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The GRB221009A gamma-ray burst as revealed by the gamma-ray spectrometer onboard the KPLO (Danuri)

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The strongest gamma-ray burst (GRB) of the century, GRB20221009A, has been detected by the Korean Pathfinder Lunar Orbiter Gamma-ray Spectrometer (KGRS) instrument onboard the Korean Pathfinder Lunar Orbiter (KPLO). KGRS uses a $LaBr_3$ detector to measure GRB counts with five energy bins in the energy range from 30 keV to 12 MeV. KGRS detected GRB221009A at a distance of 1.508 million kilometers from the Earth. The full duration of the main burst was recorded between 13:20 and 13:26 on October 9, 2022 with peak counts of over 1000 times background. The dead time of KGRS reached as high as 50%, and the intrinsic gamma-ray spectrum of $LaBr_3$ was significantly altered.

Gamma-ray bursts (GRBs) are the most energetic of known astrophysical events. Discovered in 1967[1] by the Vela Satellite Network, the physics of GRBs remains mostly unsolved. The GRB 221009A burst, which occurred on October 9, 2022, dubbed the brightest of all time (BOAT), was the strongest gamma-ray burst ever recorded. Observations made by the Swift-BAT instrument and Fermi Gamma-ray Burst Monitor (GBM) showed that it was an extremely bright and long duration burst[2,3]. Photon energies of GRB221009A reached up to 18 TeV, which was the first time that energies greater than 10 TeV have been observed[4]. The first report of global ionospheric disturbances due to the powerful GRB221009A was also reported[5,6]. The GRB221009A was detected by many instruments; the Konus-WIND experiment [7], the Spectrometer Telescope for Imaging X-rays (STIX)[8] onboard Solar Orbiter[9]; Very Low Frequency (VLF) and Low Frequency (LF) sub-ionospheric radio signals, which are used to diagnose the effect of the GRB on the lower ionosphere[5]. The THEMIS ESA and SST particle detectors also detected GRB221009A[10]. The GRB 221009A event has been identified as the brightest of all time (BOAT), and it appears to be a one-in-10,000-year event[11].

Here we report on the detection of GRB221009A by the KPLO (Korea Pathfinder Lunar Orbiter) Gamma-Ray spectrometer (KGRS) on October 9, 2022. KPLO (also officially named as "Danuri") was launched by a SpaceX Falcon 9 rocket from Cape Canaveral Space Force Station on August 5, 2022 (KST). The KGRS is one of six scientific instruments onboard the KPLO, which arrived in lunar orbit at an altitude of 100 km on December 27, 2022. During the cruise period of 4 months and 3 weeks, the KGRS was monitoring both gamma-ray bursts and background to perform its scientific objectives in deep space.

Methods

KGRS instrument

The KPLO Gamma-Ray Spectrometer (KGRS) is a compact light-weight instrument (6.3 kg) for the elemental analysis of lunar surface materials within a gamma-ray energy range from 30 keV to 12 MeV. The major components of KGRS consist of a primary 3"(ϕ) × 6 cm (H) $LaBr_3$ gamma-ray detector with an anti-coincidence counting module of 5% boron-loaded plastic scintillator to reduce both gamma-ray background from the spacecraft

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and housing materials, and cosmic ray background. The shape of BLPS detector surrounds the main detector as a horseshoe shape. The thickness of the BLPS detector ranges from 5.3 to 0.7 cm (Fig. 1). The anti-coincidence spectrum is collected by rejecting coincidence counts in the time frame between −20 ns and + 1 μs. During operation, the field of view of the KGRS is set to the nadir direction unless the anti-nadir direction is requested for a special measurement. The science goals of KGRS are associated with investigations of both lunar geology and lunar resources down to a half-meter depth below the lunar surface. Because the KPLO utilized BLT (Ballistic Lunar Transfer) trajectory in order to arrive on the Moon, it was possible for KGRS to collect signals of gamma-ray counts for the duration of its 4.5 months transfer. KGRS is designed to monitor GRBs in five energy bins, plus high gain and low gain gamma-ray $LaBr_3$ background spectra sensors, and a Boron-Loaded Plastic Scintillator (BLPS) shielding detector. The KGRS count data in all channels are integrated over a period of 10 s.

