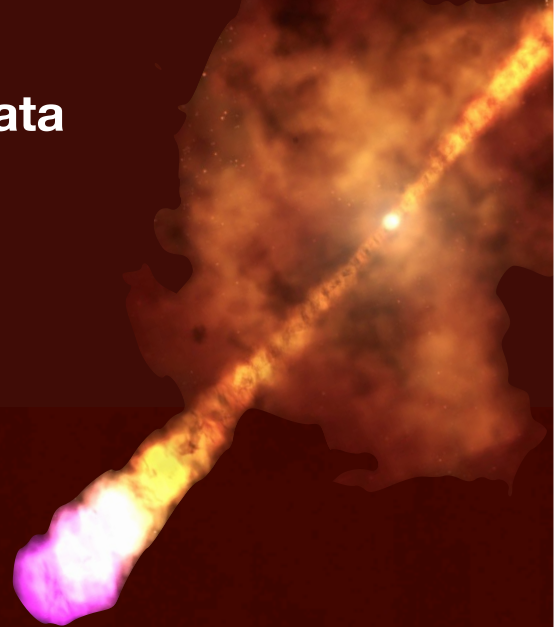
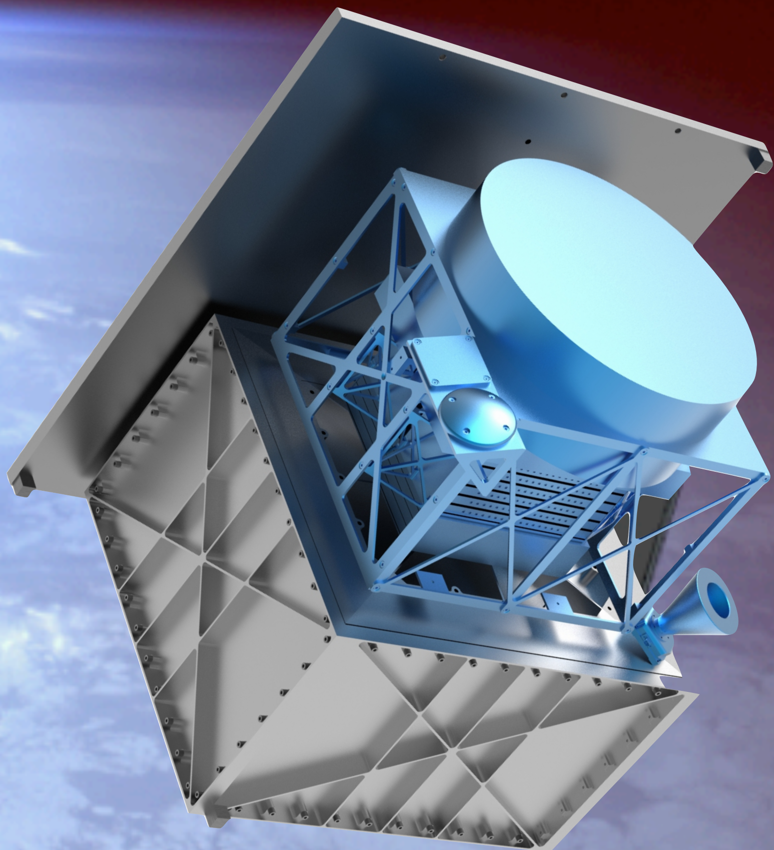
Shedding new light on GRBs with polarisation data
Geneva University
2018-11-28

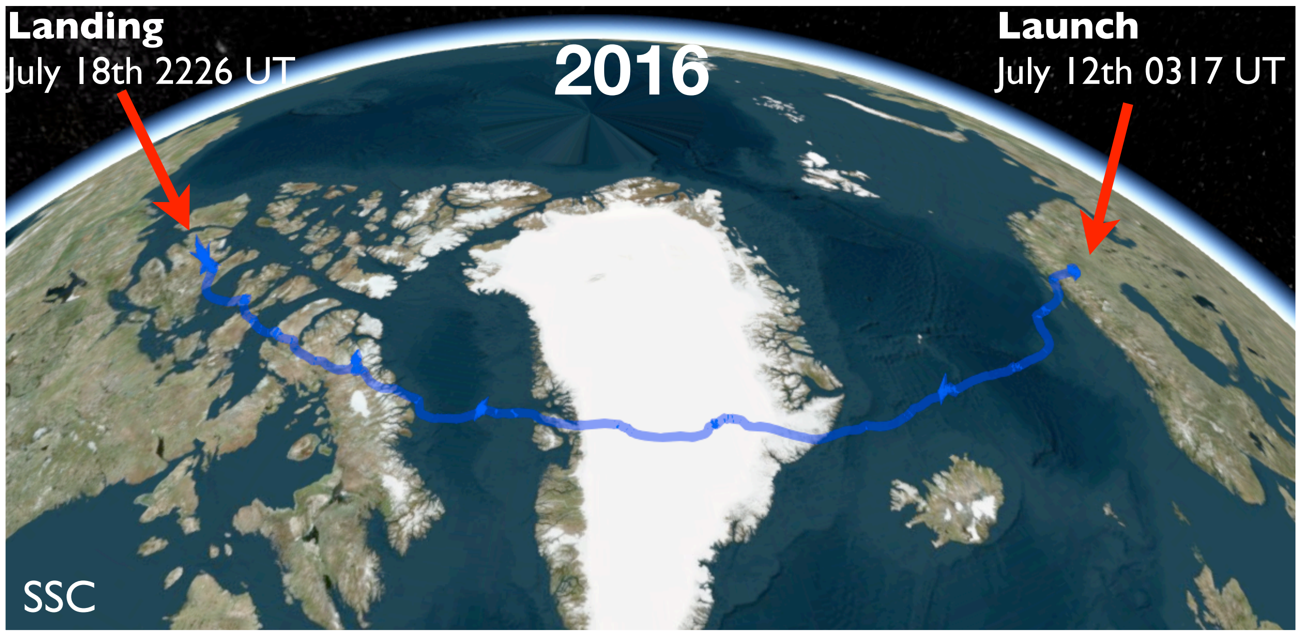


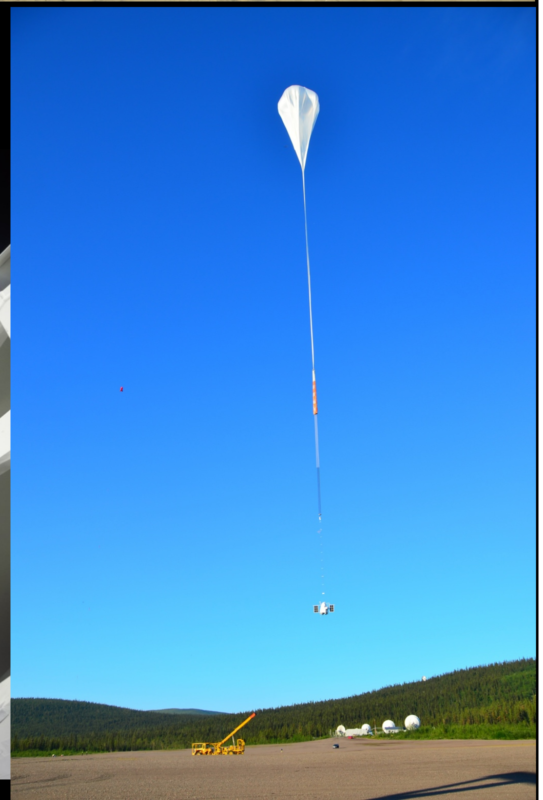
SPHiNX

Satellite **P**olarimeter for **Hi**gh e**N**ergy **X**-rays



Mark Pearce
KTH, Sweden
on behalf of the SPHiNX team





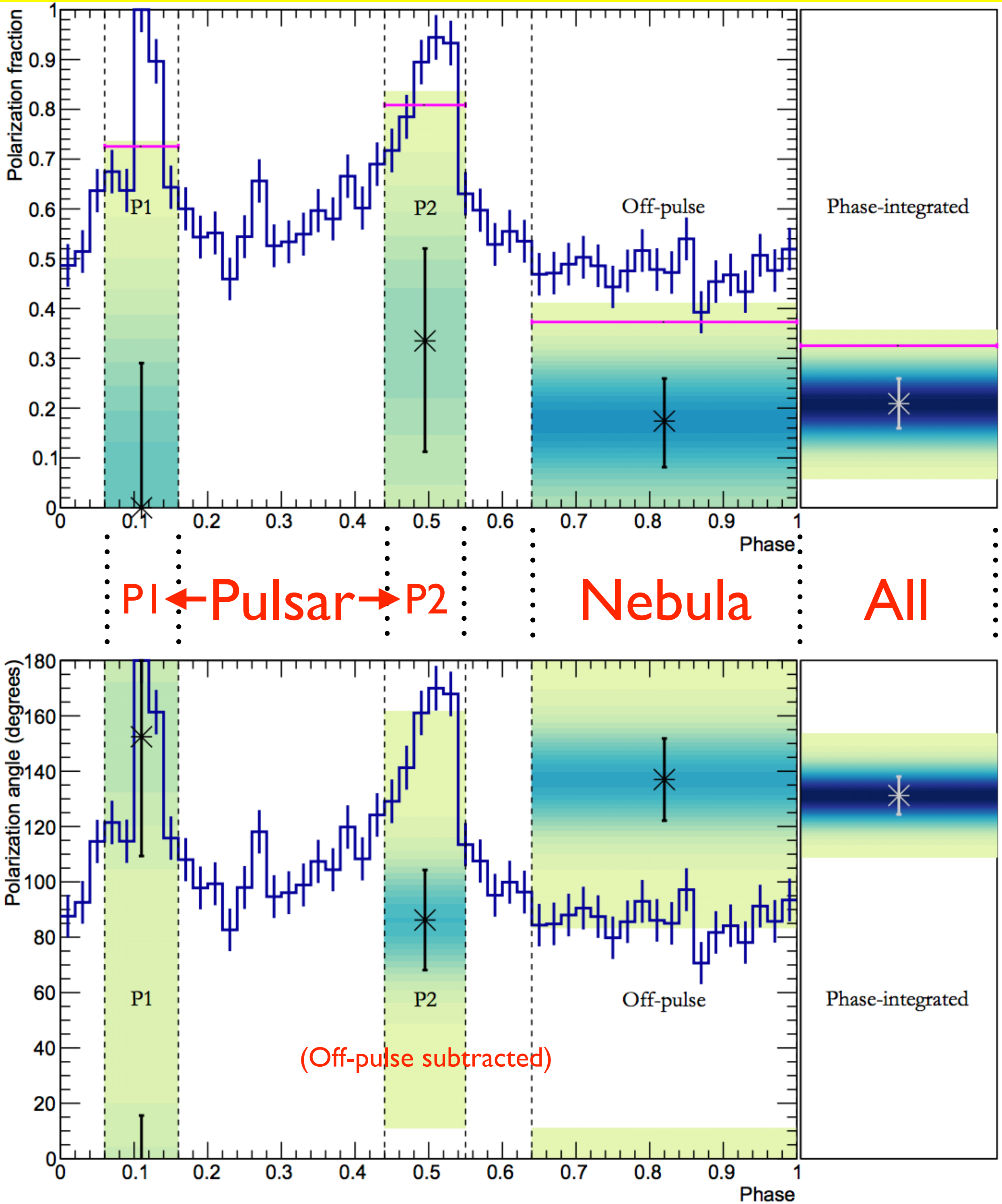
Design and calibration:

M. Chauvin et al. (PoGOLite), Exp. Astronomy 41 (2016) 17

M. Chauvin et al. (PoGO+), Astroparticle Physics 82 (2016) 99

M. Chauvin et al. (PoGO+), NIM A 859 (2017) 125

M. Chauvin et al. (PoGO+), Nature Sci Rep 7 (2017) 7816.



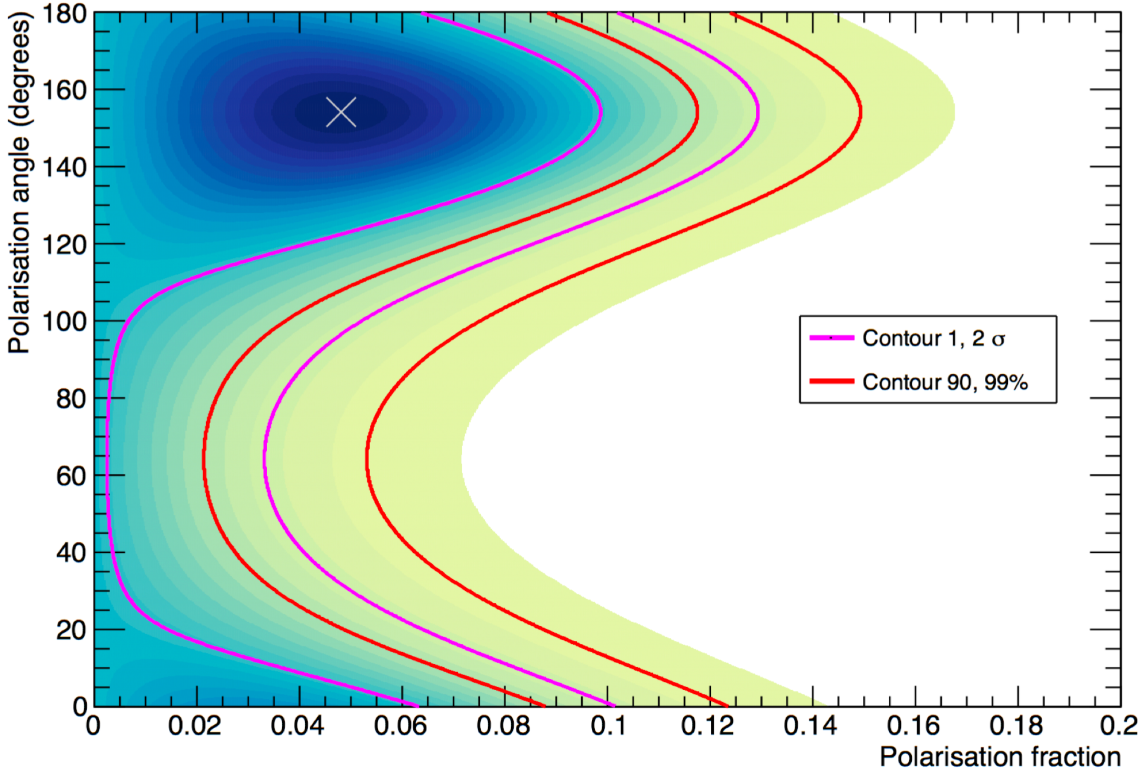
First measurement of polarised emissions from Crab in hard X-ray band (18-160 keV)

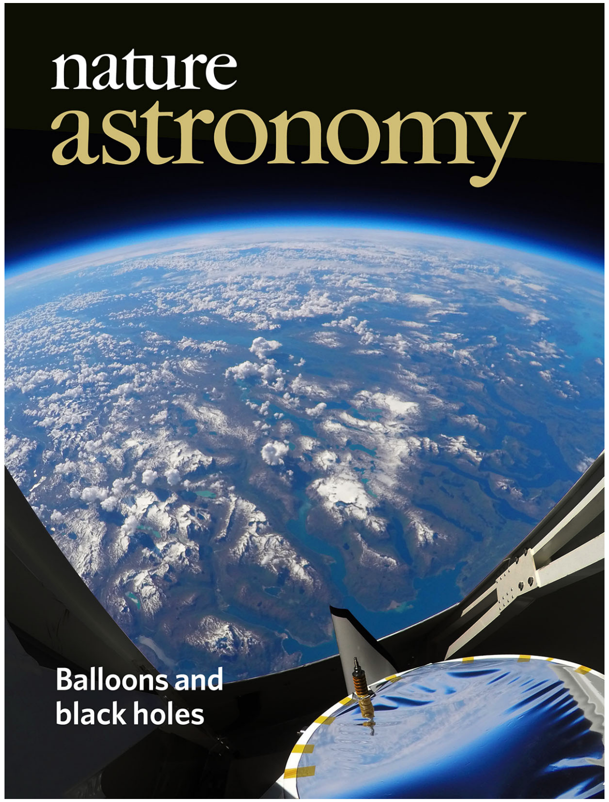
- Phase integrated PF ~ (21±5)%
  - Purely toroidal magnetic field with isotropic particle distribution ⇒ PF = 37%
  - Indicates degree of disorder in emission region
  - Explore further with MHD/PIC simulations

- **AstroSat CZTI** claimed a variable PF for the Crab "off-pulse" region. Not expected in high-energy emission models. **Refuted by PoGO+.**

  M. Chauvin et al. (PoGO+), MNRAS 477 (2018) L45

M. Chauvin et al. (PoGO+), Nature Astronomy 2 (2018) 652.





- PoGO+ results: **PF<8.6% (90% CL)** & **PA=(154±31)°**.
- **PA** is parallel with radio jet*, (158±5)°, **i.e. perpendicular to the accretion disk.** **Stirling et al. 2001; Fender et al. 2006.*
- No sign of strong gravity - **extended corona model is favoured by PoGO+ measurements.**
- **In progress:** polarimetric constraint on hard X-ray synchrotron jet emission

M. Chauvin et al. (PoGO+), MNRASL (2018). In review.

After PoGO+: X-Calibur

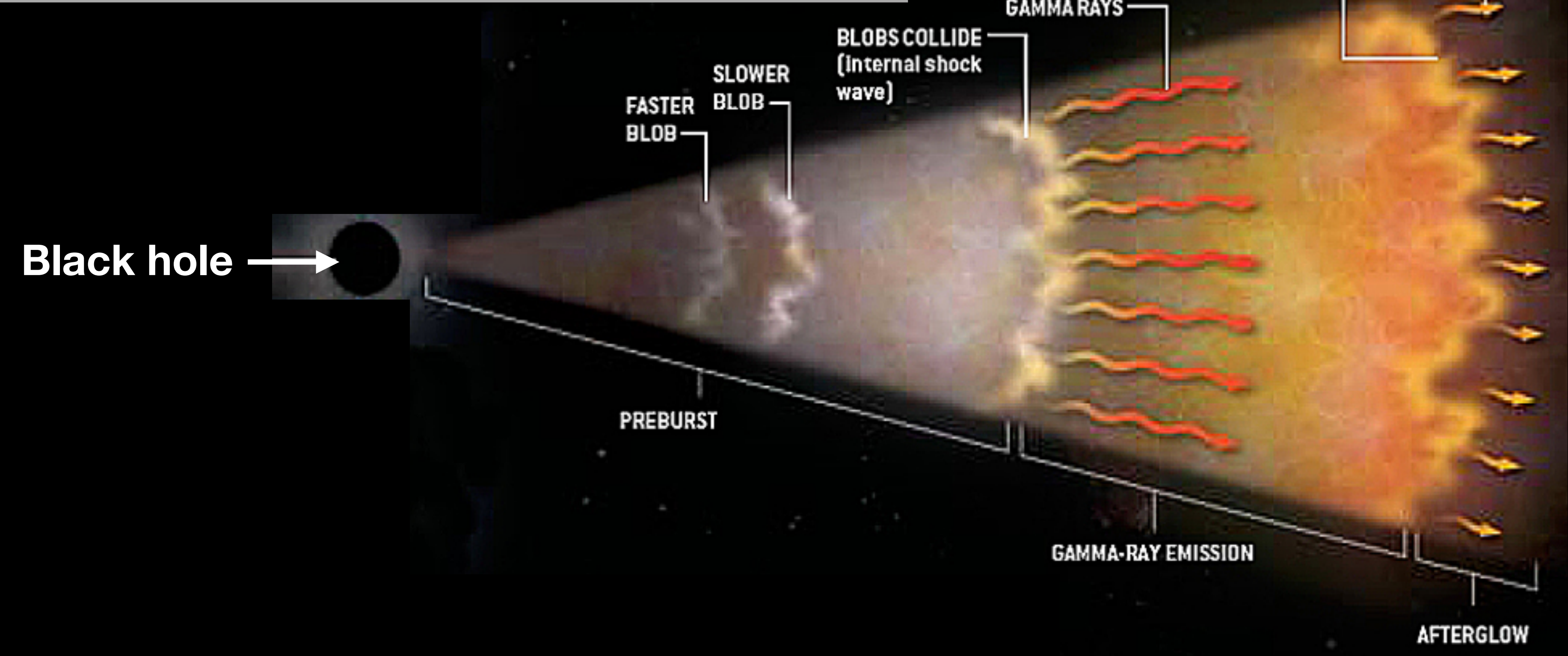
- New instrumental approach for hard X-ray polarimetry.
  - “Funnel -vs- bucket”
- Test flight 2016. **Antarctica flight 2018.** Vela X-1 main target.
- Future flights planned with upgraded telescope, XL-Calibur.
  - Simultaneous observations with IXPE?

