Future Perspectives for Gamma-ray Burst Detection from Space

Frontier Research in Astrophysics - IV

Mondello, Italy – 13th September 2024

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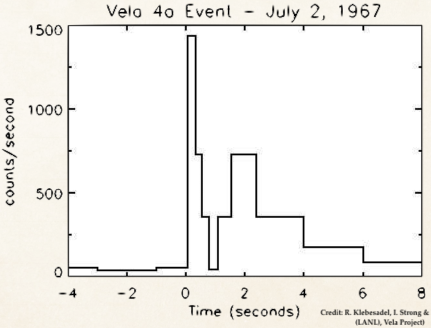
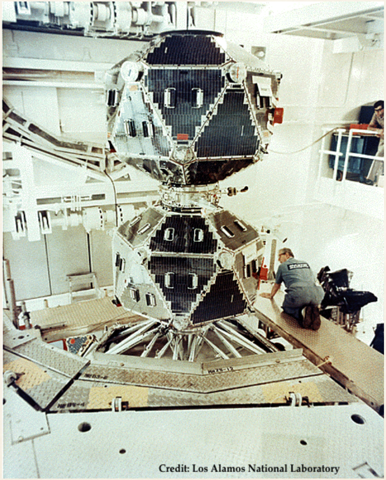
Introduction: GRB Discovery

- Project Vela from USAF monitoring compliance to the Partial Test Ban Treaty of 1963
- First GRB detected on July 2nd, 1967 by Vela-4A, published 6 years later
- Publication of 16 GRBs in 1973 by Klebesadel et al.



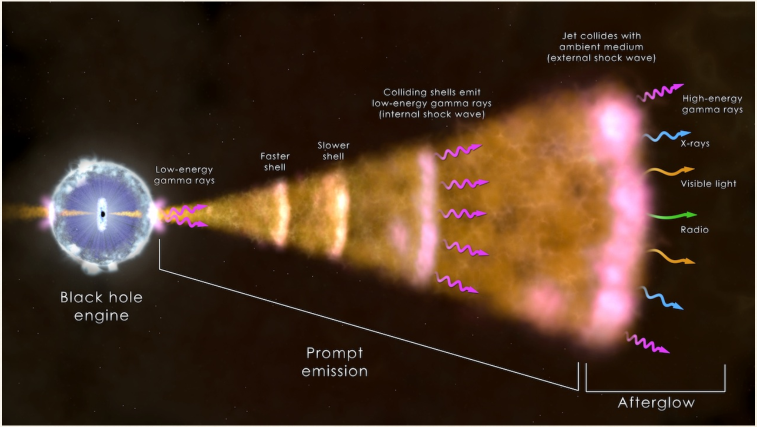
Credit: R. Klebesadel, I. Strong & R. Olson (LANL), Vela Project)



Credit: Los Alamos National Laboratory

Introduction: The Gamma-Ray Bursts paradigm

- Bright and short transient event in the γ band (**prompt emission**) followed by an **afterglow** spanning the entire EM spectrum



(Credit: NASA's Goddard Space Flight Center)

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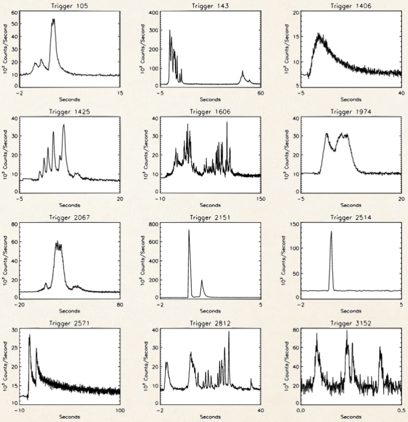

(Credit: J.T. Bonnell (NASA/GSFC))

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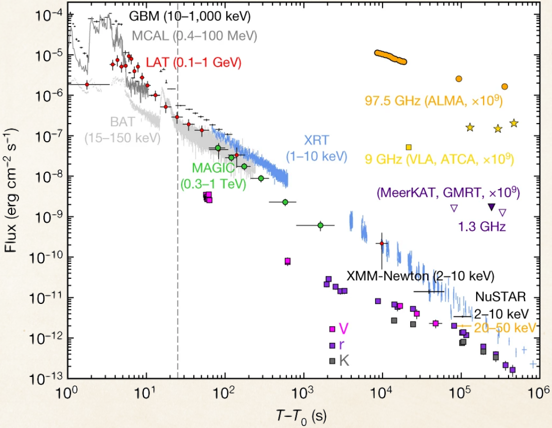
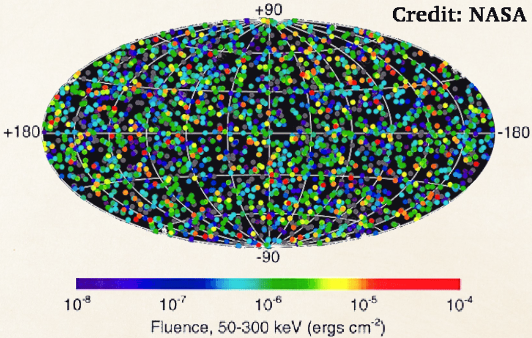


