Ultra-wide-angle Compton Camera

Japan Aerospace Exploration Agency (JAXA)

Institute of Space and Astronautical Science (ISAS) of JAXA has been working on the next-generation gamma-ray detector to observe space gamma-rays with higher sensitivity than ever before. It is to identify radioisotopes in celestial objects, and visualizes them as an image. For ground-based application, it is suitable for visualizing the distribution of Cesium 137 (Cs-137) and 134 (Cs-134) over a plot of ground or a house, thanks to its wide hemispherical view covering almost 180 degrees and a unique capability for identifying radioisotopes.

History of development

Over the past 15 years, Prof. Takahashi and his group[1] at ISAS/JAXA has been researching and developing a unique "Si/CdTe semiconductor Compton camera," which is composed of silicon (Si) and cadmium telluride (CdTe) imaging devices, with the aim of high-sensitivity observations for gamma-ray astronomy[2]. By realizing a compact high-density stack configuration, the camera was able to achieve a high sensitivity and high-accuracy tracking of incident gamma-rays, despite its small size. With this concept, we are now producing the Soft Gamma-ray Detector (SGD), which will be mounted on the X-ray astronomy satellite "ASTRO-H" scheduled to be launched in 2014[3].

Upon receiving a consultation from Tokyo Electric Power Company following the March 2011 nuclear accident , we swiftly constructed a prototype of the ultra-wide-angle Compton camera for imaging tests in Fukushima prefecture based on the SGD concept combined with elemental technology for another device onboard ASTRO-H, the Hard X-ray Imager (HXI.)

Imaging principle of a Compton camera and comparison with a conventional gamma camera

Gamma-rays emitted directly from Cesium 137 and 134 have energies ranging from 600 to 800 kilo electron volts (keV). A conventional gamma camera uses a simple pinhole for imaging observations in this energy range (Figure 1(a).) By limiting the direction of incident gamma-rays beforehand, the camera captures images of the radioisotopes. This imaging method is effective when the surrounding background radiation is low, and when the pinhole mask is thick enough to block gamma-rays that fall outside the pinhole. However, when gamma-ray energies exceed several hundred keV, the shielding turns transparent, and, even if one can visualize radioisotopes, it is difficult to obtain a clear contrast. In order to improve imaging performance, the camera has to be made heavier for sufficient shielding. In addition to these mechanical problems, the maximal field of view is limited to 40 to 60 degrees due to the aperture angle of the pinhole.

A "Compton camera" is a visualizing technology that specifies the direction of incident gamma-rays by using Compton scattering, which is the dominant interaction process of gamma-rays in this energy band (Figure 1 (b)). In the case of the Compton camera, we measure the energy imparted to electrons by a gamma-ray (E1) through Compton scattering, the energy of the scattered gamma-ray (E2), the location where Compton

1 www.astro.isas.jaxa.jp/~takahasi/index-e
2 Collaboration with Mitsubishi Heavy Industry Nagoya Guidance and Propulsion Systems Works and ACRORAD
3 Collaboration with Nagoya U., U. of Tokyo, Hiroshima U., Waseda U., Stanford U.

scattering occured (X1), and the position where photoelectric absorption of the scattered gamma-ray took place (X2). This enables us to compute the energy of the incident gamma-ray and its arrival direction. The distribution of radioisotopes is then visualized as an image using statistical processing. In this manner, a Compton camera can visualize gamma-rays without using a pinhole or a collimator. The camera also has excellent capability for reducing backgrounds to obtain higher sensitivity, and is thus recognized as a next-generation gamma camera.

