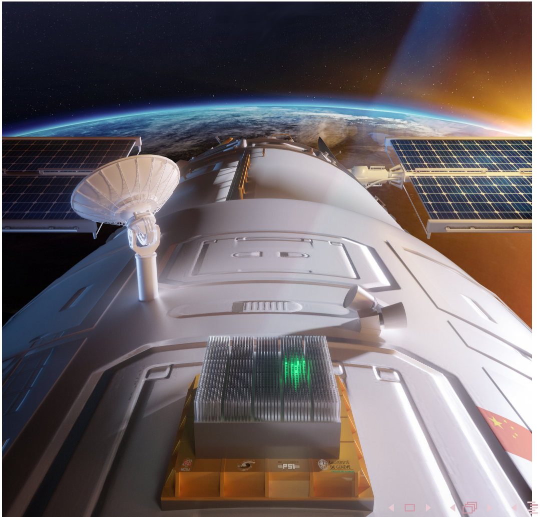
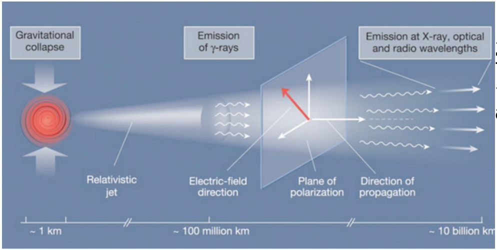
Gamma-Ray Burst Polarimetry with POLAR-2

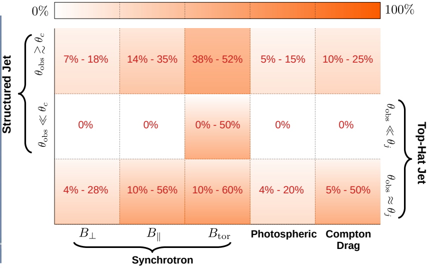
Merlin Kole on behalf of the POLAR-2 collaboration



Gamma-Ray Burst Polarimetry



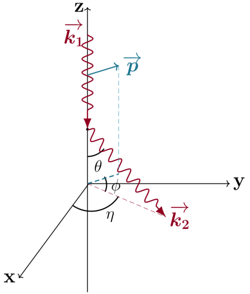
E. Waxman, Nature 423 (2006) 388

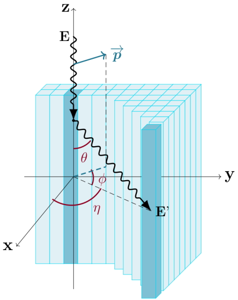


- Measure polarization of the γ-ray prompt emission of GRBs
- Unique probe into the jet environment
- Simplified: synchrotron would give high polarization, thermal emission no/low polarization
- Overview: Kenji Toma arXiv:1308.5733 and R. Gill et al. arXiv:2109.03286

- Azimuthal scattering angle (ϕ) depends on polarization vector
- Preferential scattering perpendicular to polarization vector
- Segmented detector allows to measure angle
- Scattering angle distribution $\rightarrow$ Modulation Curve

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\mathrm{r}_{\mathrm{o}}^2}{2}\frac{\mathrm{E}'^2}{\mathrm{E}^2}\left(\frac{\mathrm{E}'}{\mathrm{E}} + \frac{\mathrm{E}}{\mathrm{E}'} - 2\sin^2\theta\cos^2\phi\right). \tag{1}$$





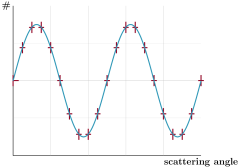
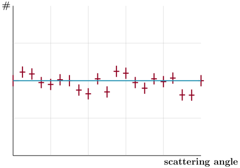
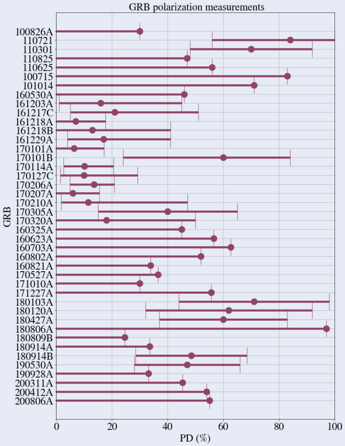


