



Energy-dependent polarization of Gamma-Ray Bursts' prompt emission with POLAR and POLAR-2

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Nicolas De Angelis¹ for the POLAR and POLAR-2 collaborations²

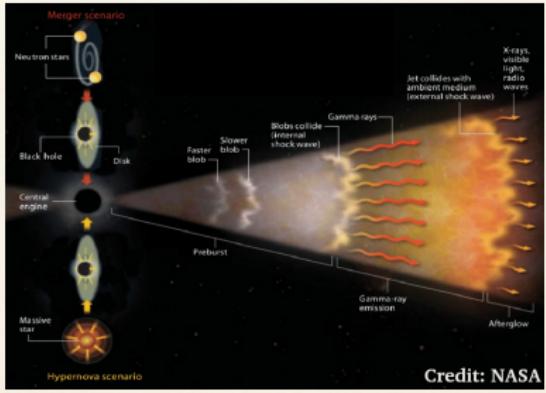
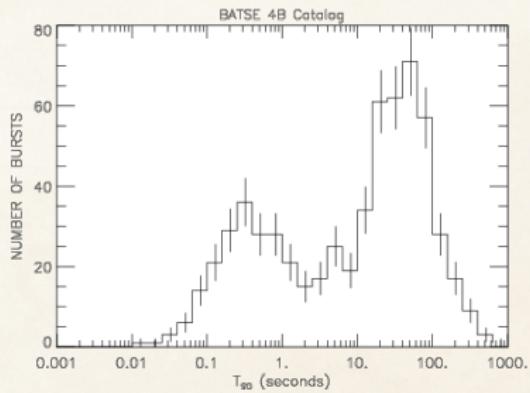
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²<https://www.astro.unige.ch/polar/collaboration>
<https://www.unige.ch/dpnc/polar-2>

Gamma-Ray Bursts paradigm

- Bright and short transient event in γ band followed by an afterglow (in all wavelengths)
- Extragalactic, 2 categories: short (from BNS) and long (from SN)
- Polarization brings a better understanding of the jet and magnetic field structures

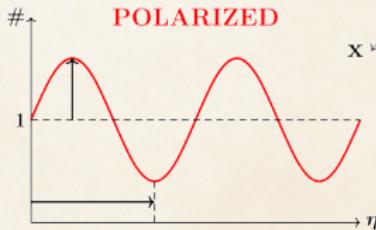
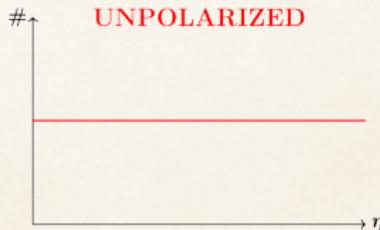
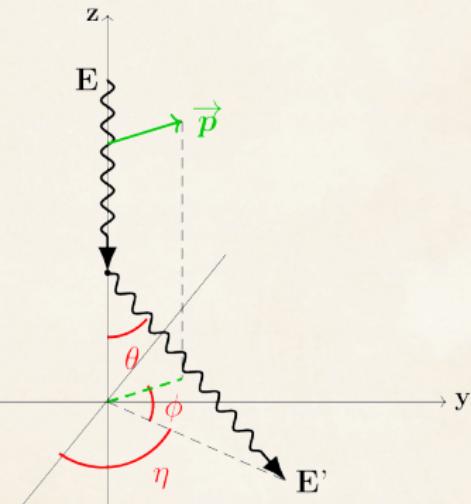


Compton scattering can be used to determine the polarization of a source:

- Azimuthal scattering angle distribution provides information on polarization degree and angle
- So called modulation curved, parametrized 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