Ultra-wide-angle Compton camera

The “ultra-wide-angle Compton Camera” is a next-generation Compton camera with a densely stacked configuration of Si and CdTe semiconductor imaging detectors (Figure 1 (c).) Although the principle of a Compton camera is well established for some time, no working model has been manufactured that is both relatively easy to use and also able to shoot images on site with sufficient efficiency and resolution. The ultra-wide-angle Compton camera is structured in a way that gamma-rays scattered by Compton scattering are unlikely to escape from the system; therefore, it can achieve an ultra wide angle view. On this occasion, we developed a silicon (Si) and a CdTe double-sided strip detector with 250 micrometer position resolution (128 cross strips) in order to achieve the resolution necessary for specifying the exact position of a hot spot where the radiation level is locally high. It is noteworthy that the position resolution of the CdTe detector is remarkably high as compared to that of a conventional gamma camera which is at a level of a few millimeter. Figure 2 below shows the prototype camera constructed this time. We verified that the camera demonstrates good resolution of 128 x 128 voxels for a 180 degree field of view through an imaging test in a laboratory as well as on site.

The realization of the ultra-wide-angle Compton camera required two key technologies developed by ISAS in the late 1990s: the first is a high-energy resolution CdTe semiconductor device manufactured in cooperation with ACRORAD, and the other is high density hybridization technology developed in collaboration with Mitsubishi Heavy Industry. CdTe semiconductor is suitable as an absorber because it is superior in photoelectric absorption efficiency as compared to NaI(Tl) scintillator or germanium semiconductor. Also, in the case of a conventional Compton camera, angular resolution is limited depending on the initial momentum of scattered electrons, but this tendency was mitigated with the use of Si. The resultant angular resolution attainable is about 1 to 2 degrees for 662 keV gamma-rays from Cesium 137.

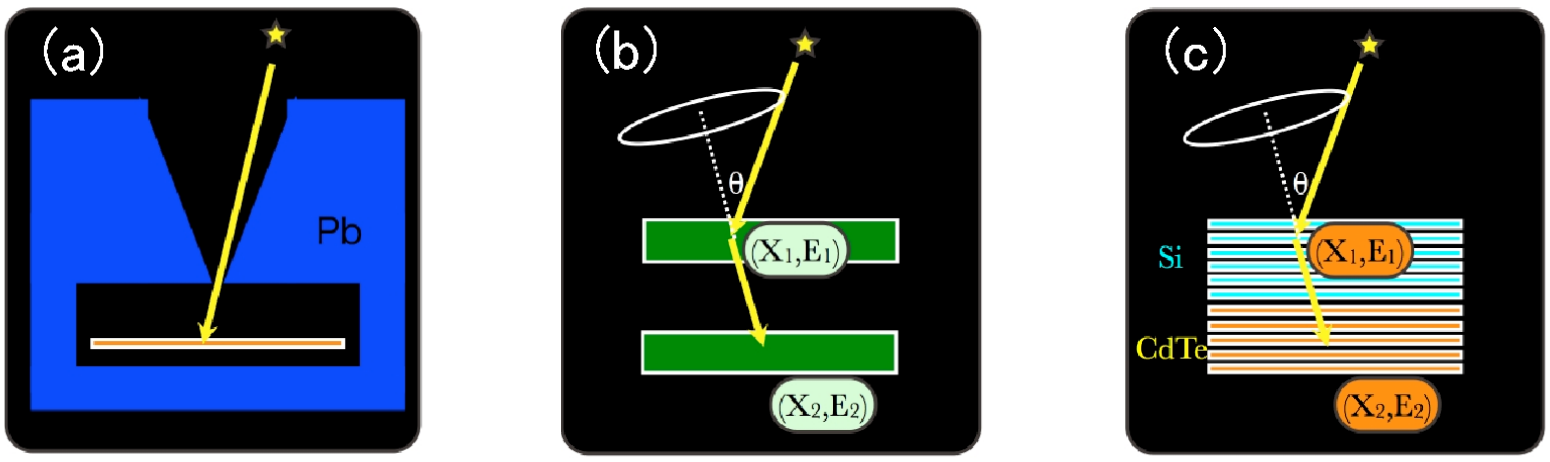


Figure 1:

(a) Conventional pinhole camera: It is required to shield gamma-rays other than those coming through the pinhole.

(b) Compton camera principle: It utilizes Compton scattering of gamma-rays.