Scientific questions

1. Are GRB jets highly magnetised?
2. How is the gamma-ray emission produced?
3. What is the geometric structure of GRB jets?

Observables

- **Polarisation fraction (1,2)**
- **Polarisation angle (3)**
- **Energy (2)**
- **Timing (3)**
- **Location (all)**



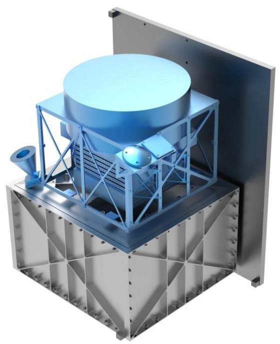
Rymdstyrelsen
Swedish National Space Agency

KTH VETENSKAP OCH KONST

SPHiNX

Satellite Polarimeter for High eNergy X-rays

Phase A/B1 Report



Principal Investigator: Mark Pearce
Department of Physics & KTH Space Centre
KTH Royal Institute of Technology

E-mail: pearce@kth.se / Tel: +46 (0)70-166 74 86

Submission date: 2017-10-06

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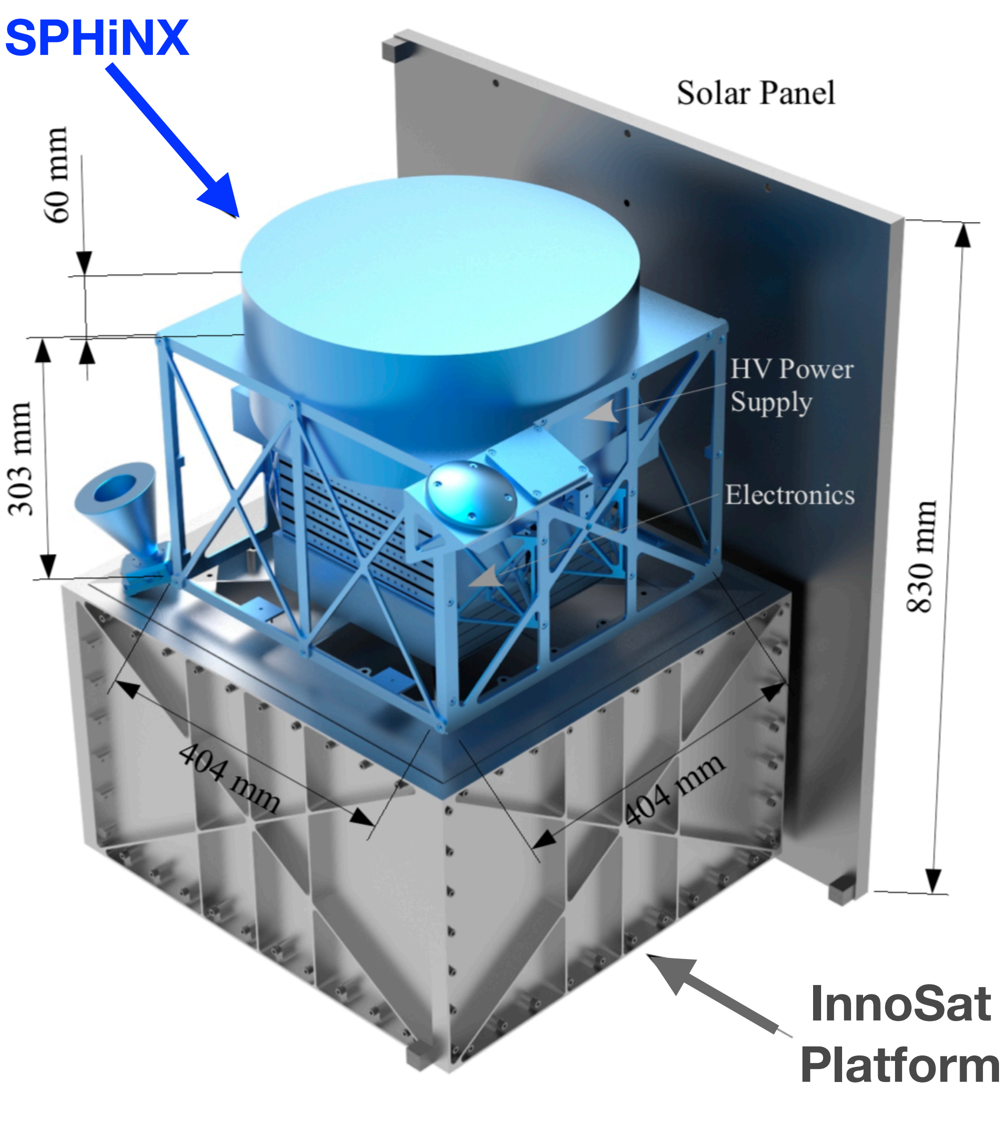
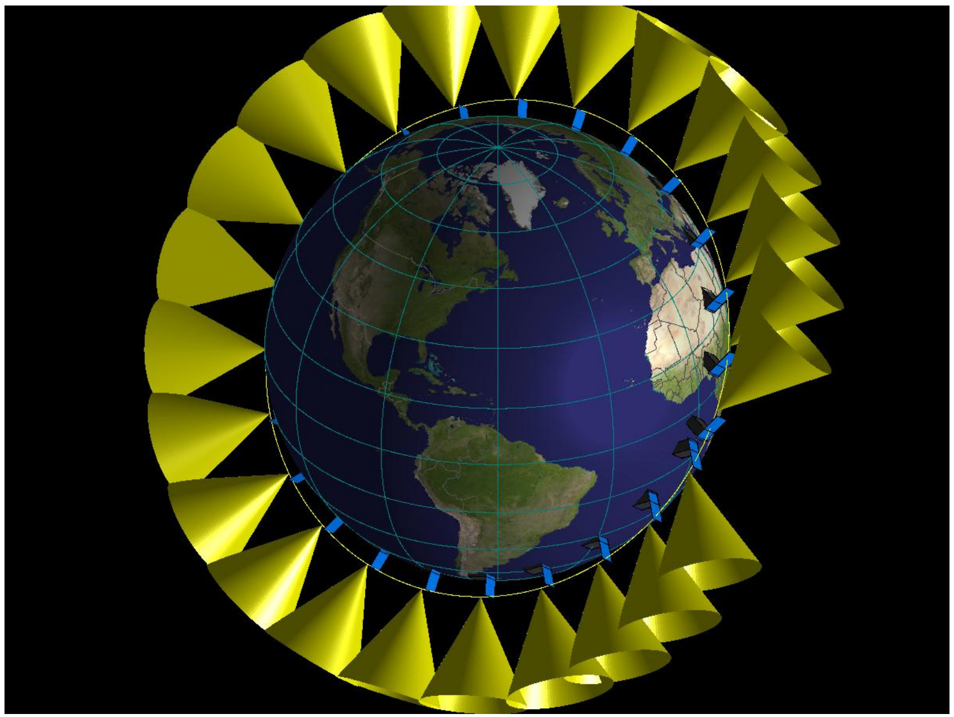
Mission overview