Polarimetry with the Compton scattering

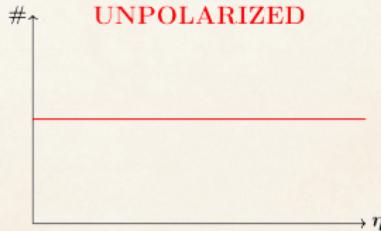
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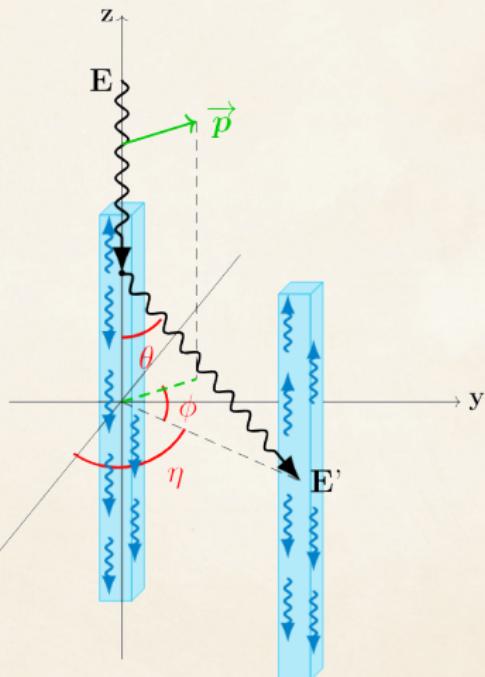
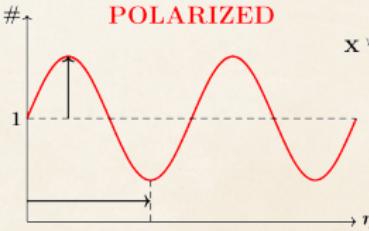
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- Relative amplitude \leftrightarrow PD, phase \leftrightarrow PA
- **A segmented array of scintillators can be used to measure the scattering angle distribution (aka modulation curve)**

UNPOLARIZED

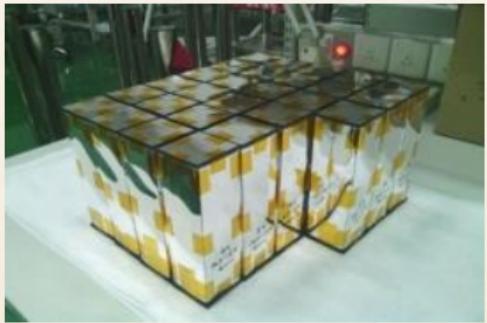
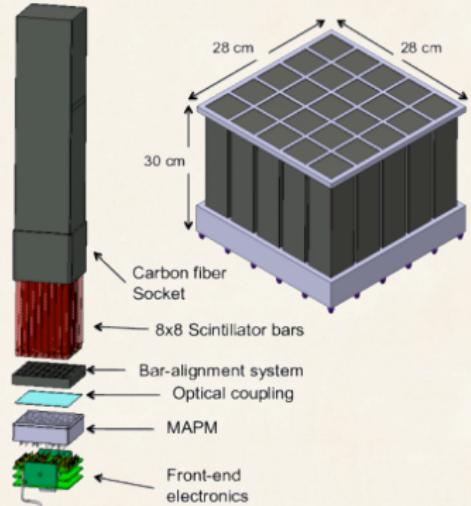


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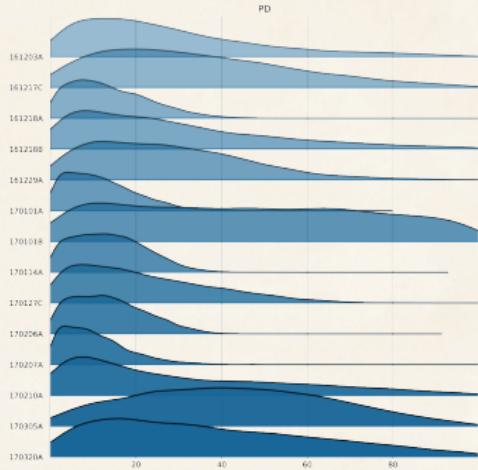
The POLAR instrument