(c) Si/CdTe Compton camera principle originally proposed by Prof. Takahashi’s group ISAS/JAXA

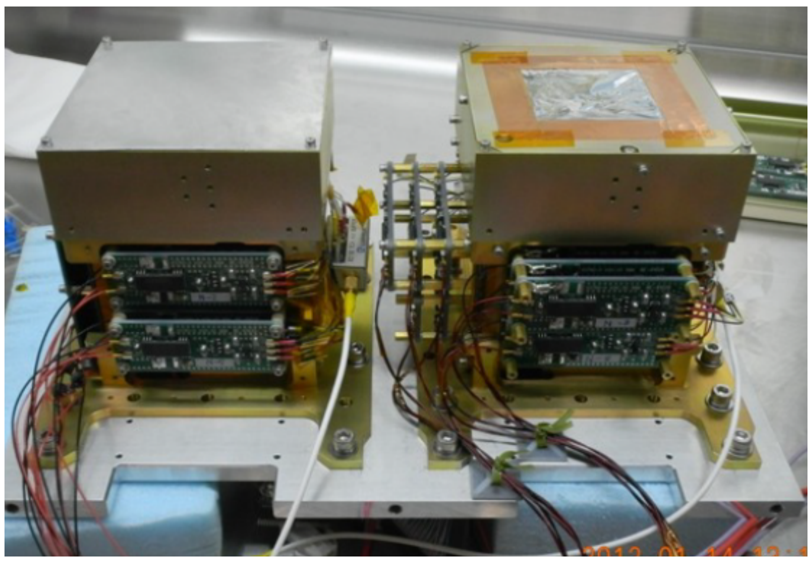


Figure 2: The Si/CdTe Compton camera constructed for imaging tests in Fukushima prefecture developed by ISAS/JAXA. It has a stack configuration with two Si layers and three CdTe layers. This structure realizes the first working model of the next generation Compton camera possessing an ultra-wide-angle view and an energy resolution capable of recognizing gamma rays unique to a radioisotope. The above photograph shows the two units comprising the ultra-wide-angle Compton camera.

Demonstration of results

Figure 3 shows one example of the imaging demonstration results obtained by the ultra-wide-angle Compton camera at the ISAS facility. In this test, we placed three kinds of calibration sources (Barium 133 (Ba-133), Cesium 137 (Cs-137) and Sodium 22 (Na-22)) on the ground (left image of Figure 3) in order to shoot an image. As you can see in Figure 4, Energy Spectrum, we analyzed gamma-rays emitted from each radioisotope by setting a specific energy window for each radioisotope. As a result, all radioisotopes are identified and visualized in an image simultaneously. By utilizing this capability, we indicate Ba-133 in green, Cs-137 in red, and Na-22 in blue.

