POLAR-2, the next generation of GRB polarization detector

Abstract

The POLAR-2 Gamma-Ray Burst (GRB) Polarimetry mission is a follow-up to the successful POLAR mission. POLAR collected six months of data in 2016-2017 on board the Tiangong-2 Chinese Space laboratory. From a polarization study on 14 GRBs, POLAR measured an overall low polarization and a hint for an unexpected complexity in the time evolution of polarization during GRBs. POLAR was also able to measure the polarization of the Crab. These results demonstrate the need for measurements with significantly improved accuracy. Moreover, the recent discovery of gravitational waves and their connection to GRBs justifies a high-precision GRB polarimeter that can provide both high-precision polarimetry and detection of very faint GRBs. The POLAR-2 polarimeter is based on the same Compton scattering measurement principle as POLAR, but with an extended energy range and an order of magnitude increase in total effective area for polarized events. Proposed and developed by a joint effort of Switzerland, China, Poland and Germany, the device was selected for installation on the China Space Station and is scheduled to start operation in 2027.

Introduction

POLAR-2 on the Chinese Space station will consist of 3 sub instruments: the high-energy polarimeter, which is described in this poster, but also an imager and a low-energy polarimeter which remains in the design phase (see fig. 1). The high-energy polarimeter construction phase has started in Switzerland and Poland, while the imager and low-energy polarimeter, which uses a wide field of view detectors similar to those on eXTP and IXPE, will be produced in China.

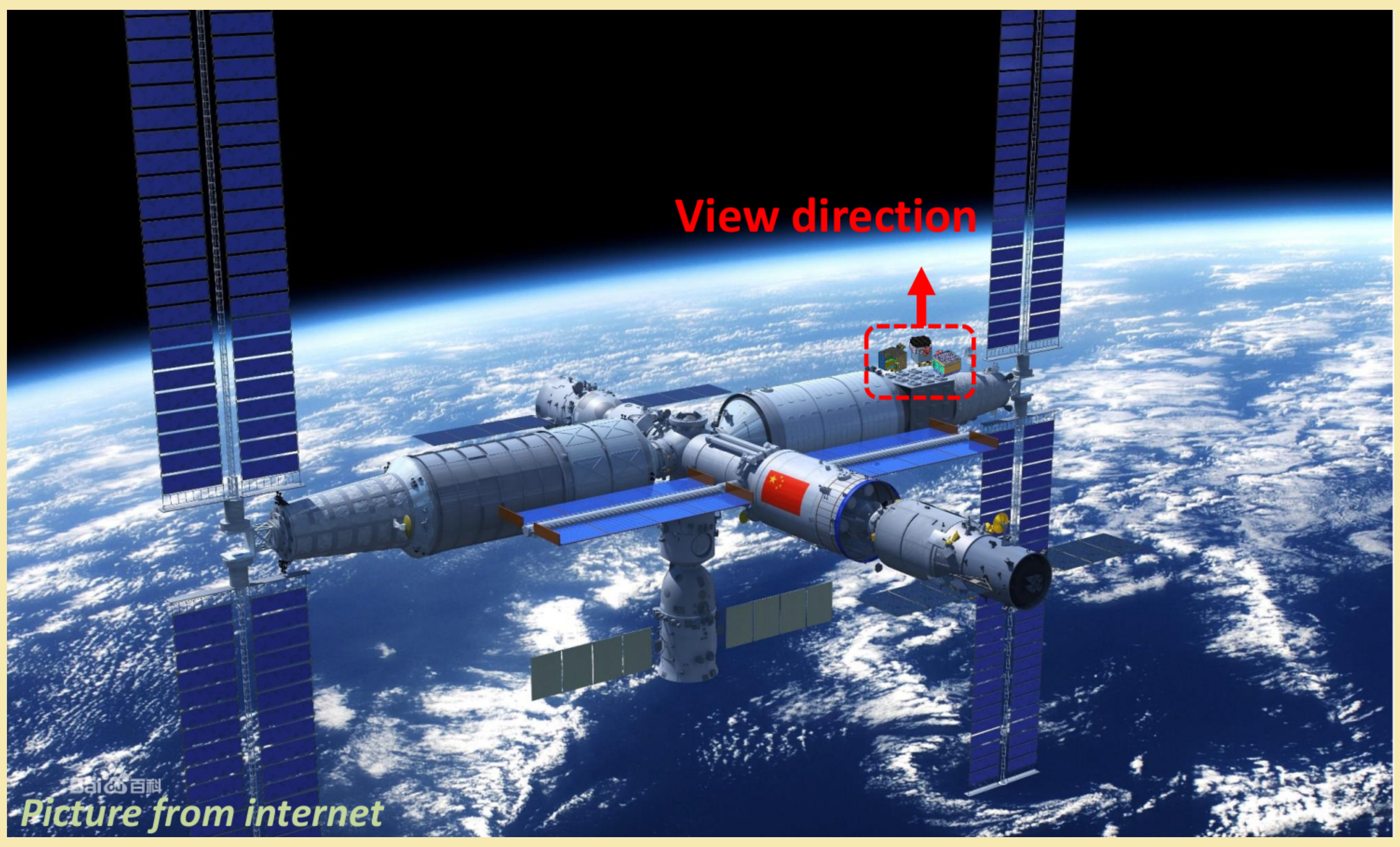

Figure 1: Completed in space in 2023, the Tiangong Chinese space station is shown along with the allocated position of the high-energy polarimeter, and the possible positions of the imager and the low-energy polarimeter