- POLAR was a dedicated gamma polarimeter composed of a 40×40 scintillator array
- Divided in 5×5 modules each made of 64 plastic scintillator bars ($176 \times 5.8 \times 5.8 \text{ mm}^3$, EJ-248M), each module being readout by Multi-Anode PMTs
- Optimized for Compton scattering in the 50-500keV range thanks to its low-Z scintillators
- 30kg instrument, half-sky FoV, $\sim 300\text{cm}^2$ effective area at 400 keV
- Design described in [Produit et al. 2018](#) (DOI: [10.1016/j.nima.2017.09.053](https://doi.org/10.1016/j.nima.2017.09.053))
- Launched in Sept 2016 on the Tiangong-2 Chinese space lab for 6 months of operation

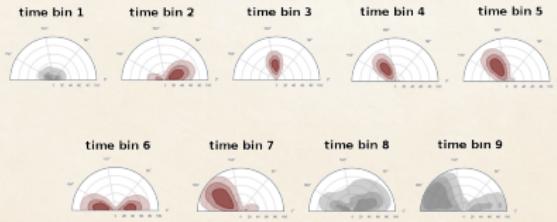


POLAR energy integrated and time resolved results

- Catalog of 14 GRBs analysed, results show a low or null polarization degree (excluding synchrotron emission models from toroidal magnetic field, compatible with photospheric emission model and other synchrotron models)
- High quality analysis of 5 GRBs published in *Nat Astron* 3, 258–264 (2019)
- Time resolved analysis show a hint of quickly evolving polarization angle that washes out polarization degree on time integrated analysis \implies need more statistics to make proper time resolved analysis



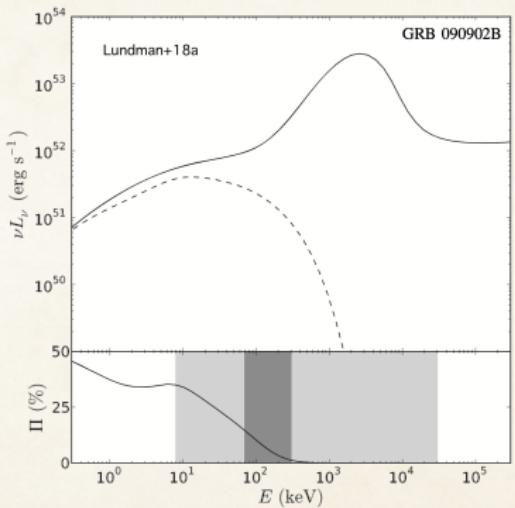
A&A 644, A124 (2020)



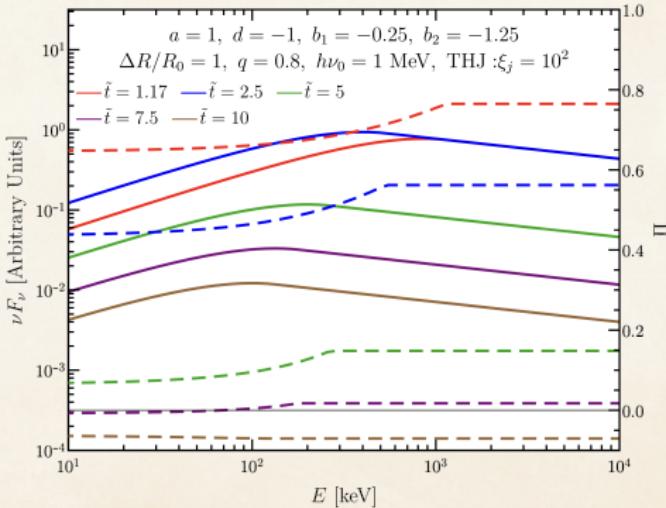
A&A 627, A105 (2019)