The energy ranges of the five specially designed KGRS GRB monitoring bins are: 35–65, 65–123, 35–123, 123–418 and 418–3607 keV. When KGRS collected the strong GRB221009A gamma-ray signals, it was located 1,508,160 km from Earth, which was almost the farthest distance it reached during its four-month BLT trajectory (Fig. 2).

Results

KGRS observed 40 GRB events at different magnitudes from August 9, 2022, to June 30, 2023. KGRS was able to record during the entirety of the GRB221009A event. At the peak of the burst, raw KGRS gamma-ray counts were as high as 98 times the background level, although it is different in each GRB counting bin. All KGRS GRB221009A light curve signals compare well with other publicly reported gamma-ray monitoring data during the duration of the main GRB arrivals (Fig. 3).

The interference of the GRB221009A emissions with the KGRS gamma-ray sensors is demonstrated in Fig. 4. The main sensor of KGRS is made of $LaBr_3$ which has an intrinsic gamma-ray background due to both ^{138}La and ^{227}Ac radioisotopes. In Fig. 4, the intrinsic gamma-ray background in the deep space environment is compared with the two GRB221009A peak arrivals. The first strong arrival occurred at 13:21 (UTC) followed by the second strong arrival 6 min later. Total counts for the main $LaBr_3$ detector in the energy range from 30 to 6500 keV are

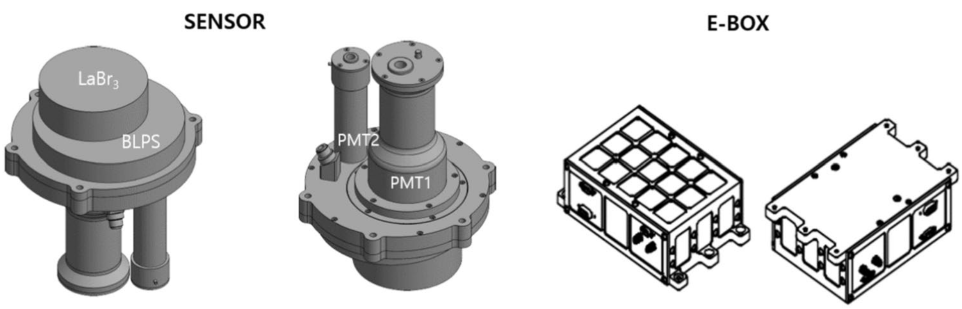

Figure 1. Configuration of the KPLO gamma-ray spectrometer sensor and electronics unit.