Construction

POLAR-2's design is an improvement over that of POLAR in several ways [1]. Firstly, the size is increased by a factor of 4, resulting in a total of 100 detector modules (25 for POLAR) each containing 64 scintillating bars. The readout of these bars is furthermore changed from using MAPMTs to SiPMs. This change along with an optimization of the scintillator bar shape, increases the light yield from 0.3 photo-electrons/keV in POLAR, to 1.6 photo-electrons/keV for POLAR-2. This significantly improves the sensitivity of POLAR-2 at low energies.

Through studies of the measured POLAR background in space, an optimization of the scintillator length was also performed. By shortening the bars, the effective area is slightly reduced, however, the background rate is significantly more reduced, thereby decreasing the Minimal Detectable Polarization (MDP). A downside of the use of SiPMs is their dark noise which requires one to operate the instrument at low temperature (our goal is -20°C, it was around +20°C for POLAR). For this purpose, all the design is optimized towards low temperatures, for example, all the external surfaces are painted with high reflectivity and high emissivity paint. Furthermore, SiPMs have been shown to degrade in space due to radiation damage. Based on simulations we know that the low energy threshold will increase due to this by approximately 1 keV per year. In order to mitigate this, we have also tested that the irradiation damage can be recuperated by bringing the SiPMs to a high temperature for a couple of hours. Heating to 60°C using simple resistors is implemented and will be performed once per year in orbit [2].

Performance Simulation

The performance of POLAR-2 was simulated using GEANT4. The background was simulated using the background measured in space by POLAR. The Monte Carlo code results were furthermore validated using fully polarized test beam data collected in 2023 using the ESRF synchrotron light source [3]. An unpolarized sample can furthermore be constructed by adding two data sets polarized in perpendicular directions. In total calibration data was used to measure the instrument response at 40, 60, 80, 100 and 120 keV for different incoming and polarization angles. The results, which are still under study, indicate a good agreement with the simulated instrument responses.

Calibrated Monte-Carlo simulations were then used to predict the scientific performance of POLAR-2. When combining this with existing GRB catalogs and known orbital elements of the spacecraft, one can predict the number of GRBs (see right side of fig. 3) for which the polarization can be measured per year.

Apart from polarimetry, POLAR-2 will be able to perform real-time analysis of the incoming angle of GRB, as well as their spectrum through access to a GPU on the space station. As uncertainties on the spectrum and location induce systematic errors, this allows POLAR-2 to completely independently measure the linear polarization for all observed GRBs.

In addition, we are investigating the possibility of POLAR-2 sending alerts with localization and spectral info to the ground within 2 minutes of the onset of the GRB.