Energy dependence of prompt emission's polarization

- Energy-resolved polarimetric measurement made possible by increasing sensitivity of high energy polarimeters
- Theoretical models recently started to be extended to predict energy dependence of GRB prompt emission polarization

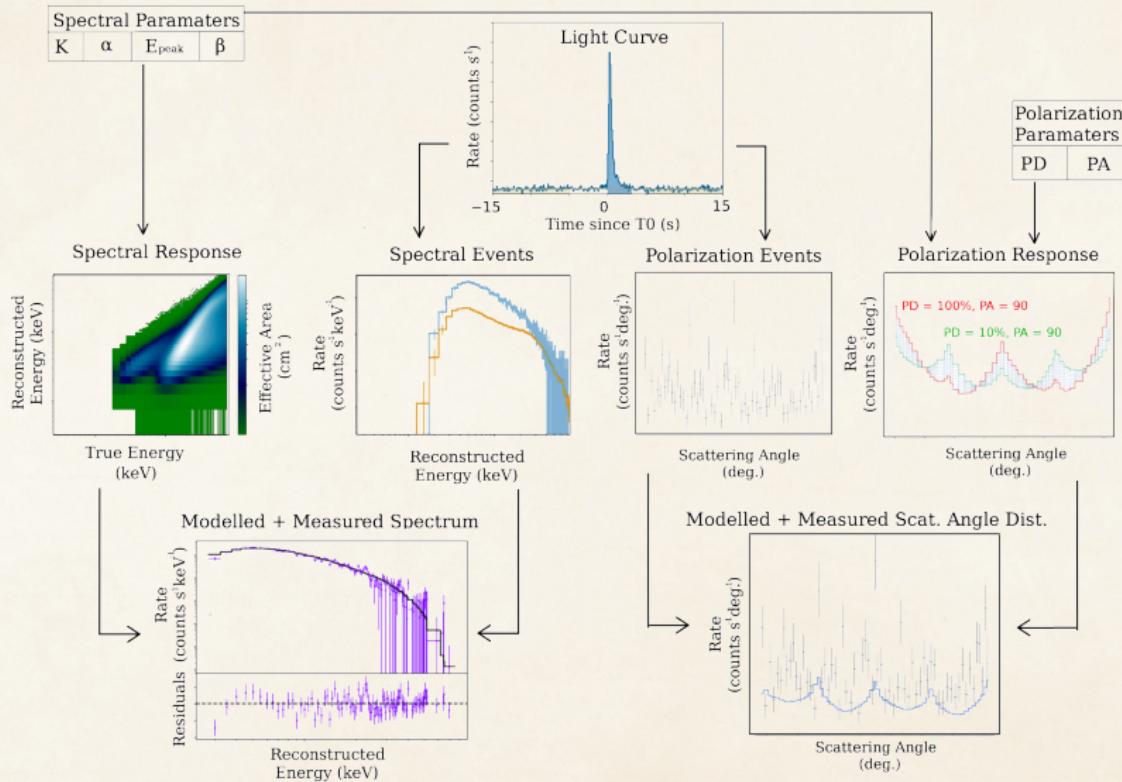


Photospheric model, Lundman+18