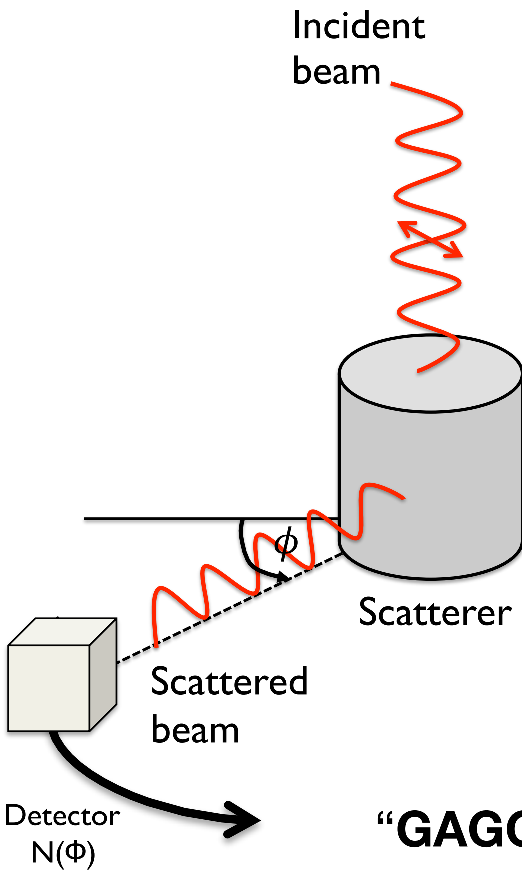


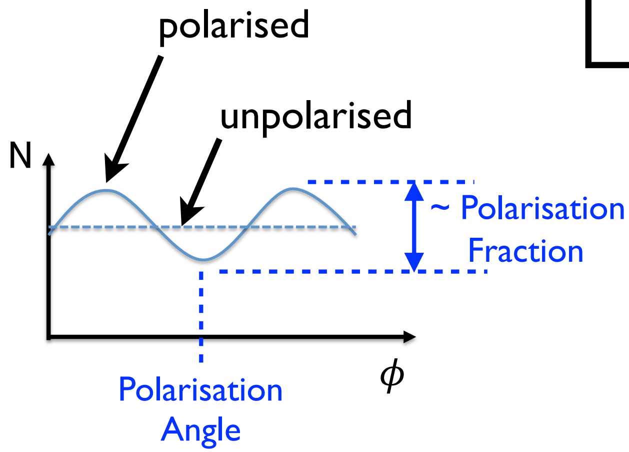
Phase A baseline design

Orbit inclination/altitude	53° / 500 km
Launch type	Piggy-back (e.g. PSLV)
Duration	2 years
Payload / total mass	25 kg / 68 kg
Payload volume	48×53×70 cm³
Payload / total power	28 W / 27 W
Downlink (S-Band)	150 MB/pass. 1 pass/day.
Pointing	Quasi-zenith, 3-axis stabilised, 0.1° precision



X-ray polarimetry



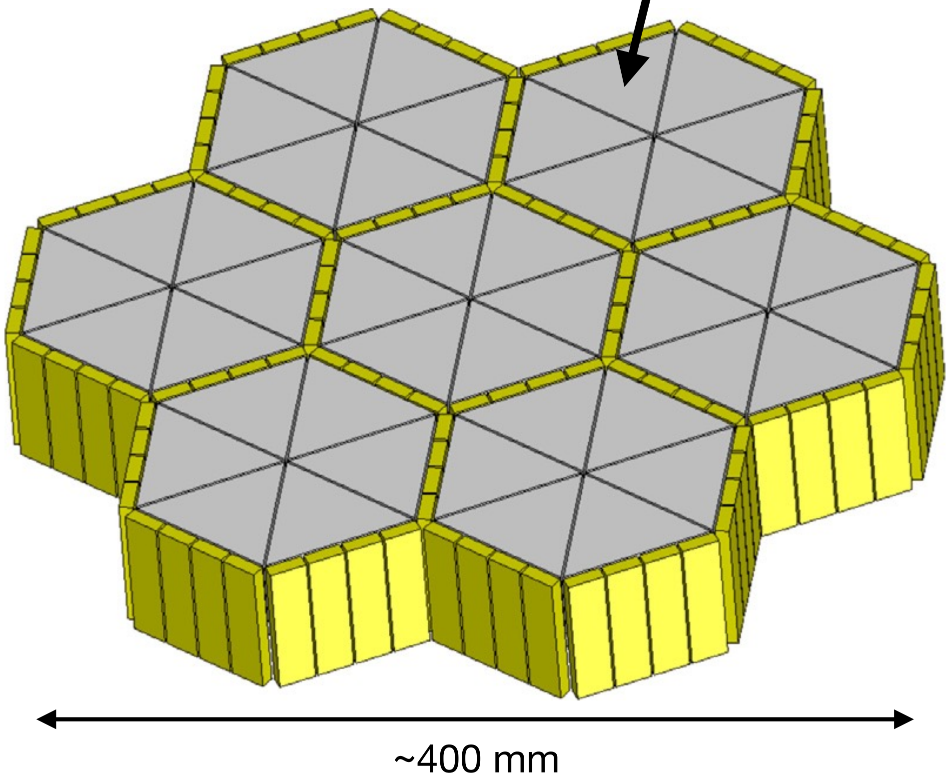


Klein-Nishina relationship

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_e^2 \frac{k^2}{k_0^2} \left(\frac{k}{k_0} + \frac{k_0}{k} - 2 \sin^2\theta \cos^2\phi \right)$$

EJ-204 **plastic scintillator**
(low Z)

“**GAGG**” = $Gd_3Al_2Ga_3O_{12}(Ce)$
(high Z)

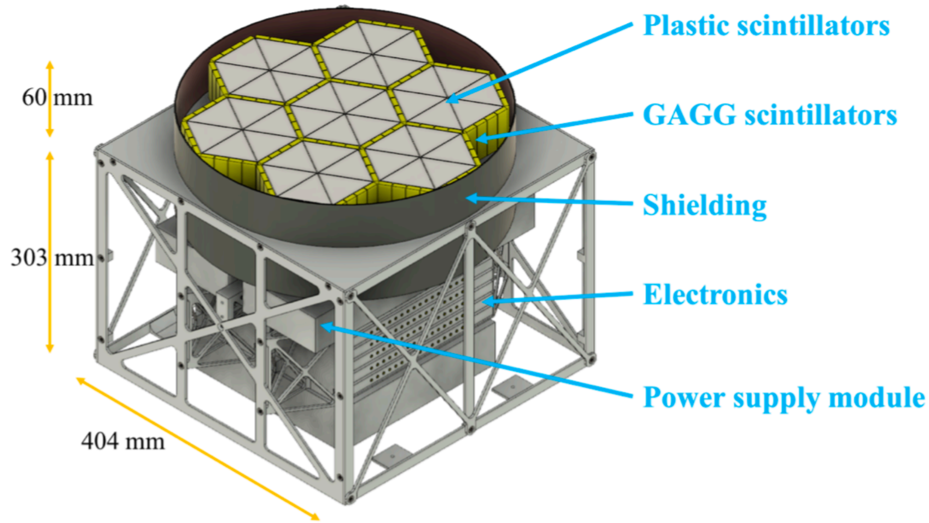


- Fast (88 ns decay)
- High density (6.6 g/cm³)
- High light-yield (LY=5.6×10⁴ γ/MeV)
- Low LY dose dependence/activation
- Self-luminescence issue? (SAA)

HIROSHIMA UNIVERSITY

Instrument characteristics

- **Observe ~200 GRBs / 2 years**
  - Field-of-view ~120°
  - Geometric area ~800 cm^2
- **Determine light-curve and spectral shape (~10-600 keV)**
  - dE < 30% (60 keV)
- Timing to ~1 ms (UT synchronised)