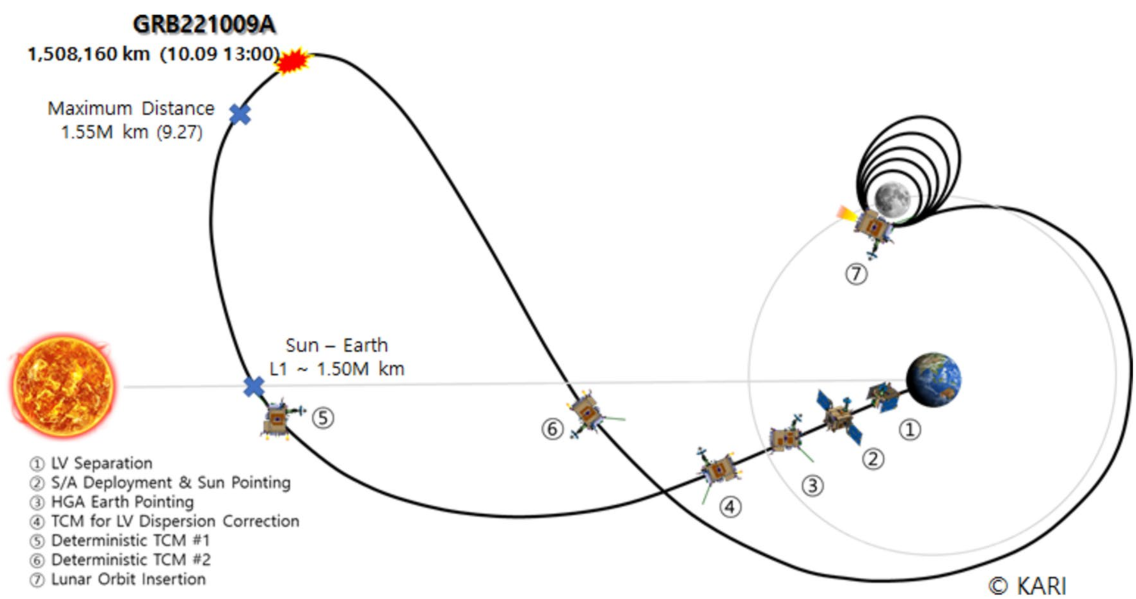

Figure 2. Location of KPLO when KGRS measured gamma-ray signals of GRB221009A (not to scale).