Synchrotron model, Gill+21

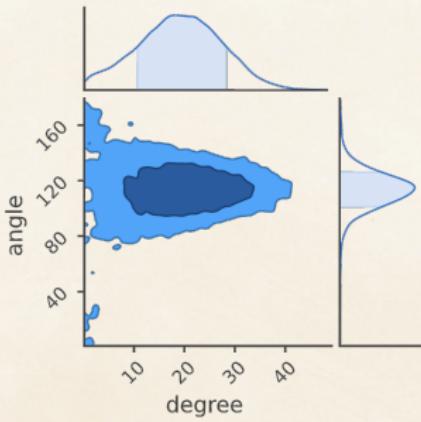
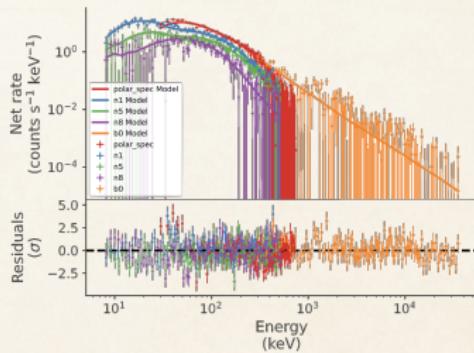
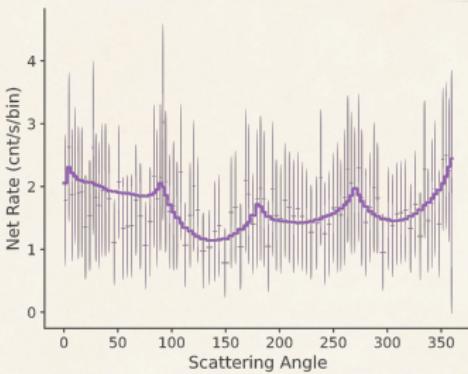
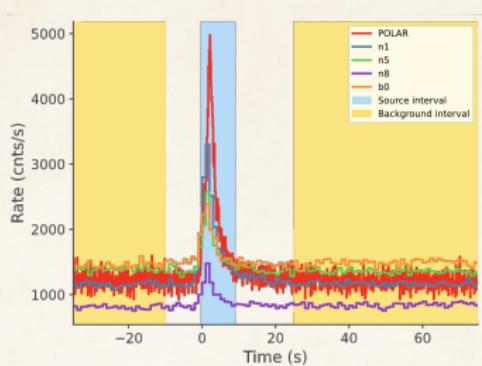
Joint polarization-spectral GRB analysis method



<https://github.com/threeML/threeML>

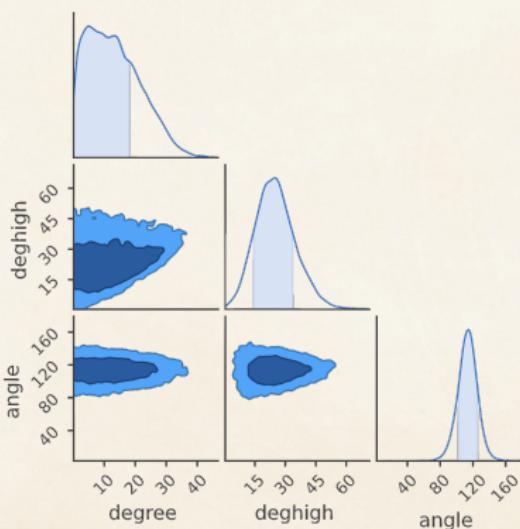
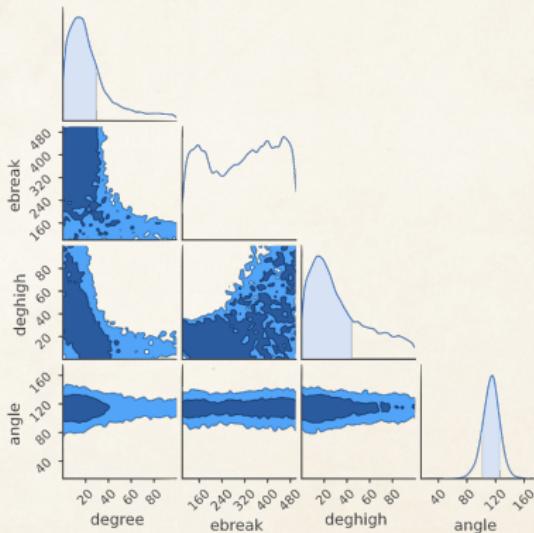
A&A 644, A124 (2020)