(Credit: Nature 575, 459–463, 2019)

Introduction: The Gamma-Ray Bursts paradigm

- Bright and short transient event in the γ band (**prompt emission**) followed by an **afterglow** spanning the entire EM spectrum
- GRBs are uniformly distributed in the sky, have very diverse spectral properties and fluence, and are of extragalactic origin



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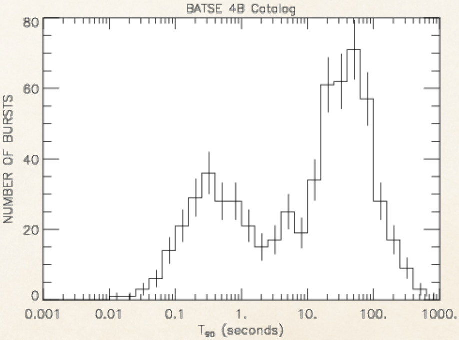
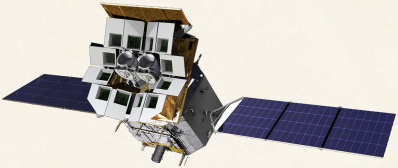
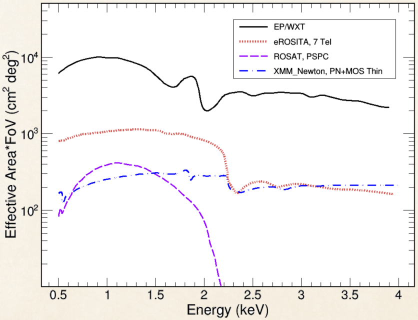
- GRBs are uniformly distributed in the sky, have very diverse spectral properties and fluence, and are of extragalactic origin
- Classified in two categories: short GRBs (T_{90}<2 s) are originated by binary compact object merger, long ones (T_{90}>2 s) are associated with supermassive star explosions



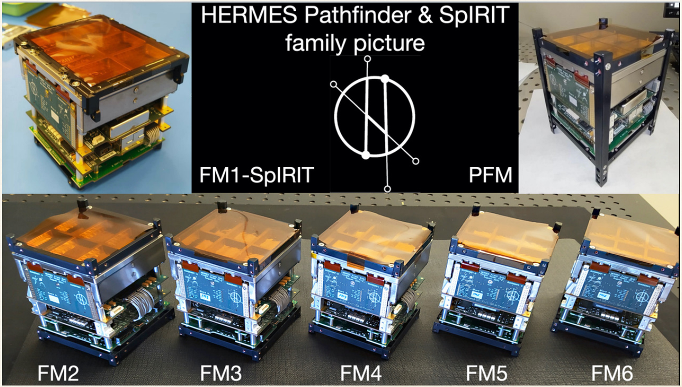
(Credit: BATSE 4B Catalog, Robert S. Mallozzi)

- Surveying high-energy transients in the soft X-ray band
- Launched on 9th January 2024
- Wide-field X-ray Telecope (WXT) based on novel lobster-eye micro-pore optics technology, 12×300 deg^2 – 0.5-4 keV – 2’
- Follow-up X-ray Telescope (FXT): 2 telescopes based on Wolter-I optics (similar mirror assembly than eROSITA), 60’ diameter – 0.3-10 keV – 5-15” (90% c.l.)
- Led by CAS, with collaboration of ESA, MPE, CNES
- Sending many GCN Circular alerts