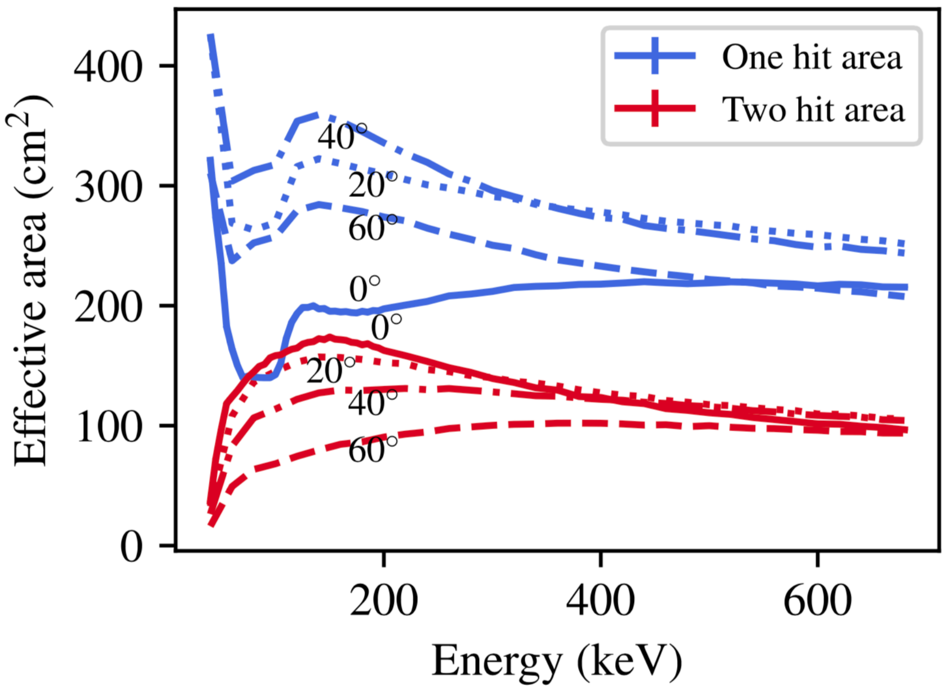


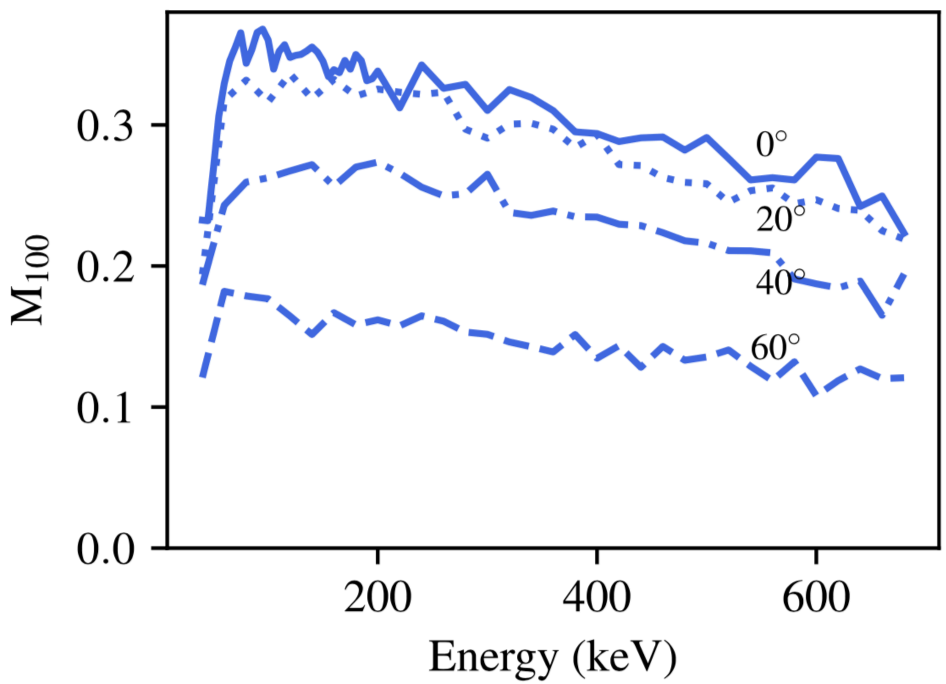
- **Instrument design is optimised for polarimetry**
  - Determine Polarisation Fraction (PF) and Polarisation Angle (PA) with ~10% ("MDP<0.3") precision for **~50 (long) GRBs / 2 years**
  - Energy range: **50-600 keV**

GRB property	Measurement
Jet structure	Time evolution of PA within a burst
Jet magnetism	Distribution of PF for a population of bursts
Emission mechanism	- Distribution of PF - Energy dependence of PF - Time evolution of PF

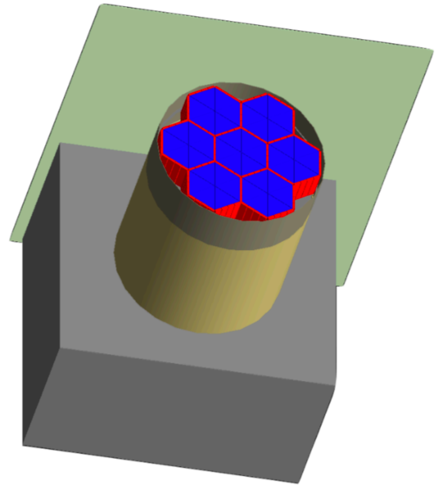
M. Pearce et al., Astroparticle Physics 104 (2019) 54

Instrument characteristics





LEO background



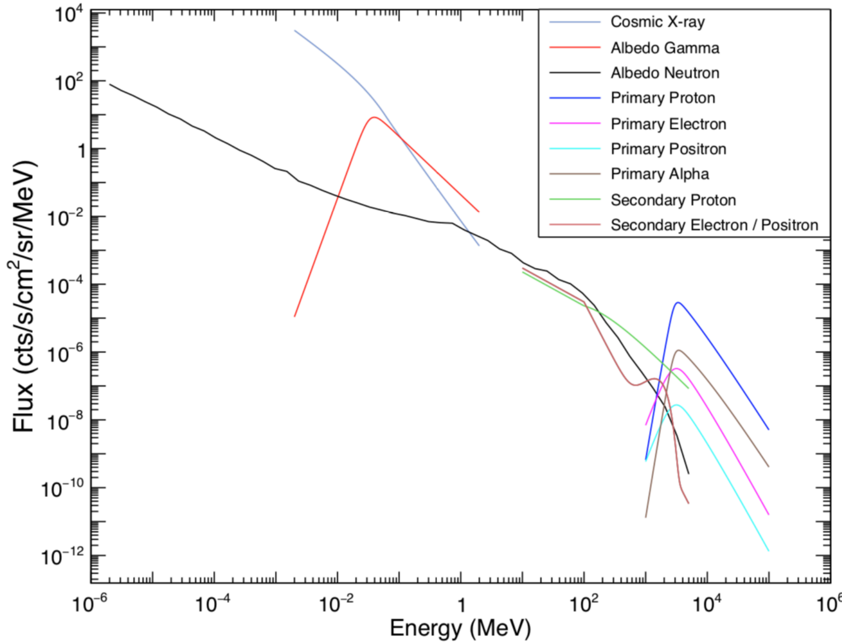
Background mitigation

- Periphery of scintillator array covered in Pb/Sn/Cu shield
- 1 mm CFRP shell covers sides/top of array
- Albedo attenuated by InnoSat

Geant4 simulations

Prompt

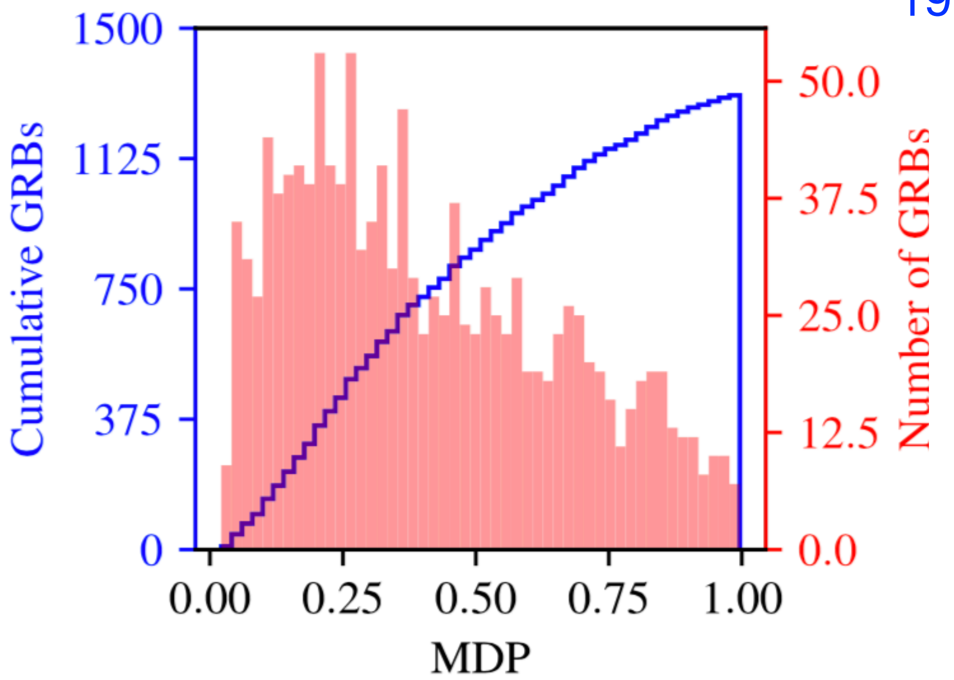
Component	One-hit rate (Hz)	Two-hit rate (Hz)
Cosmic X-ray	1270	195
Albedo gamma	398	113
Albedo neutron	14	5
Primary particles	16	5
Secondary particles	9	5
Total	1707	323
+ Delayed (platform activation)		190 (after 1 year)