Energy integrated results: GRB170114A



Fitting the PD using two energy bins (using complex functions is not possible due to limited statistics):

$$PD = \begin{cases} PD_{low} & \text{if } E < E_{break} \\ PD_{high} & \text{if } E > E_{break} \end{cases}; \quad PA = cst.$$



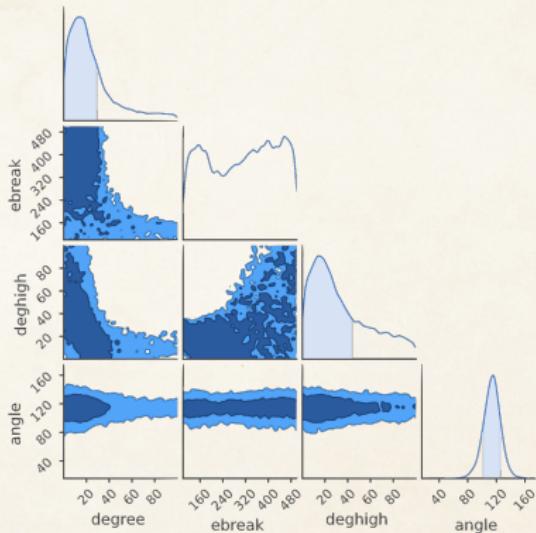
Fitting PD vs. energy with a Heaviside function

Energy of the step fixed to $E_{break} = 150\text{keV}$

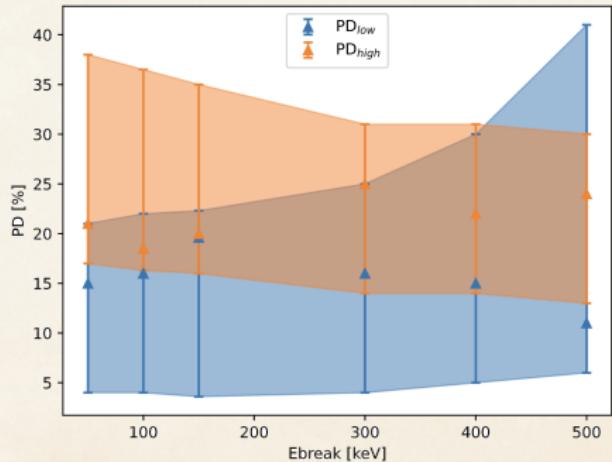
PD Energy resolved results on GRB170114A

Fitting the PD using two energy bins (using complex functions is not possible due to limited statistics):

$$PD = \begin{cases} PD_{low} & \text{if } E < E_{break} \\ PD_{high} & \text{if } E > E_{break} \end{cases}; \quad PA = cst.$$