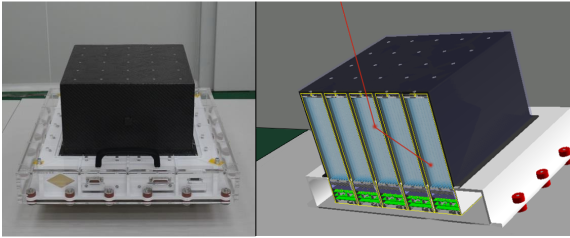
Figure 8: Modulation Curve



Recent measurement results



- Measurements by calibrated polarimeters:GAP, POLAR, COSI + AstroSAT
- Wide FoV segmented detectors
- PD now appears to be low ($< 50\%$)
- Still, no clear image of time integrated PD
- Hints of time evolution (see e.g. Burgess et al 2019)



POLAR-2

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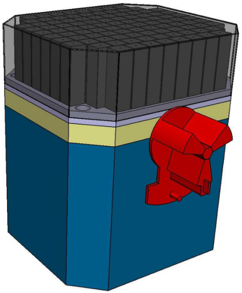
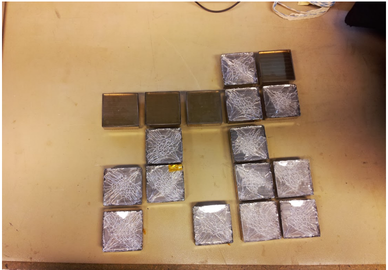
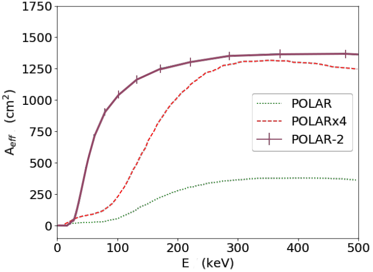
- POLAR results raised more questions
- We need a significantly more sensitive detector: POLAR-2
- Launch approved to go to the CSS in early 2025
- `https://www.unige.ch/dpnc/polar-2`

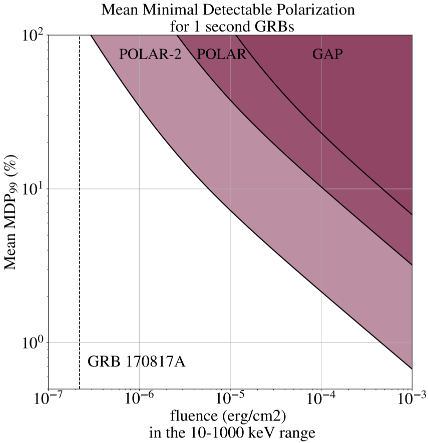


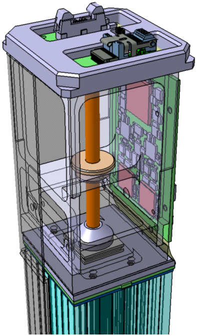
- Photons scatter in segmented plastic scintillator array
- 6400 scintillator bars of 5.9x5.9x125 mm
- In POLAR readout was with Multi-Anode PMTs
- Replaced with SiPM arrays (S13, 75μm)
- Higher Q.E. and more direct coupling (250μm pad) to scintillator improves light yield
- Light yield per scintillator: 1.6 p.e./keV $\rightarrow$ 0.3 p.e./keV for POLAR
- Also more robust and no HVPS required



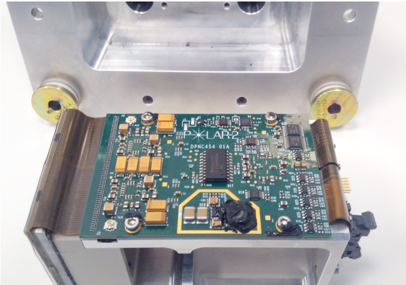
- 4 times larger than POLAR
- Technological improvements provide another factor 2.5
- Main gain at lower energies
- Gain of factor 10 for typical GRB
- Capable of rudimentary polarization measurements for GRBs with a fluence exceeding $4 \times 10^{-7} \mathrm{erg/cm^2}$



