



POLAR: a Gamma-Ray Burst Polarimeter onboard the Chinese Spacelab

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Abstract: POLAR is a novel compact space-borne Compton polarimeter conceived for a precise measurement of hard X-ray polarization and optimized for the detection of the prompt emission of Gamma-Ray Bursts (GRB) in the energy range 50–500 keV. A first detailed measurement of the polarization from astrophysical sources will lead to a better understanding of the source geometry and of the emission mechanisms. Thanks to its large modulation factor, effective area, and field of view (1/3 of the visible sky), POLAR will be able to reach a minimum detectable polarization (1- σ level) of about 3% for several GRB measurements per year. POLAR consists of 1600 low-Z plastic scintillator bars, read out by 25 flat-panel multi-anode photomultipliers. The incoming photons undergo Compton scattering in the bars and produce a modulation pattern; simulations and experiments have shown that the polarization degree and angle can be retrieved from this pattern with the accuracy necessary for pinning down the GRB mechanisms. Details on the qualification test campaign of the POLAR Engineering and Qualification Model are described in detail elsewhere in this conference (see abstract ID:1351). A first full-scale copy of the flight model of POLAR is currently under construction in Geneva based on the positive outcome of the qualification tests, in view of a flight on the Chinese spacelab TG-2 expected in 2014.

Keywords: Scintillator detector; X-ray polarization; Synchrotron radiation; Astrophysics; Gamma Ray Burst (GRB); GEANT4 Monte Carlo simulations; Space experiment.

1 Introduction

POLAR [1] is a novel compact space-borne apparatus design to precisely measure the polarization of hard X-rays; it is optimized for the detection of the prompt emission of Gamma-Ray Burst (GRB) photons in the energy range 50–500 keV. GRBs are sudden flashes of γ -rays that appear randomly in the sky and outshine for a few seconds all other γ -ray sources. They are produced at cosmological distances, and are believed to be the most powerful explosions in the universe after the Big Bang. In the past 40 years many instruments have performed extensive studies of GRBs, but their creation mechanism and their progenitors are still uncertain. Several theories have been elaborated to explain their origin: All of them relate the emission of the GRB to the creation of a black hole, differing in the physical processes involved in the γ -ray generation, and also in the level of linear polarization of the emitted photons. The direction and the level of polarization of high-energy photons emitted by astrophysics sources such as

GRBs are therefore very good observable candidates for the understanding of the corresponding emission mechanisms, source geometry and strength of magnetic fields at work [2] [3].

2 The POLAR Experiment

POLAR consists of a target of 40×40 plastic scintillator bars, each of dimension $5.9 \times 5.9 \times 176$ mm³, wrapped in a highly reflective foil (Vikuiti ESR, 3M), organized in 25 independent modular units, with 64 bars each. Each unit contains a flat panel multi anode photomultiplier tube (MAPMT; H8500, Hamamatsu), mechanically coupled to the bottom of the scintillator bars via a 0.7 mm thick transparent optical pad, and enclosed in a 1 mm carbon fiber socket. The electrical signals coming from the MAPMT are first processed by an ASIC and FPGA at the front-end electronics (FEE), then sent to a central processing unit, where the trigger decision is taken considering the outputs

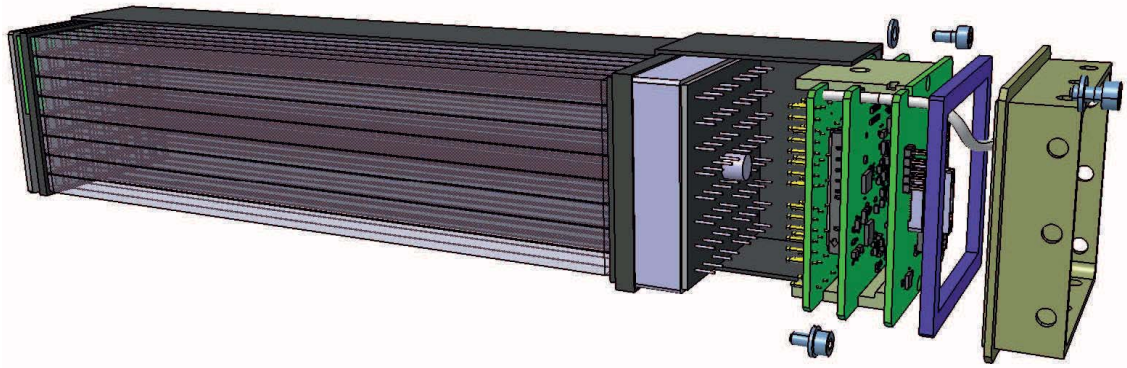


Figure 1: Exploded view of one POLAR modular unit.