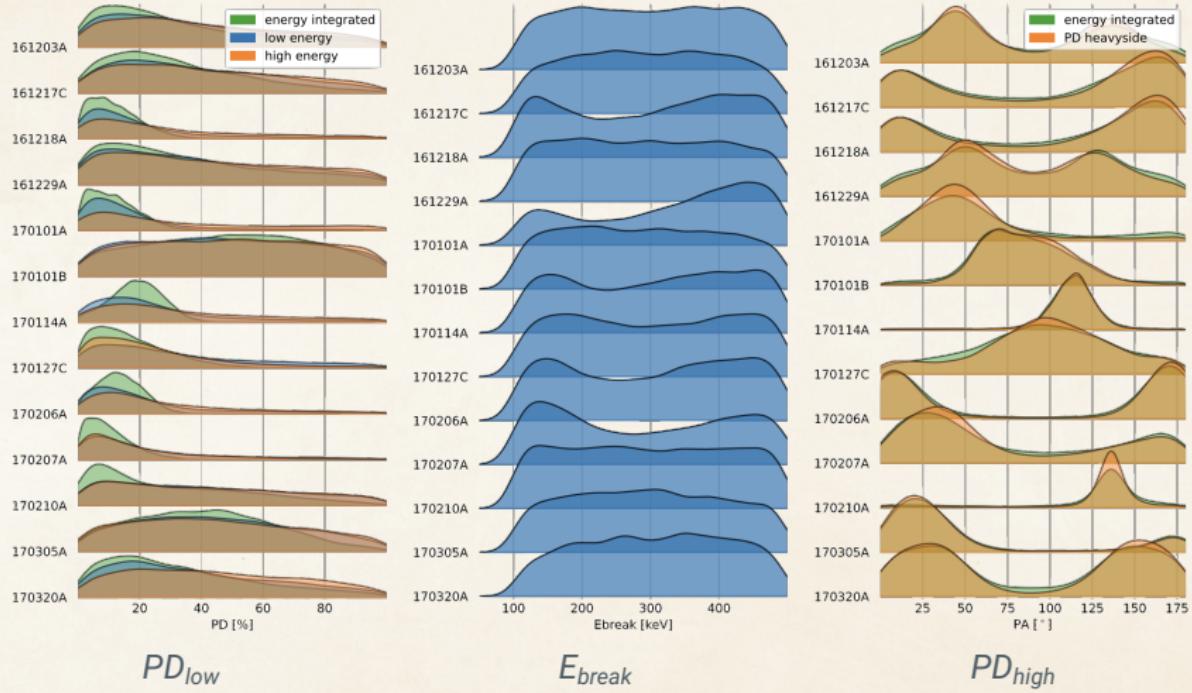


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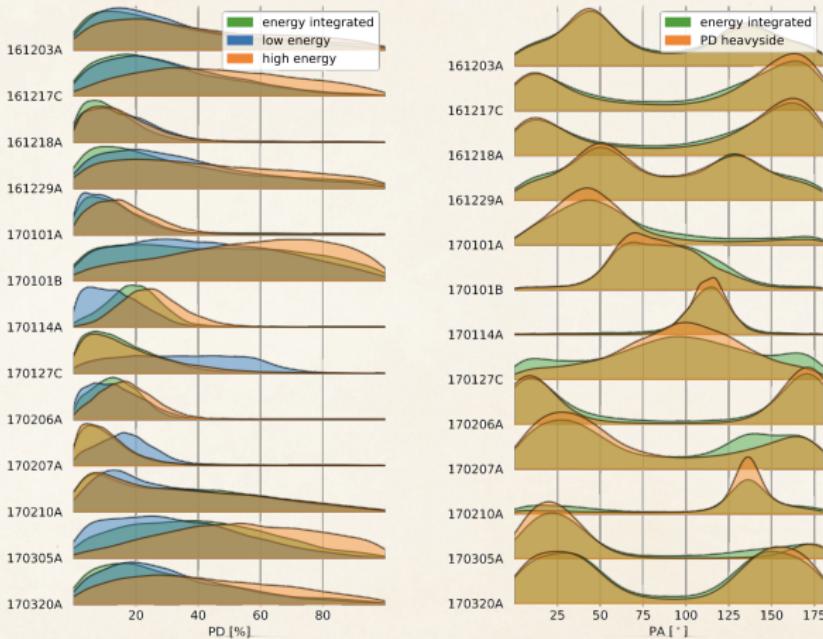