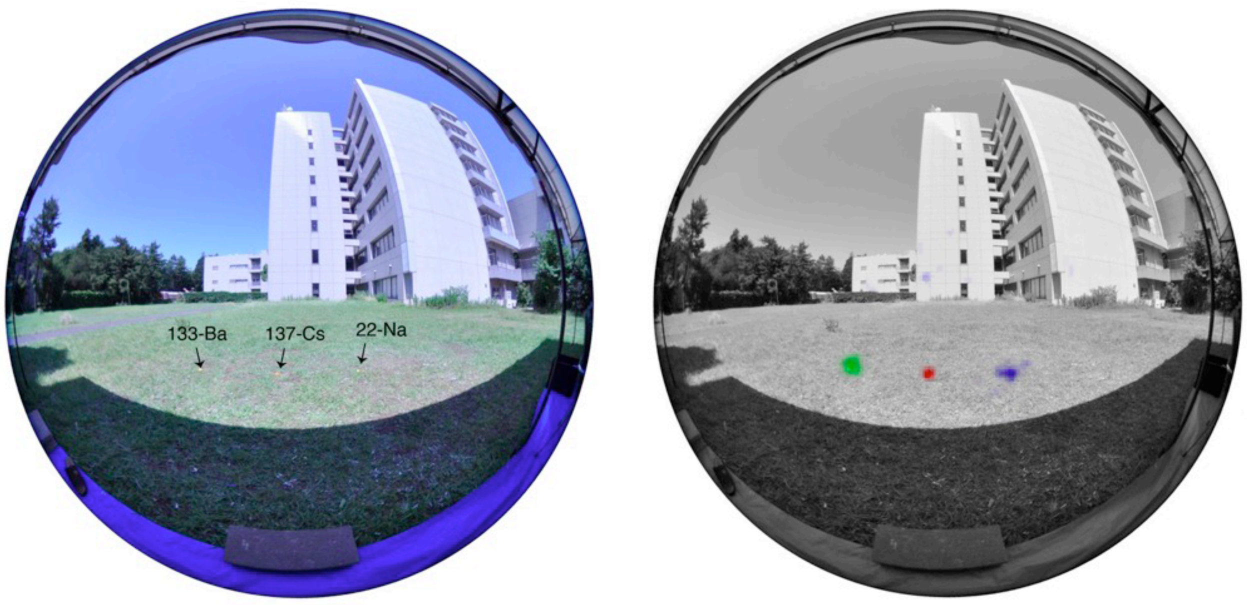


Figure 3:

(Left) An image captured by a digital camera equipped with a fisheye lens. Three calibration sources (from left, Ba-133, Cs-137, and Na-22) were set on the ground. The energy of the gamma-rays emitted by these radioisotopes is 356 keV for Ba-133, 511 keV for Na-22, and 662 keV for Cs-137.

(Right) A composite photograph compiled by combining an image taken by the ultra-wide-angle Compton camera and one taken by the fisheye lens digital camera.