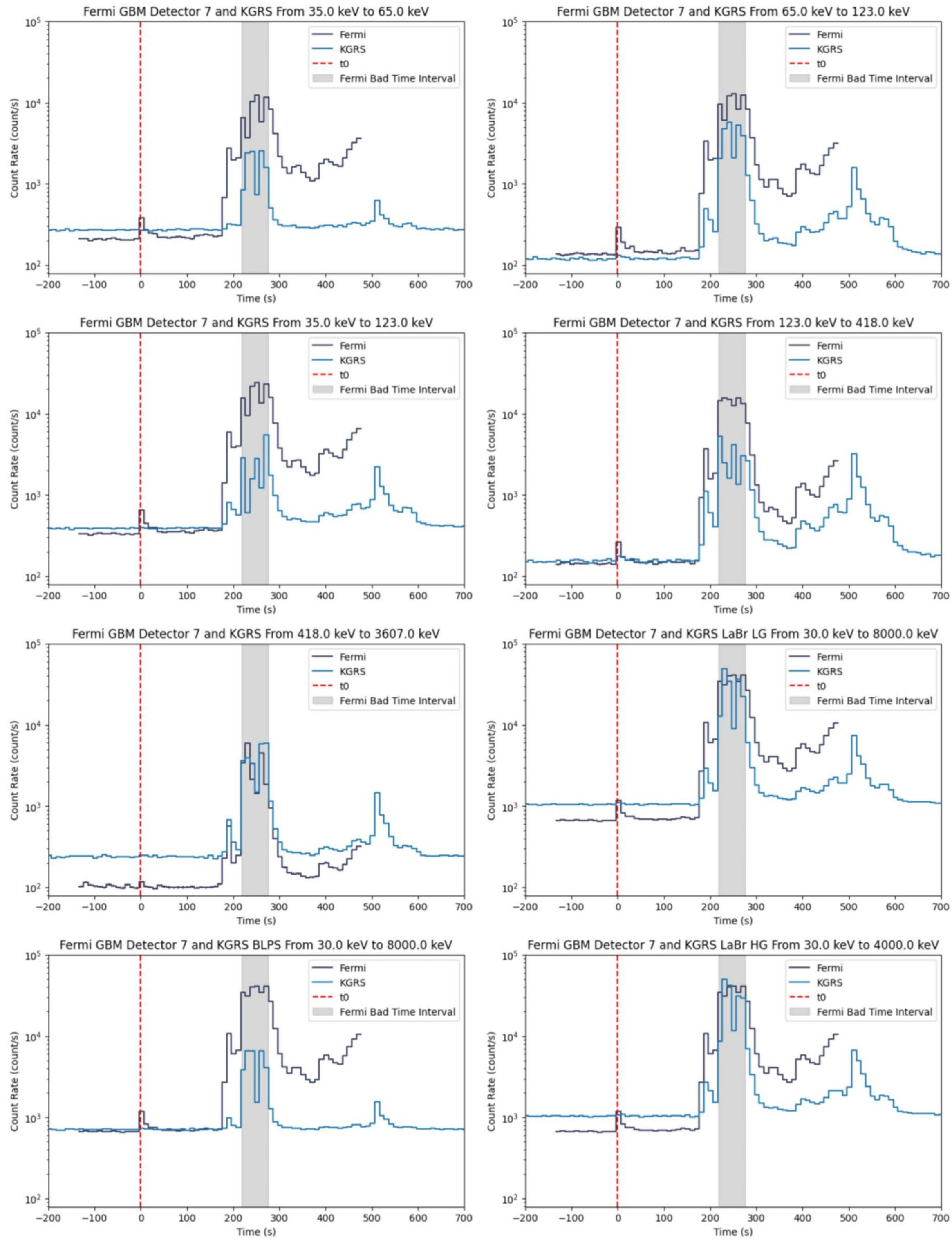

Figure 3. Comparison between KGRS and available Fermi Gamma-ray Burst Monitor (GBM) Detector 7 count rates versus time since initial trigger at 13:16:59.99 UTC[12]. The Fermi data have been re-binned using the same energy and time bins as KGRS. Grey shaded areas indicate the Fermi "Bad Time Interval" where counts are unreliable due to pulse pile up. Based on the known direction of the GRB source, the light-time difference between Fermi and KPLO is estimated to be 1.955 s. Errors due to Poisson counting statistics during the KGRS 10-s measurement intervals are on the order of less than 1% and have no appreciable effect on the interpretation.

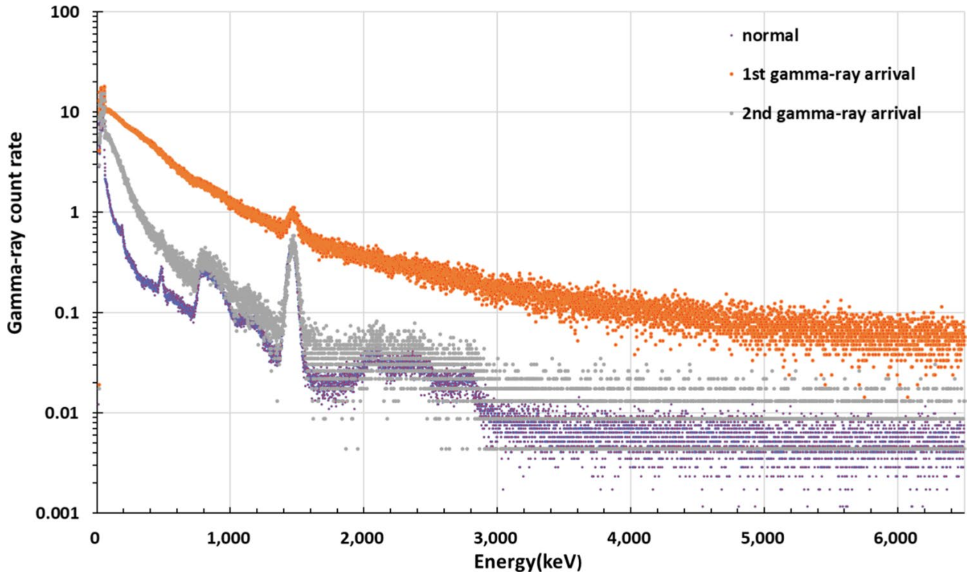

Figure 4. Comparison of gamma-ray spectrum measured during the gamma-ray burst and background. The mean count rate(cps) for "normal", "1st gamma-ray arrival", and "2nd gamma-ray arrival" are 1030.0, 17,770.2, and 5008.8 for the measurement time (s) of 1800, 80, and 30, respectively. The uncertainties (%) of these are calculated as 0.23, 0.27, and 0.82, respectively.

recorded to be 948, 1,401,656, and 4971 for background level, 1st arrival, and 2nd arrival, respectively. At the peak of the first arrival, KGRS counts rates were up to 1479 times stronger than background, without considering dead time. The measured energy spectra of the peak events were generally featureless, and the ratio between the peaks of the 1st and 2nd GRB events was 282.

Figure 5 demonstrates the quantity of packet data, dead time, high voltage variations for both the main detector and for the shielding detector, and energy spectra for both the main detector and shielding detector of