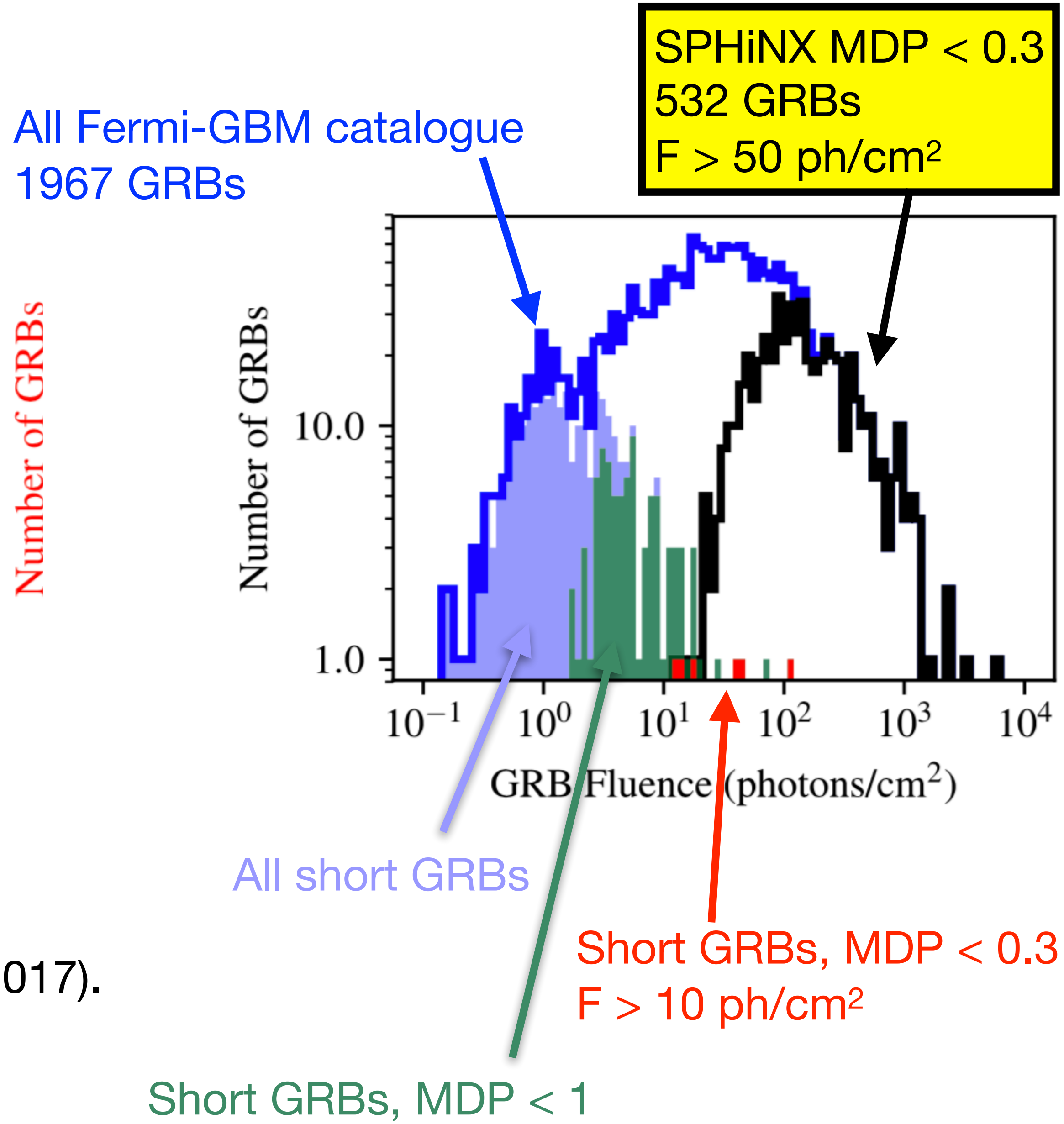


- InnoSat platform mass model implemented
- Background spectra as used for HXMT. Solar minimum conditions.
- ~5.5 h/day in SAA (80% duty cycle)
  - Trapped fluxes from SPENVIS.
    - AP-8 (protons - **activation**). AE-8 (electrons).

F. Xie & M. Pearce, Galaxies 6 (2018) 50

‘Measurement’ sample

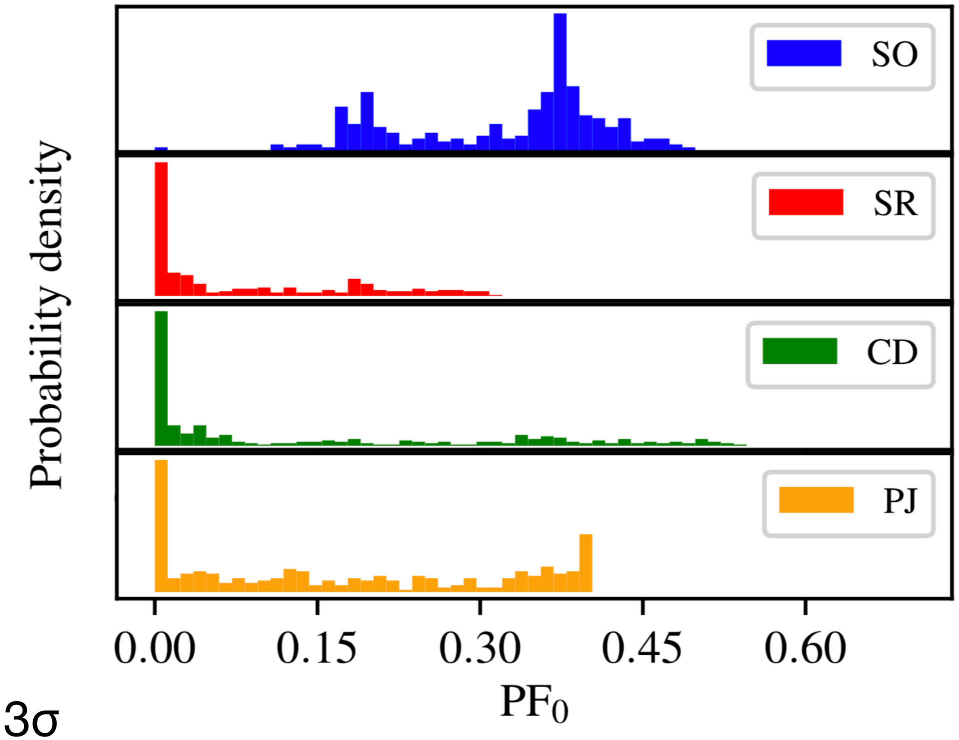


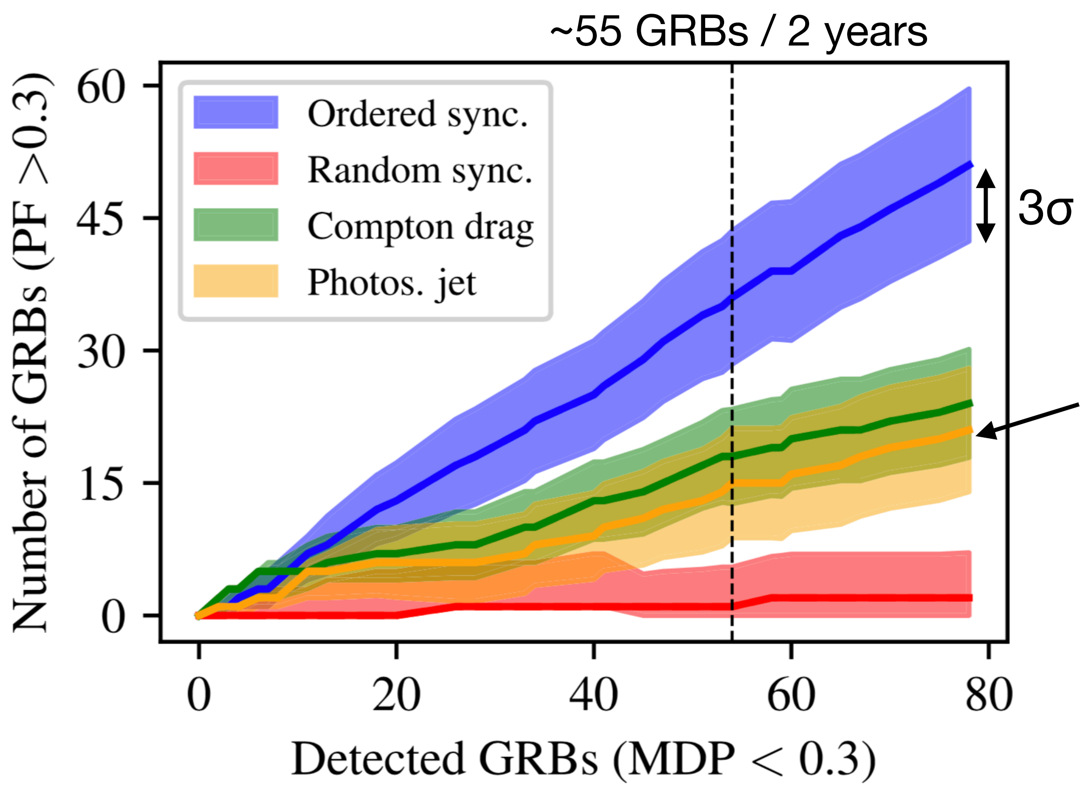


- MDP distribution for 1967 GRBs in Fermi-GBM catalogue (-Nov 27th 2017). **NB:** MDP > 1 is not shown.

Model discrimination?

SO/SR/CD: K. Toma et al., ApJ 698 (2009) 1042
PJ: C. Lundman et al., MNRAS 440 (2014) 3292.