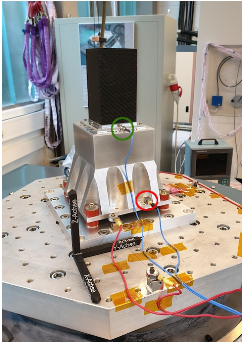




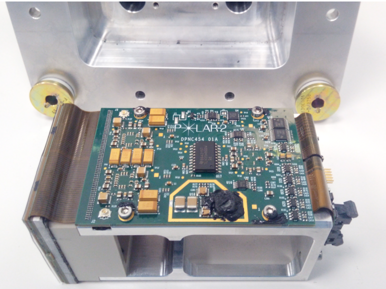
- Design to readout 64 SiPM channels
- 2 CitiROC ASICs for SIPM readout
- FPGA for trigger logic
- Regulated HVPS for SiPM
- Power consumption 1.7 W (3.8 V input)
- Optimal cooling for SiPM
- Peltier element for extra cooling SiPM



FEE Design

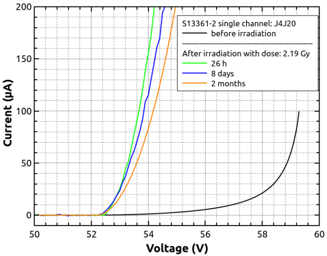


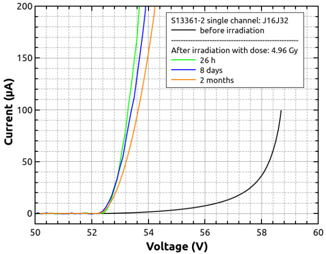
- Tested with plastic scintillators
- Tests with CeBr3 to be started soon
- Successfully tested in shock/vibration/TVT at MPE
- COST components (no ITAR)



SiPM Radiation Tests

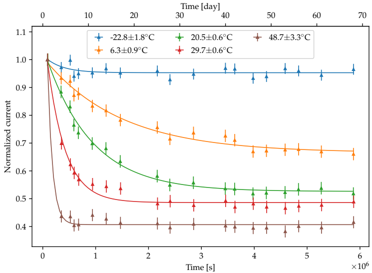
- Dedicated campaign to measure degradation of Hamamatsu S13 SiPM arrays
- Irradiation with 58 MeV protons at IFJ Krakow
- Dose upto 2.31 Gy, equivalent to 20+ years in space
- Dedicated simulations to determine in-orbit dose → except $\sim 0.1\mathrm{Gy/year}$
- Dark current increases by order of magnitude during mission
- Upcoming paper by S. Mianowski et al. (online in a few days)

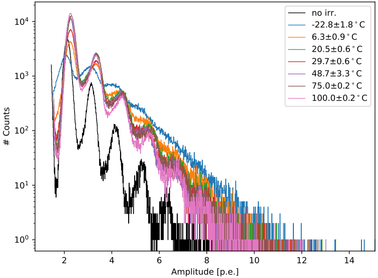




SiPM Radiation Tests

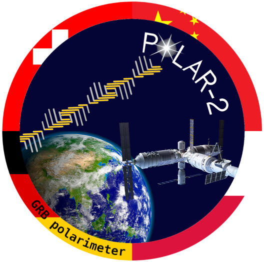
- Annealing shoul go faster with temperature
- Dedicated tests in Geneva
- Results show recovery of $\sim 60\%$ within days at 50 deg.
- Possible to reverse current in Peltier to heat/anneal SiPMs in orbit
- Detailed paper by N. de Angelis et al. in final stages



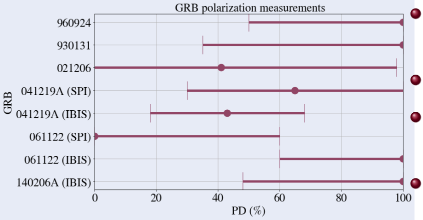


Summary

- Polarization of GRB prompt emission highly interesting
- Previous measurements lacked required sensitivity
- POLAR-2 will perform 10's of detailed measurements per year
- Adaptable FEE developed and tested in Geneva
- SiPM dark noise small issue, annealing helps



Early measurement results



- Measurements by RHESSI/BATSE/INTEGRAL (SPI + IBIS)
- Segmented designs allows for polarimetry
- Not-dedicated instruments: low sensitivity + prone to systematics
- PD not really constrained