of all modular units. This modular design provides a good mechanical stability and facilitates the interchange of modules during the testing phase of the detector. The bars in each modular unit are kept together with two aligning plastic frames located at the top and at the bottom of the carbon fiber sockets to provide resistance to vibrations and to reduce the optical crosstalk between adjacent channels. Figure 1 shows an exploded view of a modular unit. The whole target, together with the central computer, the high voltage power supply and the rest of the electronics, is further enclosed in a 3 mm thick carbon fiber box that enhances the mechanical stability and acts as a shield against low energy charged particles. While the detector is located on the outside of the spacecraft facing deep space, the low-voltage power supply and a part of the electronics system will be located inside the spacecraft. The POLAR detector is space-borne, to be able to study photons in the energy range between 50 and 500 keV, which cannot reach the ground because the Earth atmosphere is opaque to X-rays coming from space. POLAR will fly on the future Chinese Tian-Gong 2 Spacelab in 2014.

The qualification model (QM) is currently under construction, and space qualification tests on a first prototype of the QM are undergoing. More details on performed qualification tests (vibration, thermal, thermo-vacuum) and on tests planned for the near future (EMC, irradiation) are presented in [5]. Figure 2 shows a photo of one POLAR modular unit installed on the vibration table during qualification tests.

2.1 The Data Acquisition System

The electronics read-out system for POLAR is based on a Front-End Electronic system (FEE) for each of the 25 modules and on one central unit that handles the trigger logic with information coming from the 25 FE units. Each FEE unit consists of one ASIC chip that reads the (analog) outputs from the flat panel multi-anode photomultiplier, digitalizes the information and transfers it to an FPGA, which communicates with the central unit. The central unit asserts the trigger flag when within a time window of ~ 50 ns

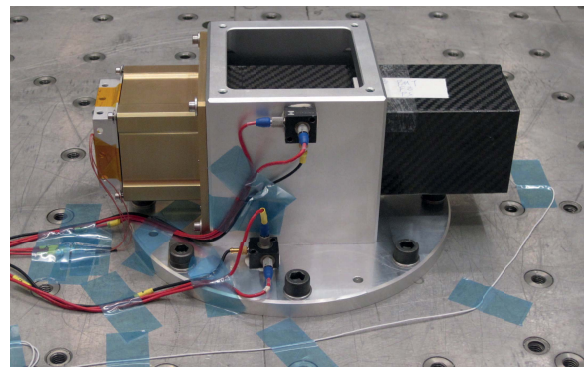


Figure 2: Photo of one POLAR modular unit installed on the vibration table in Bern during qualification tests (May 2011).

an energy deposition of at least 5 keV is registered in two bars part of the same module or part of neighbor modules. The trigger condition is based on the fact that to measure the polarization of X-rays POLAR detects the interaction via Compton scattering of the incoming photon and the subsequent interaction (Compton or photoelectric) of the resulting photon in a different bar. Data are then sent to the spacecraft for storage and transmission to Earth. The communication between the various subsystems is done via LVDS lines capable of handling 4 Mbps, while the data transfer to the spacecraft is ensured by a high-speed LVDS dedicated link at 100 Mbps. This high speed, together with the presence of FIFOs at the FEE level and also inside the central unit, ensures that the apparatus is able to sustain a continuous rate of several kHz, with short peaks. This was a requirement for the system, since the aim of POLAR is to detect very intense bursts of X-rays coming from GRBs, over a background of diffuse gamma rays and other sources (gamma rays induced by low-energy positrons, cosmic rays, etc.).

Figure 3 shows a CAD view of the POLAR instrument seen from below; the FEE for each module is visible on the right of the figure, while the 25 carbon fiber boxes, one per mod-

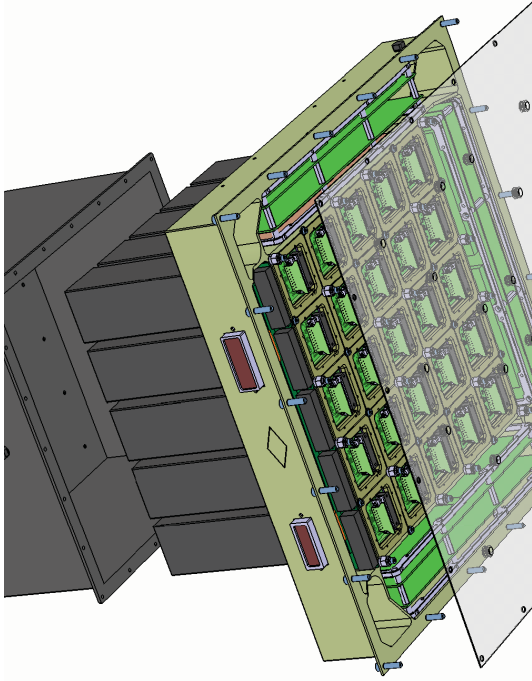


Figure 3: CAD view of the POLAR experiment. The outer carbon fiber box, the aluminum baseplate, and the connectors to transfer data, commands and power between the spacecraft and POLAR are clearly visible.

ule, are shown in the left part of the figure, as well as the external carbon fiber enclosure.