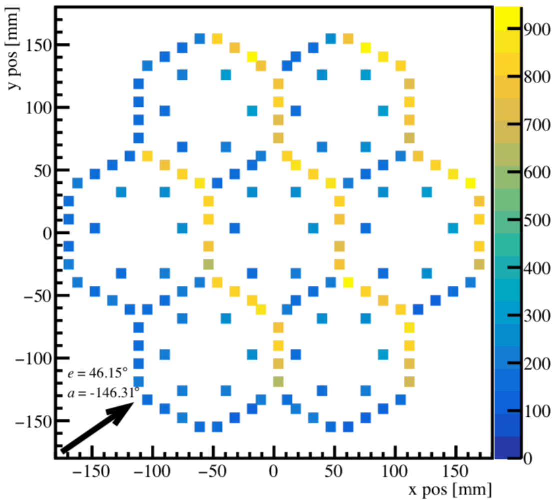




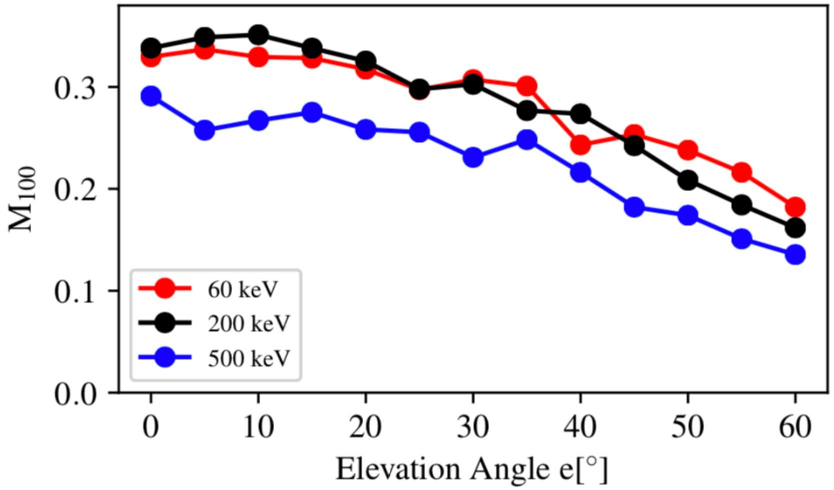
PF(E) needed for discrimination

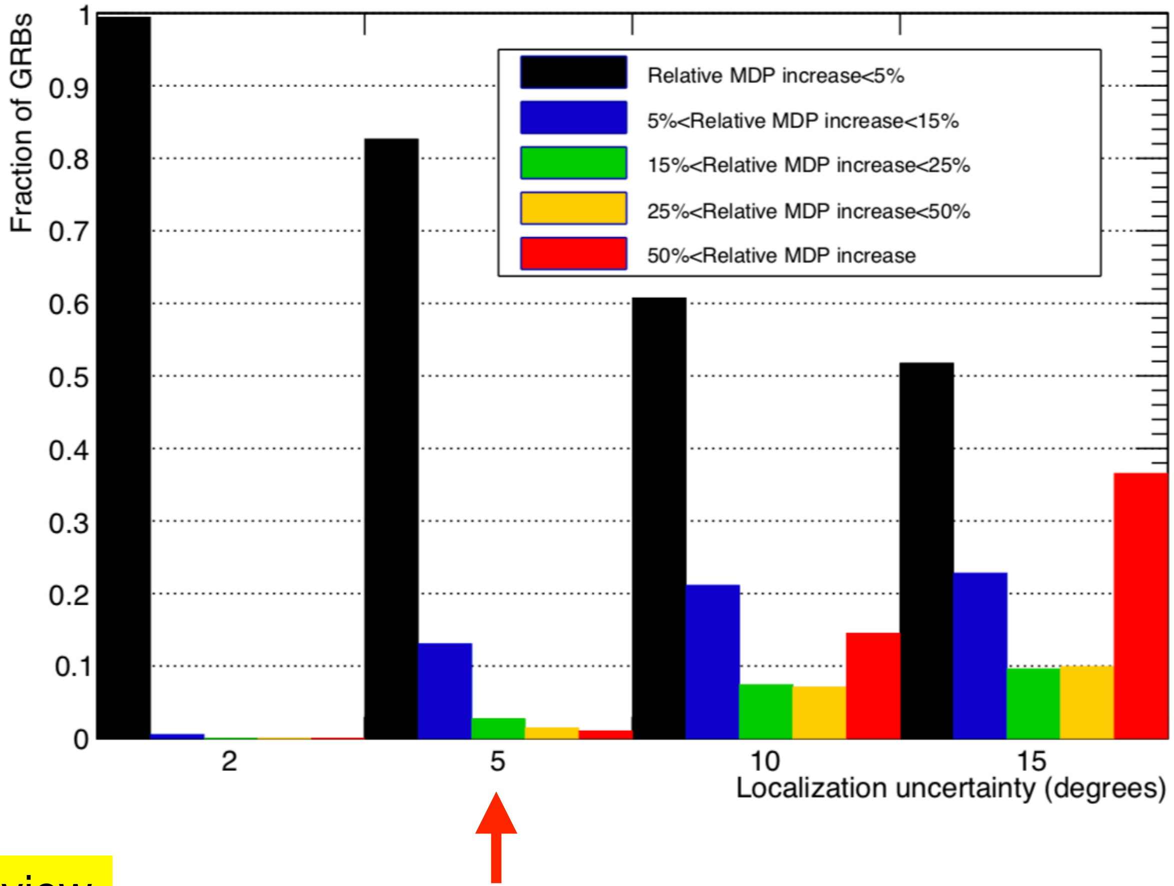
- PJ ✔
- CD ✘

- Systematic errors **not** considered:
  - M_{100}
  - Spectral reconstruction
  - GRB localisation



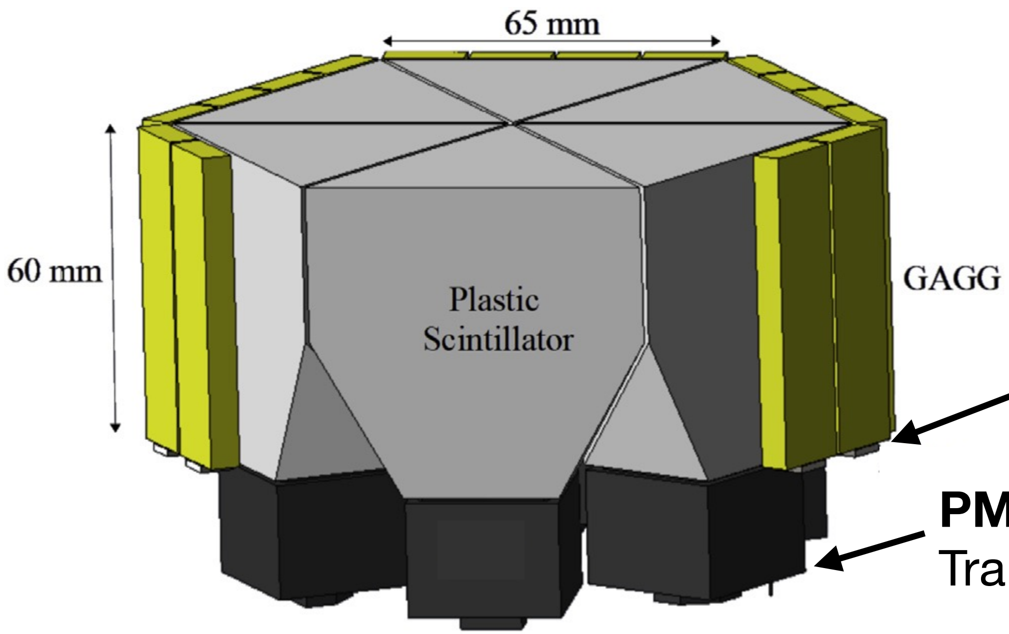
- **Stand-alone localisation performance** studied
  - Flat geometry not ideal…
- Baseline: 1 downlink/day ⇒ **localise on-ground**
- Single hits (>50 keV) used
- Response database from Geant4
- Three **(simple!) algorithms** considered: “modulation curve for outer units”, “χ^2 minimisation”, “max. likelihood”





- Localisation uncertainty ≲ 5° for median fluence GRBs in Fermi-GBM catalogue
- Cannot localise weaker GRBs.

L. Heckmann et al., SPIE JATIS (2018), in review.



MPPC = Hamamatsu S13360-6050

PMT = Hamamatsu R7600U-200 (single anode).
Transition to MPPC (?)

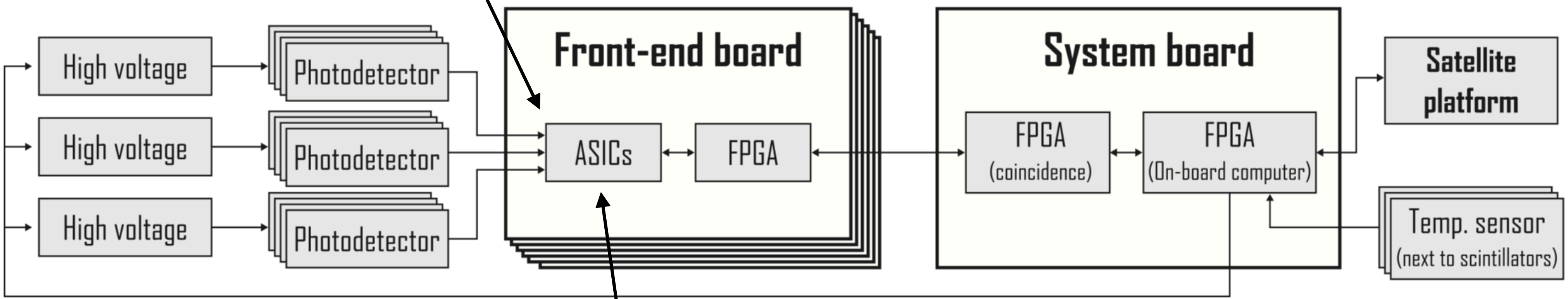
But…

Challenges:

- *50 keV polarisation requires 5 keV Compton scatter detection in plastic*
- *Radiation tolerance?*