Varying the fixed E_{break}

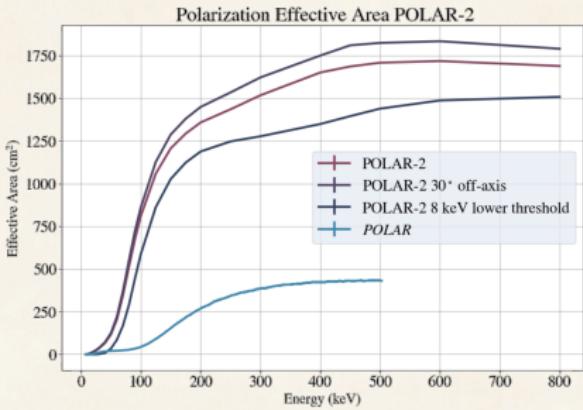
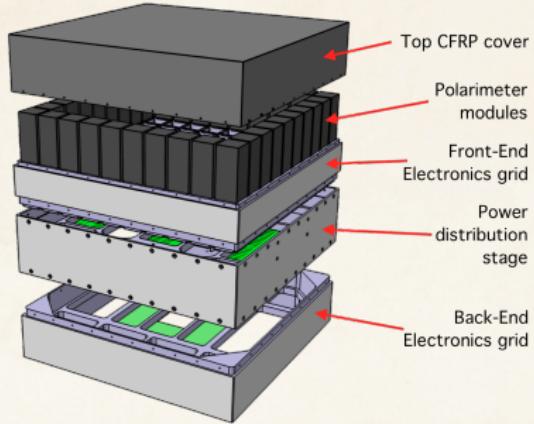
PD heaviside fitting on the POLAR catalog



Fixing the energy break at $E_{break} = 150$ keV:



Other simple fits have been tried: linear fits, fitting the PA vs. energy, see
[DOI:10.13097/archive-ouverte/unige:173869](https://doi.org/10.13097/archive-ouverte/unige:173869) for more details



- See next talk by **Hancheng Li**
- 4 times more channels, 10 times more sensitivity
- Launched to the CSS mid-2027
- UniGe (CH), IHEP (CN), NCBJ (PL), MPE (DE)
- <https://www.unige.ch/dpnc/polar-2>

Next step: predicting POLAR-2's sensitivity to polarization energy dependence



- No significant energy dependence of the polarization parameters was observed with the POLAR data
- Implement the energy-dependent fitting in a more generic way, such that not only empirical functions can be used but also actual energy-dependent theoretical models. → currently developing a universal analysis tool for X-/gamma-ray polarimetry → **polpy**, presented by Sujay Mate on Friday 9th
- Higher quality measurements are needed for time and energy resolved polarization analysis: **POLAR-2**
- **Next step:** Compare the sensitivity of POLAR vs. POLAR-2 to energy dependence of polarization using fake GRBs
- Entire work to be published later this year, some of it already published in:



DOI:10.22323/1.444.0619



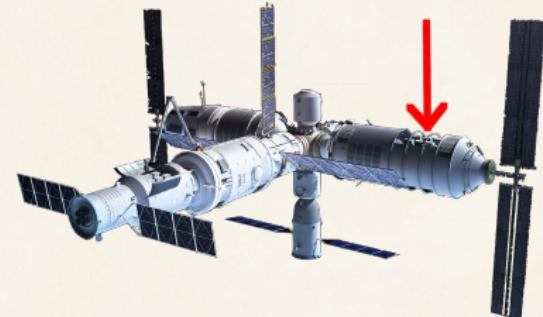
DOI:10.13097/archive-ouverte/unige:173869

Backup slides

Two other payloads proposed to the China Space Station (CSS):

X-ray polarimeter (LPD)

& Spectrometer (BSD)



➤ Low-energy Polarization Detector:

LPD

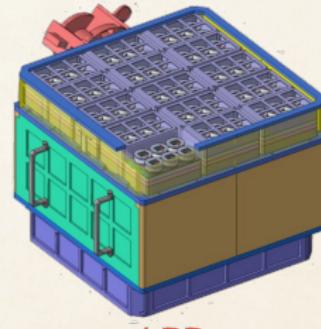
- ~2-10 keV X-ray polarimetry

➤ Broad energy-band Spectrum Detector: BSD

- ~10-2000keV

- Accurate GRB localization and spectroscopy for HPD and LPD

➤ Status: Selected, to be adopted



from Jianchao Sun, IHEP