2.2 Operational Modes

During its operation in orbit, POLAR will continuously acquire physics data ('physics mode'), and all the recorded events (coincident energy deposition in 2 bars) will be stored on disk and downlinked to Earth within few days. During each orbit, on the equatorial ascending node a calibration is performed with random triggers to evaluate the stability of the pedestals and the parameters on each FE are updated. After calibration, POLAR is automatically re-initialized and re-enters physics mode. When the counting rate in the detector exceeds a pre-fixed threshold the instrument enters 'GRB mode': a transient phenomenon has been detected. The special mode is kept as long as the counter remains above the threshold and for ~ 15 minutes after its end. During GRB mode the physics acquisition continues without accepting telemetry commands; calibrations are not performed during GRB mode. Only alarms from subsystems that can compromise the integrity of the experiment (e.g. high reading from temperature sensors) are allowed to put an end to GRB mode and eventually to shut it down, after a re-initialization of the detector. A special mode allows diagnostic operations to be performed on the various subsystems. Data are continuously transferred to the spacelab during physics operation, as described in

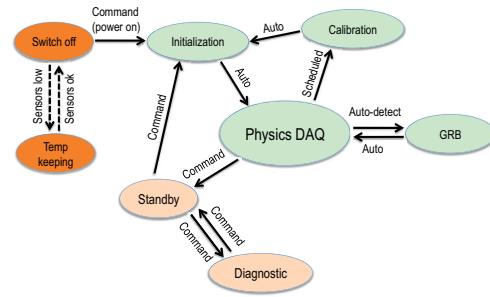


Figure 4: Details on the operational modes for POLAR during operation in space.

the previous section. Four thermostats are installed near the electronic boards of the detector to keep a minimum temperature of -30°C ; the temperature sensors are driven by the spacecraft, in order to maintain a minimum temperature also when POLAR is switched off. Figure 4 shows the operational modes and the transitions among them.

3 Tests with Synchrotron Radiation

In December 2009 one modular unit of POLAR was tested at the high energy diffraction and scattering beam line ID15A at the European Synchrotron Radiation Facility (ESRF), in Grenoble. This beam line provides 100% polarized X-rays in the energy range between 30 keV and ~ 500 keV, creating ideal conditions for the calibration of a hard X-ray polarimeter as POLAR.

We have performed a systematic calibration of one modular unit of POLAR at four different energies in the energy range 200 keV–511 keV with 100% polarized synchrotron radiation. The experiment consists of recording all pairs of bars that show a coincident energy deposition. From the distribution of the azimuthal scattering angle ξ we have reconstructed the angle of polarization ξ_0 of the incoming photon beam and the modulation factor μ_{100} , i.e. the response of the instrument to a fully polarized photon flux.

One scan of the detector consisted in collecting 20,000 events with the beam centered on each bar of the POLAR modular unit, for a total of $1.28 \cdot 10^6$ events. Putting the 64 runs together allows to approximately reproduce the flat illumination expected from a GRB. Several rotations around the beam axis allowed to test the response of the detector to several polarization angles.

Some details on the experimental setup and on the obtained results are present in the proceedings of this conference [5]. A detailed technical description and a full list of results in form of tables are also published [4].

Measurements with low-energy synchrotron radiation at the Swiss Light Source (SLS) in PSI (Villigen, Switzer-

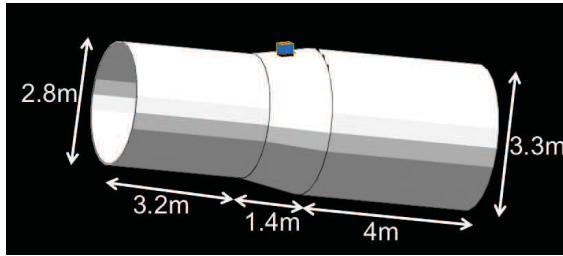


Figure 5: The POLAR experiment installed on the Chinese spacelab TG-2. The small blue box at the top is the POLAR instrument.

land) have been performed to study the energy region near the trigger threshold for the single hit (5 keV). Data analysis is currently ongoing.

4 Conclusions and Outlook

POLAR is a novel compact space-borne Compton polarimeter conceived for a precise measurement of hard X-ray polarization and optimized for the detection of Gamma-Ray Burst photons in the energy range 50–500 keV. A beam test with high-energy synchrotron radiation at ESRF in December 2009 confirmed that the polarimetric capabilities of POLAR are excellent, as predicted by Monte Carlo simulations. The qualification model of the instrument is currently being constructed, in parallel with the design of the flight model, in view of the launch on the Chinese spacelab Tian-Gong 2 in 2014 (figure 5).

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