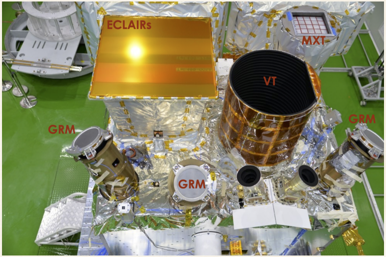


- High Energy Rapid Modular Ensemble of Satellites (HERMES): Cubesat constellation for GRB triangulation, based on GAGG crystals coupled to SDDs (used both to optically readout the scintillators for γ-ray measurements and as an X-ray spectrometer)
- First payload sent on-board the SpIRIT Australian Cubesat last December $\rightarrow$ **see talk by Ezequiel Marchesini tomorrow**



SVOM

- Space-based Variable astronomical Object Monitor (SVOM) launched on 22nd June 2024
  $\rightarrow$ **see next talk by Diego Gotz**
- Dedicated network of ground optical telescopes for afterglow follow-up

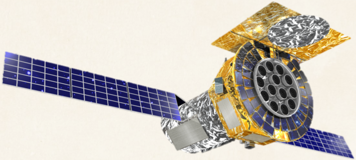


	ECLAIRs	GRM	MXT	VT
Energy/Wavelength	4–150 keV	15–5000 keV	0.1–10 keV	650–1000 nm
Field of View	2 sr	2.6 sr (combined)	$58' \times 58'$	$26' \times 26'$
Localization Accuracy	$<12'$	$<20°$	$<2'$	$<1''$
Expected GRBs Year^{-1}	60	90	50	40

enhanced X-Ray Timing and Polarimetry (eXTP)

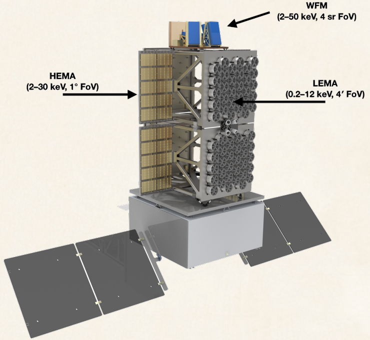
The eXTP mission, born from XTP and LOFT, will be composed of:

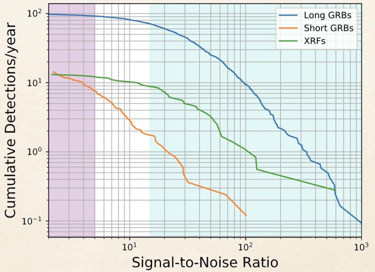
- Large Area Detector (LAD): effective area of 3.4 m^2 in the 6-10 keV range, FoV $< 1^\circ$, full range 2-30 keV, energy res. of 250 eV at 6 keV
- Spectroscopic Focusing Array (SFA): 0.5-10 keV, 9 X-ray optics of 12' FoV each, time resolution of 10 μs
- Polarimetry Focusing Array (PFA): based on imaging GPD, 4 telescopes, polarimetry in 2-10 keV
- Wide Field Monitor (WFM): 6 coded mask cameras, FoV of 5.5 sr in 2-50 keV
  - WFM based on SDD technology coupled with coded masks, localization/timing/spectral accuracy of <1 arcmin/10μs/<300 eV at 6 keV, detection rate of 100 GRBs/yr
  - The European contribution is currently blocked, the current plan is to have only SFA (9$\rightarrow$5) and PFA (4$\rightarrow$3) + probably another version of wide field monitor by Chinese institutes



STROBE-X

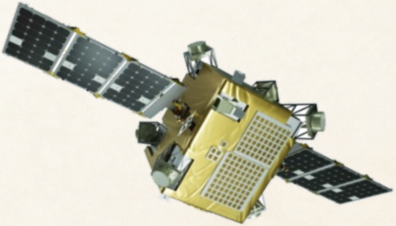
- Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays
- Proposal led by NRL for the NASA call for an X-ray probe-class mission
- Low-Energy Modular Array (LEMA) covers the soft or low-energy band (0.2–12 keV), 85–175 eV energy resolution and 100 ns time resolution, based on technology developed for NICER
- High-Energy Modular Array (HEMA) covers the harder or higher energy band (2–30 keV or beyond), 3.4 m^2 eff.area and spectral resolution of 200–300 eV, based on SDD technology developed for eXTP
- Wide-Field Monitor (WFM) comprises a set of coded-aperture cameras operating in the 2–50 keV band, FoV of 1/3 of the sky and arcmin localization
- Trigger by GW events and repointing <11.5 min for accessing early X-ray afterglow

