distance will place stringent constraints on the violation of Lorentz invariance, which has great impact on the fundamental physics. In addition to above, we expect to make progress in studies of origin of CXB (Cosmic X-ray background), particle acceleration in SNR, origin of hard X-ray around the Galactic center and non-thermal emission from galaxy clusters.

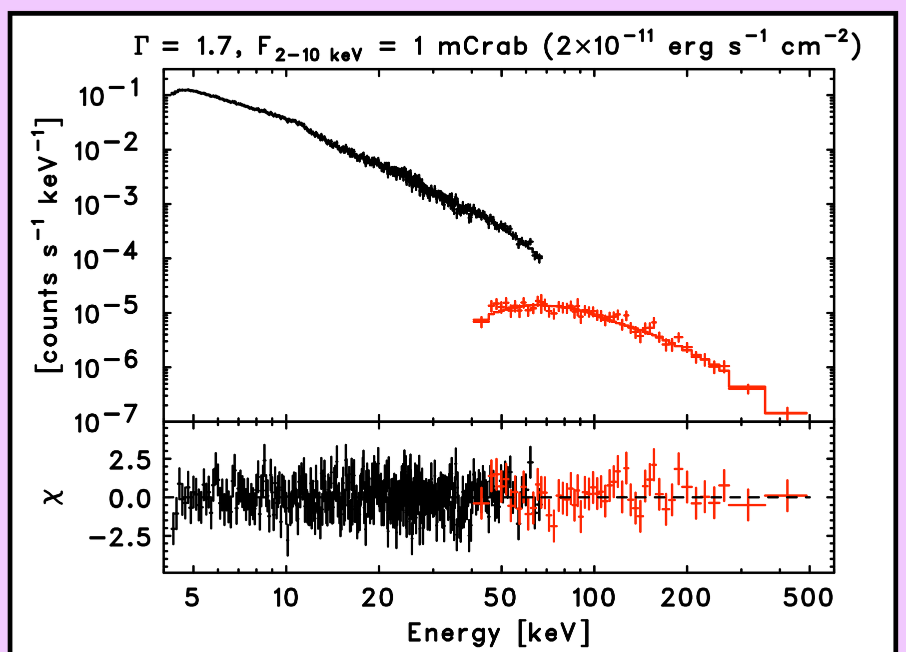

Fig.2 HXI (black) and SGD (red) simulation results for a 100 ks observation of a source with with 1/1000 of the Crab brightness and power law index of 1.7

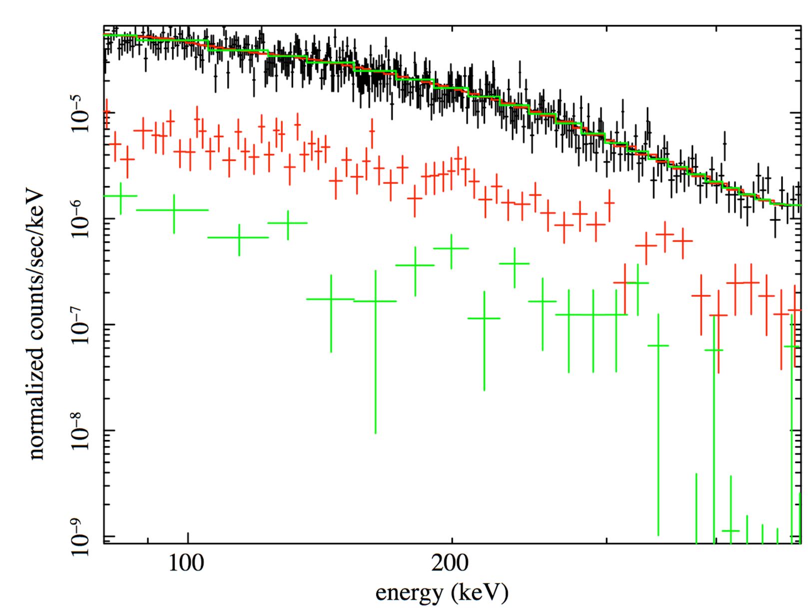

Fig. 3 SGD simulation results for a 100 ks observation of bremsstrahlung emissions from Cas-A with three magnetic field hypotheses, 0.1 mG (black), 0.3 mG (red) and 1.0 mG (green).

Development Status:

We are conducting following technology development to realize SGD.

Optimization of Si/CdTe sensors: SGD employs single-sided pixel sensors for easier assembly and readout. However, pixel sensors require large number of readout channels which results in high power consumption. Pixel size is maximized to 3.2 mm without affecting angular resolution in order to minimize the number of readout channels. Initial evaluations of test sensors shows the performace as expected.

Low power, low noise front-end ASIC: Energy resolution has great impacts on background rejection using Compton kinematics as well as spectral measurements. We have successfully developed an ASIC (Application Specific Integrated Circuits) that satisfies noise and power requirements for SGD. We also integrated digitization functionality in the ASIC to minimize required components, which is essential to realize a compact Compton camera. The integrated digitization circuits also allow us to implement common mode noise (CMN) detection circuits. Fig.4 shows spectra for ^{241}Am obtained from a CdTe sensor with the ASIC with integrated digitizer. It clearly shows that the CMN subtraction in ASIC is as good as that in offline calculation.