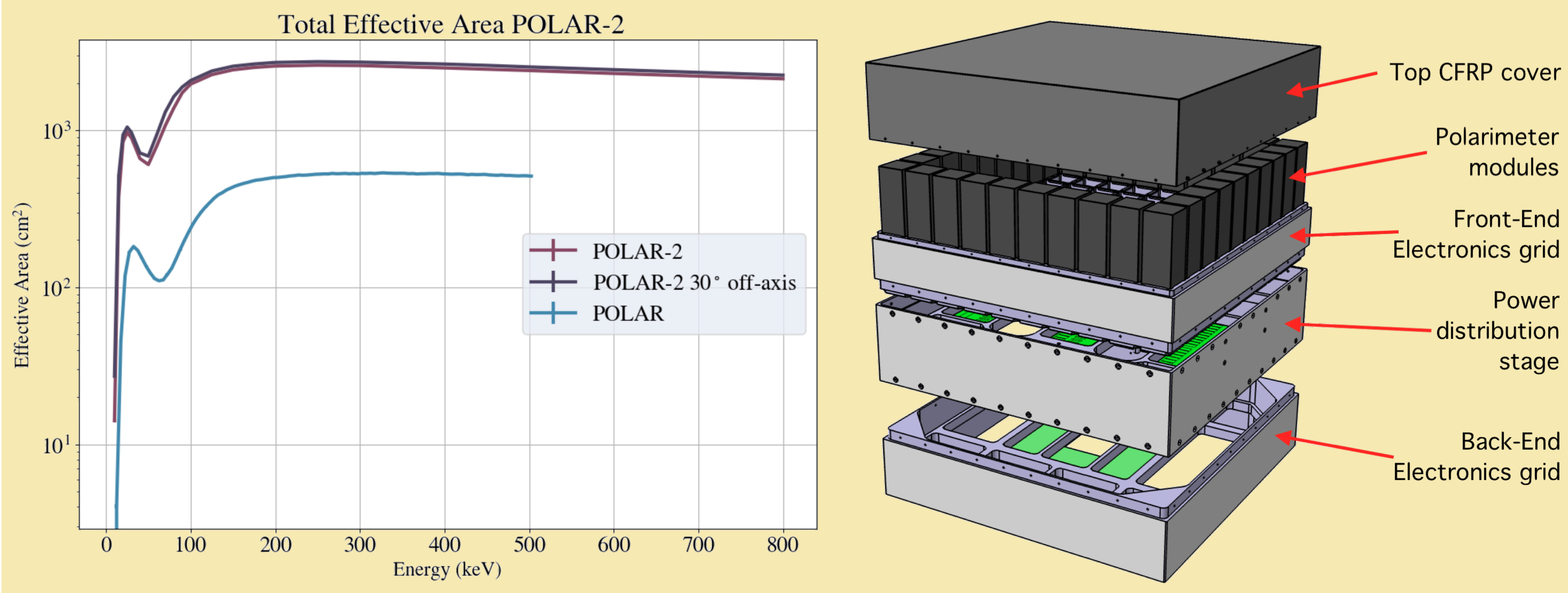

Figure 2: Left: the total effective area of POLAR-2 that can be used for alerting. It can be seen that POLAR-2 is significantly more sensitive at low energies thanks to the SiPM technology, Right: an exploded view of the POLAR-2 high energy polarimeter. We can see the 100 modules in black and the electronics in green. Taken from [1, 3].

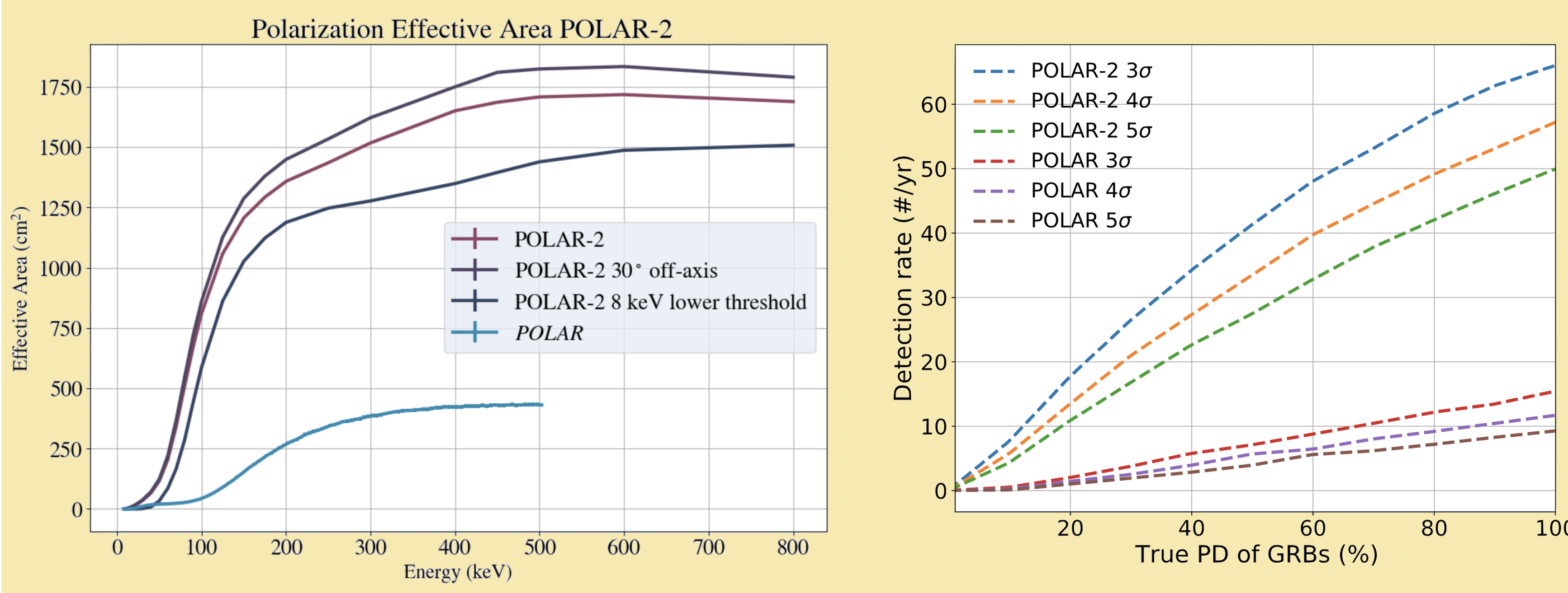

Figure 3: Left: the effective area for polarisation measurement versus initial photon energy. Right: the number of GRBs for which a significant polarization measurement can be performed per year as a function of their intrinsic polarization. The significance of the measurement is shown for various confidence levels. Taken from [3, 4].

Take-home Messages

- In 2027, POLAR-2 will detect GRBs with the largest grasp ever flown;
- POLAR-2 will obtain a larger sample of GRB prompt polarization measurement and investigate their temporal and energy evolution;
- POLAR-2 will play an important role in multi-messenger astrophysics.

References

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[4] Gill R., et al., *Galaxies 9, 82* (2021)

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