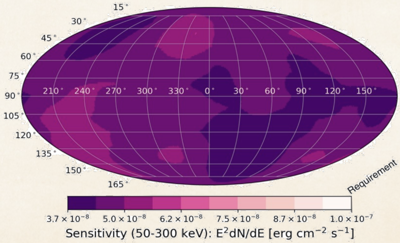




MoonBEAM

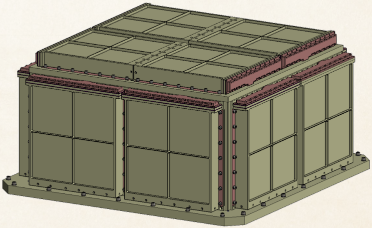
- The Moon Burst Energetics All-sky Monitor (MoonBEAM) is proposed to be operated in cislunar orbit (to reduce Earth occultation from 30% down to $\ll$1% of the sky) as an all-sky γ-ray monitor
- Sensitive in the 10–5000 keV range, with an energy resolution better than 12% at 662 keV
- Planned to detect 1000 GRBs over 30 months of operation, with a localization accuracy similar to that of Fermi-GBM

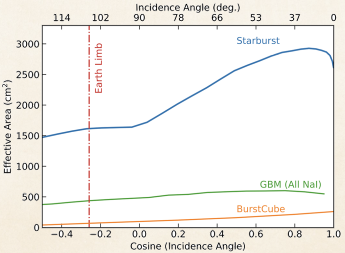




StarBurst

- SmallSat to be deployed to LEO in 2027 to match the O5 run of LIGO
- Based on the heritage of the GBM, Glowbug, and BurstCube instruments
- Consists of 12 plates of 24 cm$\times$24 cm$\times$1.6 cm of NaI(TI) read out by 2$\times$38 linear arrays of 6 mm$\times$6 mm SiPMs
- Housed in aluminum transparent down to 30 keV with a beryllium-copper back shield cutting the sub-200 keV photons
- Energy range of 30 keV to 2 MeV, 1 σ localization accuracy of 3° for a GRB170817A-like peak flux ($\sim$3 photons cm^{-2} s^{-1})
- Similar duty cycle and FoV than Fermi-GBM, detection rate of 158 sGRBs/yr (40 and 8.6 sGRBs/yr for GBM and Swift)

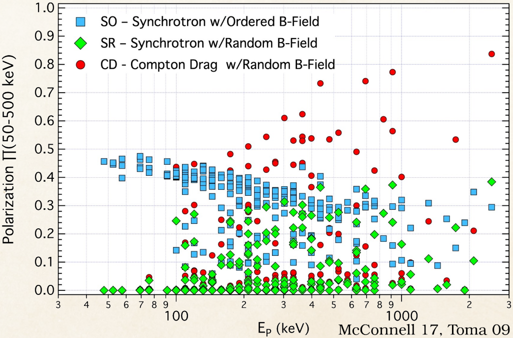




GRB prompt polarization

Spectral information alone does not allow to disentangle the existing emission models.
Measuring polarization is a very powerful tool to probe the physics of GRBs, as it can inform us about:

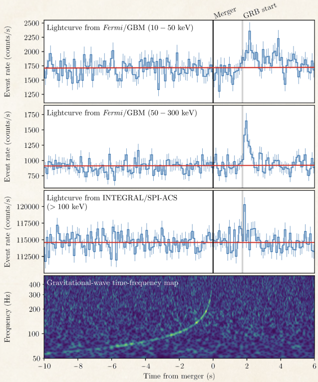
- The emission mechanism at play in the source (synchrotron vs. photospheric)
- The outflow dynamics: Kinetic Energy vs. Poynting Flux Dominated
- The jet angular structure: top hat jet, with smooth edges, truly structured
- The magnetic field configuration (random, ordered)

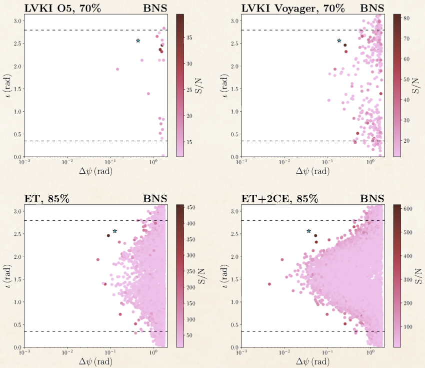


McConnell 17, Toma 09

GRB prompt polarization & GW detection

Combining gamma-ray polarization of short GRBs and detections of GWs from binary neutron star systems would allow to rule out most of the emission models in a few measurements (Kole et al. 2023 A&A 669, A77)