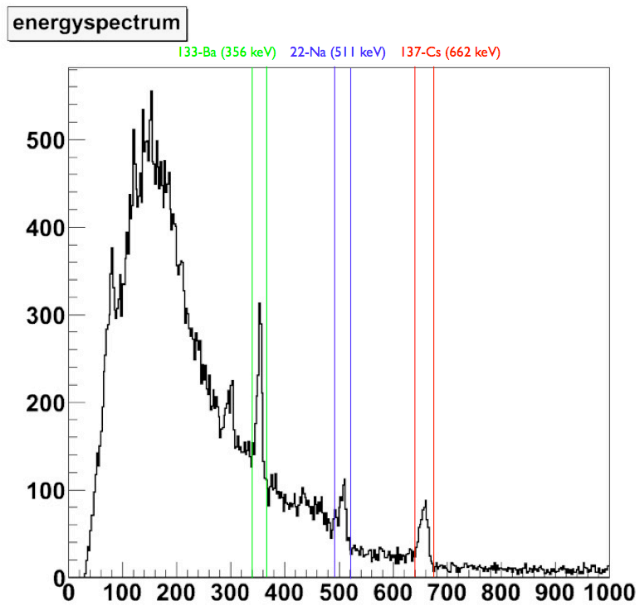
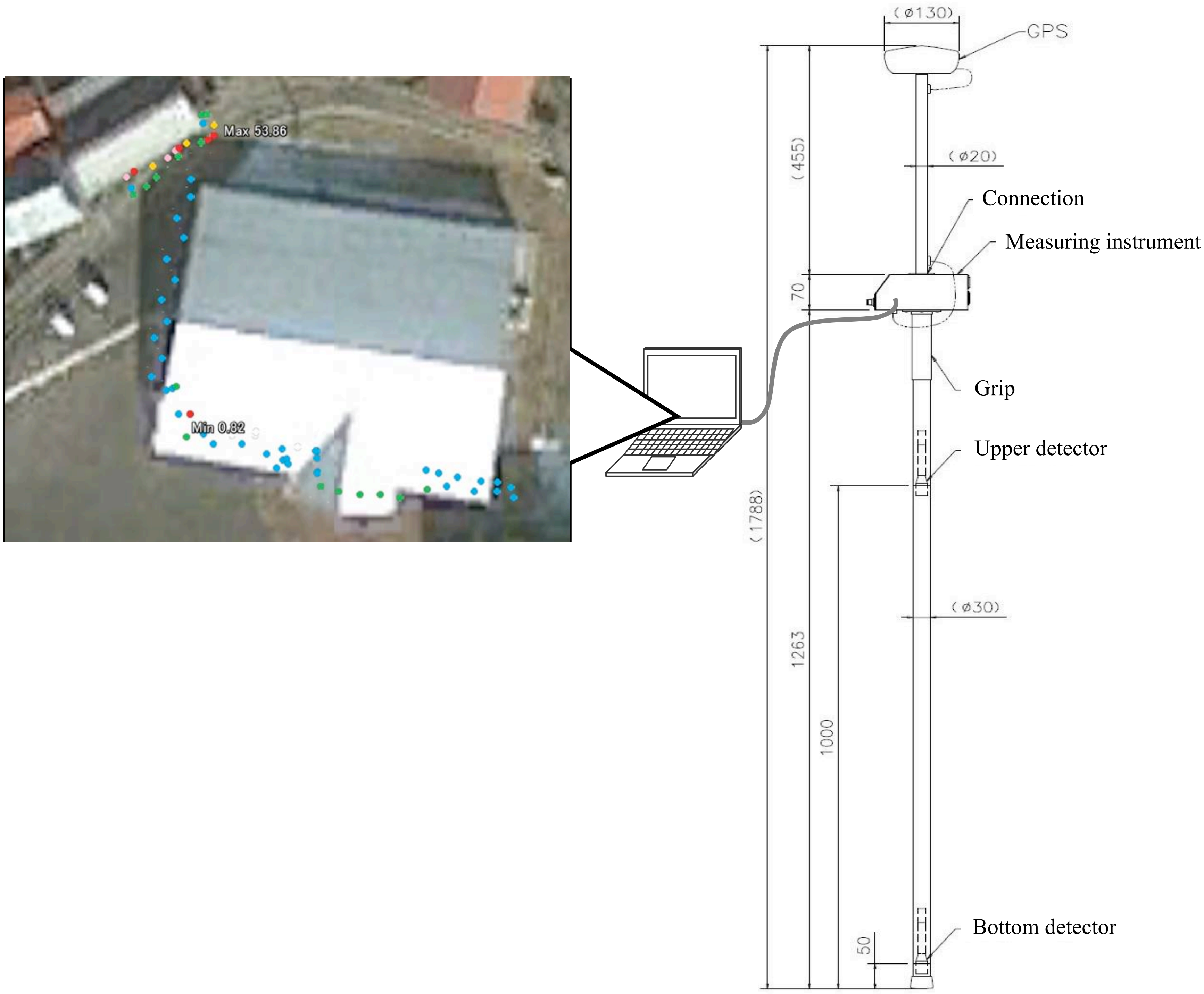


Figure 4: Energy spectrum when three calibration sources of Ba-133, Cs-137, and Na-22 placed on the ground were shot by the ultra-wide-angle Compton camera. The horizontal axis of the above graph indicates energy in keV.

Gamma Plotter H

Japan Atomic Energy Agency

Gamma Plotter Horizontal (H) is a radiation measuring device in the shape of a walking stick installed with a plastic scintillator detector at five centimeters and 100 centimeters in height from the ground surface. It functions as a dosimeter in the environment operated by walking around a target site with this walking stick. If the same site is mapped by a satellite positioning system (GPS), we can easily compile a radiation dose rate map.



Special features

1. It can precisely measure the spatial dose rate (0.1 to 300μSv/h) at a height of five centimeters and 100 centimeters above the ground.
2. It can either automatically (with a preset interval) or arbitrarily record a radiation dose rate and positioning information.
3. It can compile a radiation dose map using six colors to indicate preset radiation dose ranges.
4. Hot spots can be detected by an alarm (buzzer) if it is preset.
5. It can be operated by battery for about three hours.