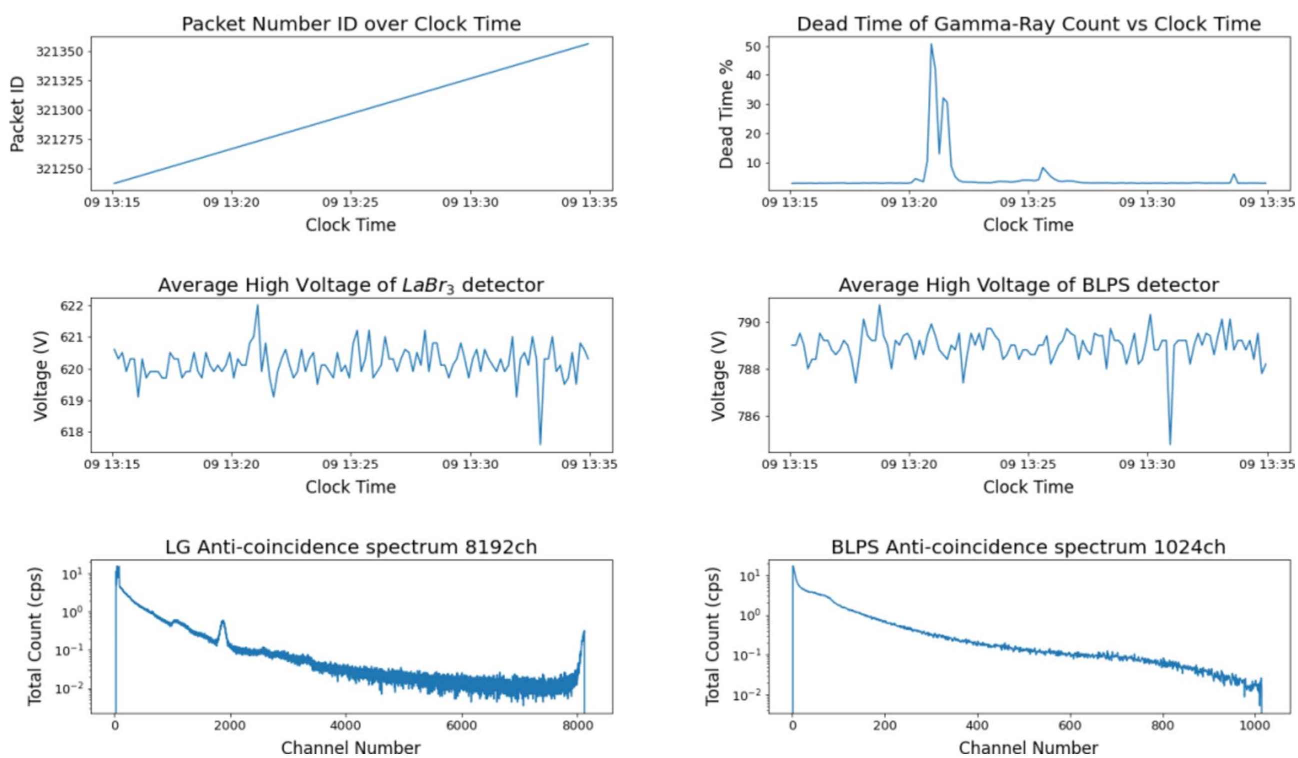

Figure 5. KGRS data for deadtime, HV variations and gamma-ray spectra of the main and shielding detector for the 7 min of the GRB221009A event. The standard deviation of the high voltage during the period of the gamma-ray burst is less than 0.1%, so the electronic circuit is believed to be unaffected by the gamma-ray burst.

KGRS during the first 7 min of the GRB event. The dead time during the GRB event is recorded as high as 50%. This implies that the dead time corrected counting signals will be higher than the value reported here. As demonstrated by the housekeeping and high voltage data, the KGRS instrument did not experience any significant interference during the 7-min peak GRB221009A event.

Conclusion

GRB221009A produced very strong transient signals relative to KGRS background levels. While KGRS was designed primarily as a planetary gamma-ray spectrometer, the measured gamma-ray burst signals were within the spectrometer's detection capability. The detection and quantification of GRBs in deep space by planetary gamma-ray spectrometer instruments can complement measurements made by dedicated GRB observatories.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available because [not necessary, as the figures in this manuscript sufficiently explain the scientific results of the GRB measurements made by the KGRS instrument], but are available from the corresponding author upon reasonable request.

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Author contributions

K.J.K. did data analysis and interpretation of the data, S.Y.K., K.Y.K. contributed to data processing. D.P. and J.G. contributed scientific interpretation of data and analysis. All the authors contributed to the discussion of the results and to writing the paper.

Competing interests

The authors declare no competing interests.

Additional information

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