B. P. Abbott et al 2017 ApJL 848 L13

Kole et al. 2023 A&A 669, A77

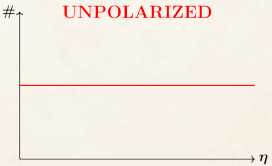
Compton Polarimetry

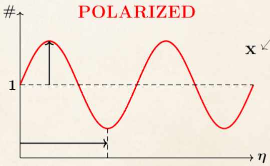
Compton scattering can be used to determine the polarization of a source:

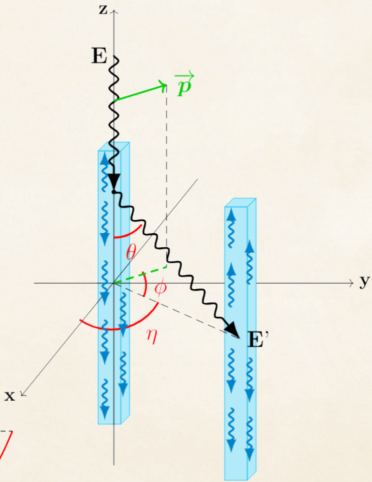
- Azimuthal scattering angle distribution provides information on PD and PA
- Modulation curve parameterized by the Klein-Nishina cross-section:

$$\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2}\left(\frac{E'}{E}\right)^2\left[\frac{E'}{E} + \frac{E}{E'} - 2\sin^2(\theta)\cos^2(\phi)\right]$$

- Relative amplitude $\leftrightarrow$ PD, phase $\leftrightarrow$ PA
- **A segmented array of scintillators can be used to measure the scattering angle distribution (aka modulation curve)**

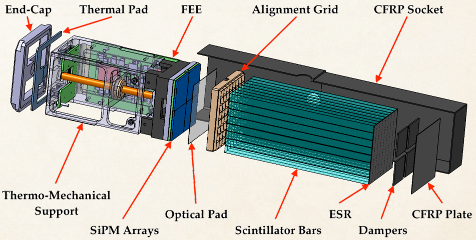


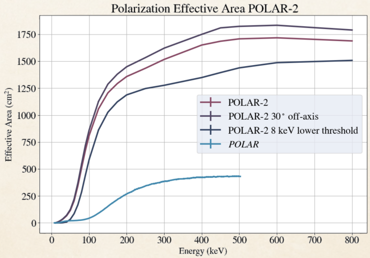




POLAR-2

- Based on the legacy of POLAR which reported low integrated PD for 14 GRBs and hint for temporal evolution of the PA (A&A 644 A124 2020)
- Array of 6400 plastic scintillators bars (single phase polarimeter) read out by SiPMs, divided into 100 modules
- Collaboration between UniGe (CH), MPE (DE), IHEP (CN), NCBJ (PL)
- Schedule for a launched in 2027 to the CSS, coincident with LIGO/Virgo O5 run, ability of fast alerts to the ground (within 1 minute)
- Baseline 2-years operation, aims to detect 50 GRBs/yr with better quality measurements than the best by POLAR





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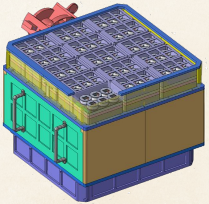
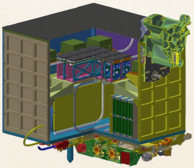
- Two other payloads being proposed in China to be operated together: a low energy polarimeter (based on GPDs) by GuangXi University and a spectral imager (based on GAGG crystals + coded mask) by IHEP

➢ Low-energy Polarization Detector: LPD
- ~2-10 keV X-ray polarimetry

➢ Broad energy-band Spectrum Detector: BSD
- ~10-2000keV
- Accurate GRB localization and spectroscopy for HPD and LPD

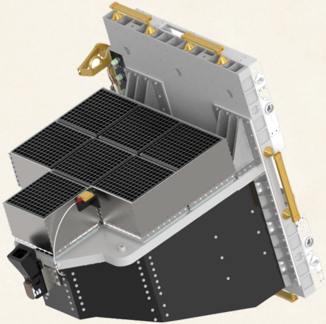
➢ Status: Selected, to be adopted

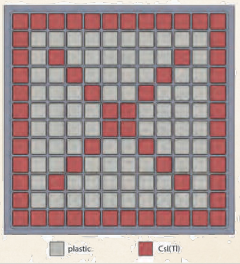

LPD


BSD

The LargE Area burst Polarimeter (LEAP)