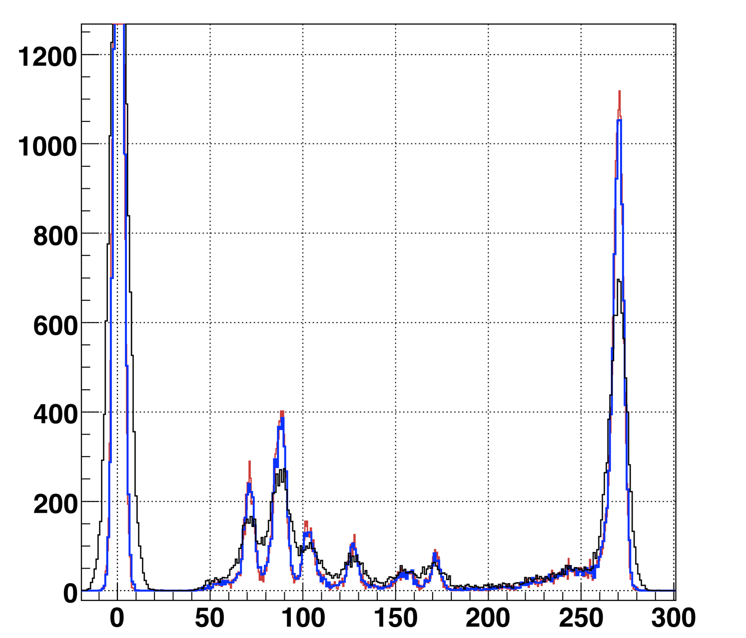

Fig.4 ^{241}Am spectrum from a CdTe sensor readout by an ASIC with on-chip digitization. Comparison of spectra without CMN subtraction (black), with on-chip CMN subtraction (blue) and with off-line CMN subtraction (red).

Next and final version of ASIC utilizes this functionality for zero suppression of data after the CMN subtraction to reduce the readout time by a factor of 10. This new ASIC has been fabricated and being evaluated now.

Compton camera mechanical support: It is critical to closely pack Si/CdTe sensors together in order to efficiently detect Compton events. Mechanical models were fabricated based on the initial mechanical design in order to evaluate the mechanical rigidity and assembly feasibility. Fig.5 shows pictures of the mechanical models, which passed component level vibration test in March. We also confirmed that the resonance frequency is sufficiently high. Currently improvements are made to make it easy to assemble.

APD readout of BGO: It is impossible to use conventional photomultiplier to detect scintillation light from the BGO since it is assembled into a very complex structure as shown in Fig.1. SGD employs APD (Avalanche Photo-Diode) for the readout. Fig.6 shows an ^{241}Am spectrum from APD with a BGO similar in shape as the one in the SGD shield. Though the spectrum still has some room for improvement, this result is quite satisfactory for our use.

We are also making progress on design of BGO enclosures and Compton camera cooling.

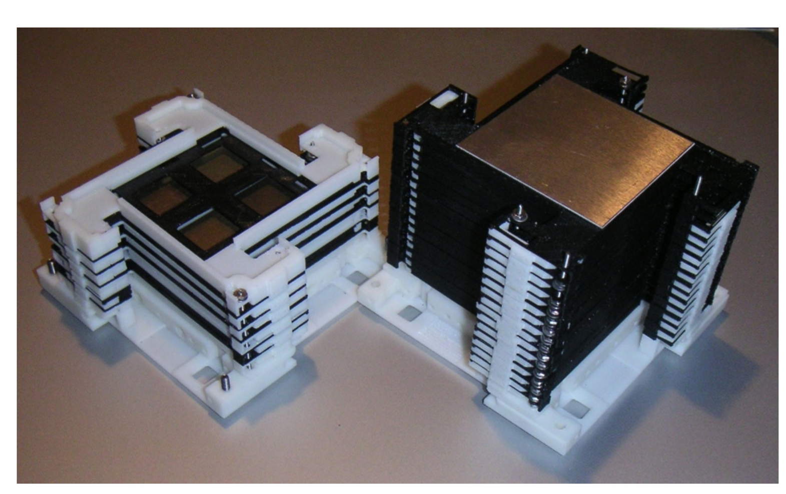

Fig. 5 Pictures of mechanical models for SGD Compton camera. The model on the right survived a vibration test.

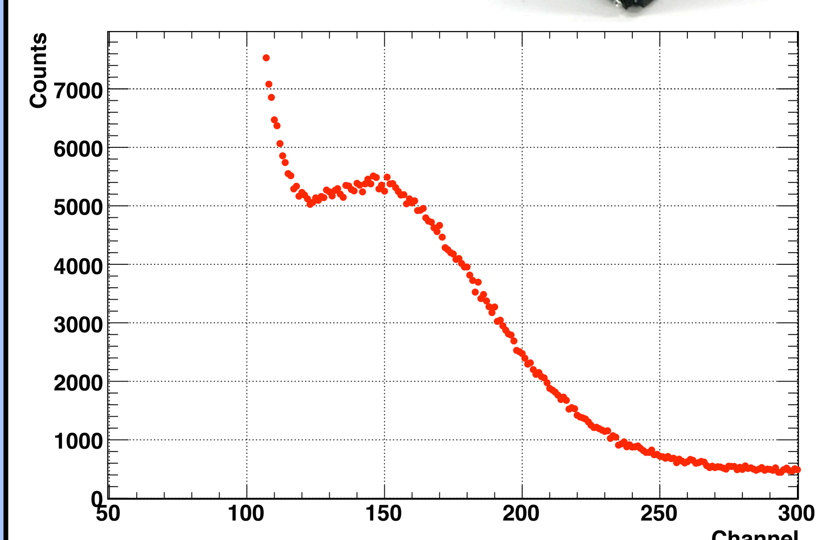

Fig.g 6 ^{241}Am spectrum from APD with a BGO similar in shape as the one in the SGD shield.