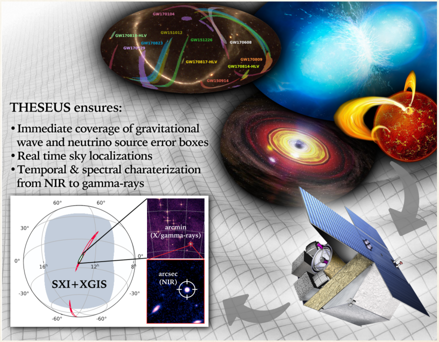
- Dual phase wide-FoV Compton polarimeter: Plastic scatterers + CsI absorbers, read out by PMTs from Hamamatsu
- 7 modules of 12×12 arrays
- Polarimetry from 50 keV to 1 MeV, spectroscopy from 20 keV to 5 MeV
- Baseline observation of 65 GRBs with a minimum detectable polarization (MDP) of 30% or better for population studies
- Proposed for a 3-years operation from 2027 on the ISS, unfortunately not selected

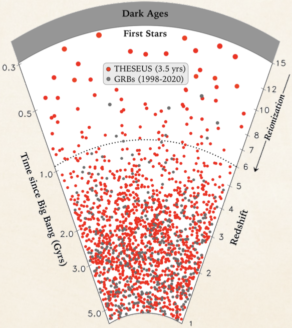




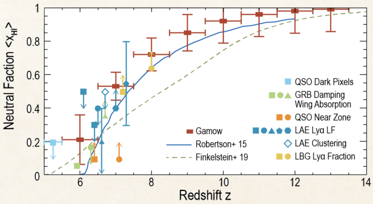
THESEUS

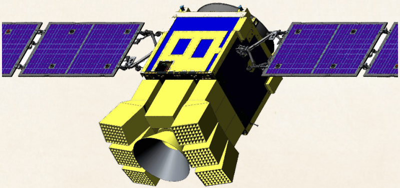
Transient High-Energy Sky and Early Universe Surveyor (THESEUS) will study GRBs at high redshift (re-ionization epoch). Multi-band with 3 instruments: Soft X-ray Imager (SXI, 0.3–5 keV) based on lobster-eye wide-field ($\sim$0.5 sr) focusing optics, X- and Gamma-ray Imaging Spectrometer (XGIS, 2 keV–10 MeV) based on GAGG+SDD, Infra-Red Telescope (IRT, 0.8–1.6 μm) for photometry+spectroscopy $\rightarrow$ **see talk by Smiriti Srivastava tomorrow**





- Similar science goals than THESEUS: detection of high redshift GRBs and EM counterpart measurements of GW events
- The Gamow Explorer was proposed in the 2021 NASA MIDEX call, composed of two instruments: lobster-eye X-ray telescope (LEXT) and photo-z infra-red telescope
- HiZ-GUNDNAM is proposed as a medium-class mission at ISAS/JAXA, made of two payloads: wide-field X-ray monitor (WFXM) and near-infrared telescope (NIRT)





Summary

- GRB observation has a bright future with many space-based missions being planned or proposed
- This was only a non-exhaustive list of selected missions, there are indeed many more instruments out there (e.g. CATCH, DAKSHA, GECAM-E...)
- A review can be found in **Bozzo et al. 2024, Universe**:

universe MDPI

Review

Future Perspectives for Gamma-ray Burst Detection from Space

Enrico Bozzo [1,*,†], Lorenzo Amati [2], Wayne Baumgartner [3], Tzu-Ching Chang [4], Bertrand Cordier [5], Nicolas De Angelis [6,7], Akihiro Doi [8], Marco Feroci [7], Cynthia Froning [9], Jessica Gaskin [3], Adam Goldstein [10], Diego Götz [5], Jon E. Grove [11], Sylvain Guiriec [12,13], Margarita Hernanz [14,15], C. Michelle Hui [3], Peter Jenke [16], Daniel Kocevski [3], Merlin Kole [6], Chryssa Kouveliotou [12], Thomas Maccarone [17], Mark L. McConnell [18,19], Hideo Matsuhara [8], Paul O'Brien [20], Nicolas Produit [1], Paul S. Ray [11], Peter Roming [9], Andrea Santangelo [21], Michael Seiffert [4], Hui Sun [22], Alexander van der Horst [12], Peter Veres [16], Jianyan Wei [22], Nicholas White [12], Colleen Wilson-Hodge [3], Daisuke Yonetoku [8,23], Weimin Yuan [22,24], Shuang-Nan Zhang [24,25]

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