"Commercial" ASIC

- IDEAS "SIPHRA"
- Weeroc Citiroc

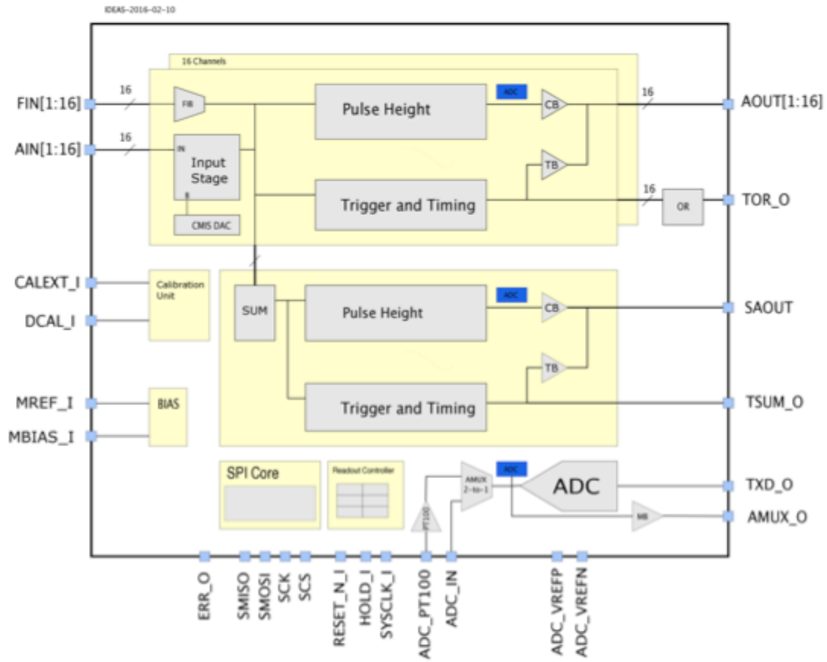


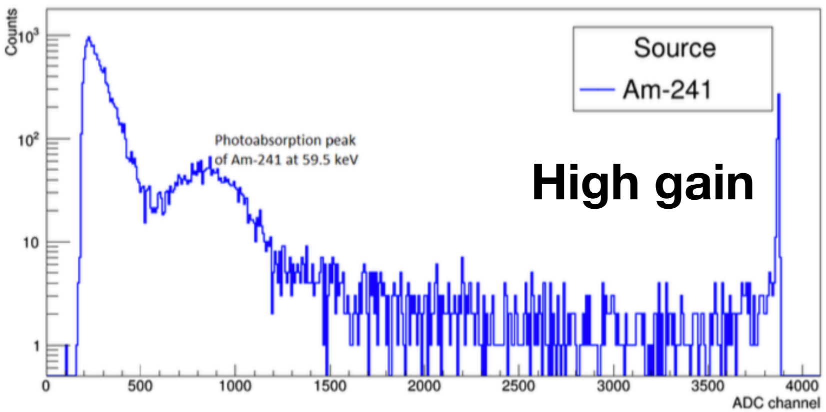
preamp/shaper/peak detect/digitise

SIPHRA

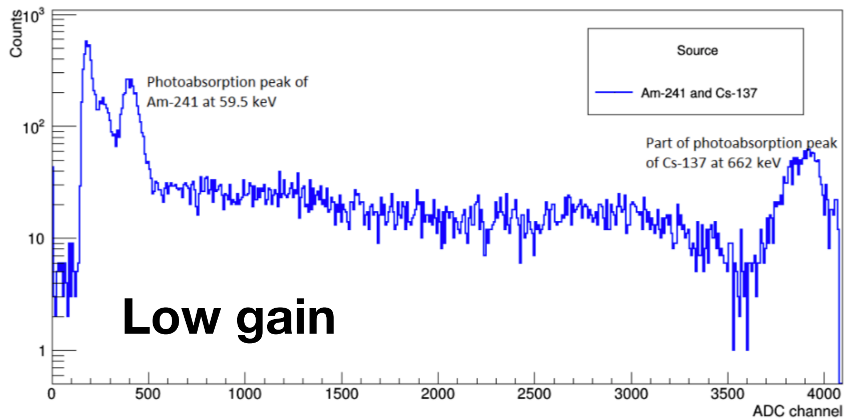
- SPHiNX baseline uses the IDEAS "SIPHRA"
  - 16 ch / +ve "pC", -ve "nC"
  - In-built 12 bit ADC, 50 kips
  - ~20 mW
  - Radiation tolerant by design

- Two channels (different gain settings) required per PMT/MPPC channel for desired dynamic range
  - **Plastic/PMT:** 10-270 keV + 50-500 keV
  - **GAGG/MPPC:** 10-100 keV + 20-650 keV





SPHiNX plastic + PMT
10-270 keV



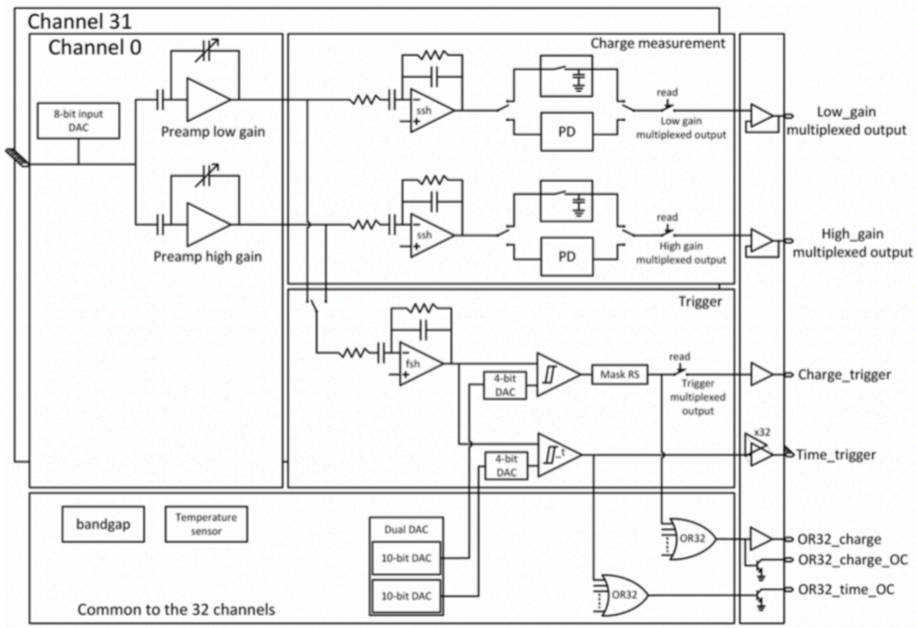
GAGG + MPPC
20-650 keV

CITIROC

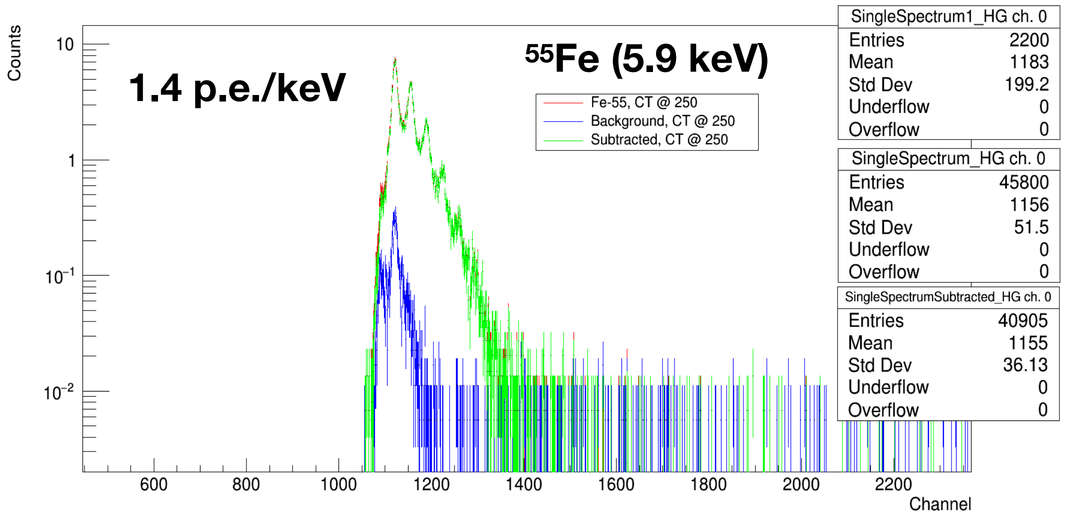
weeroc

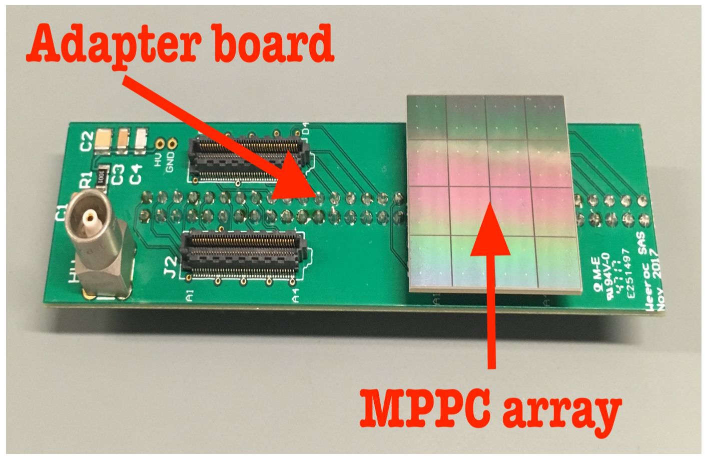
- Also studying Weeroc CITIROC
  - 32 ch / +ve “400 pC”
  - External ADC needed
  - 225 mW
  - Radiation tolerant?

- Current focus on MPPC read-out…
  - MPPC+GAGG: as SIPHRA
  - MPPC+plastic?



POLAR plastic scintillator (6×6 mm²) + MPPC*

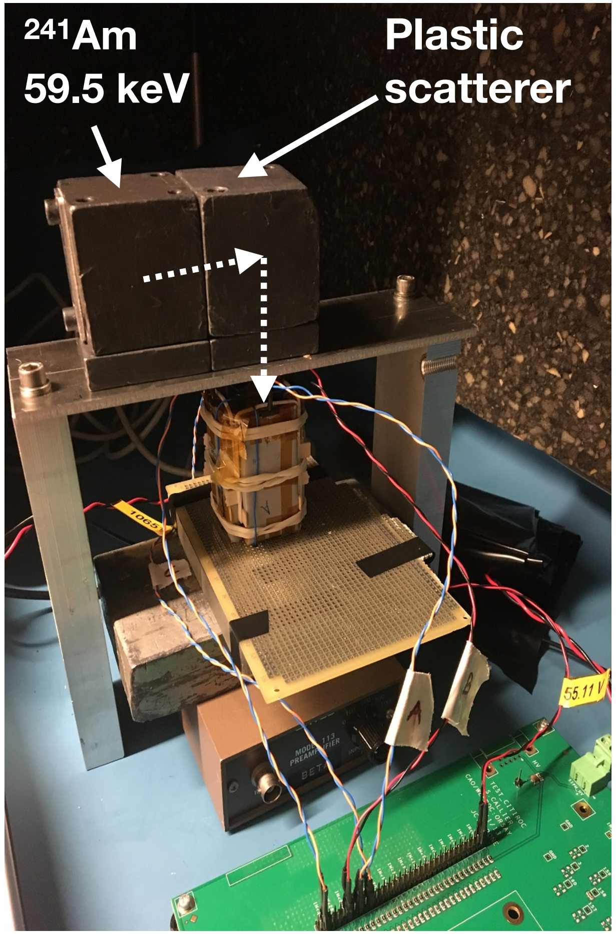


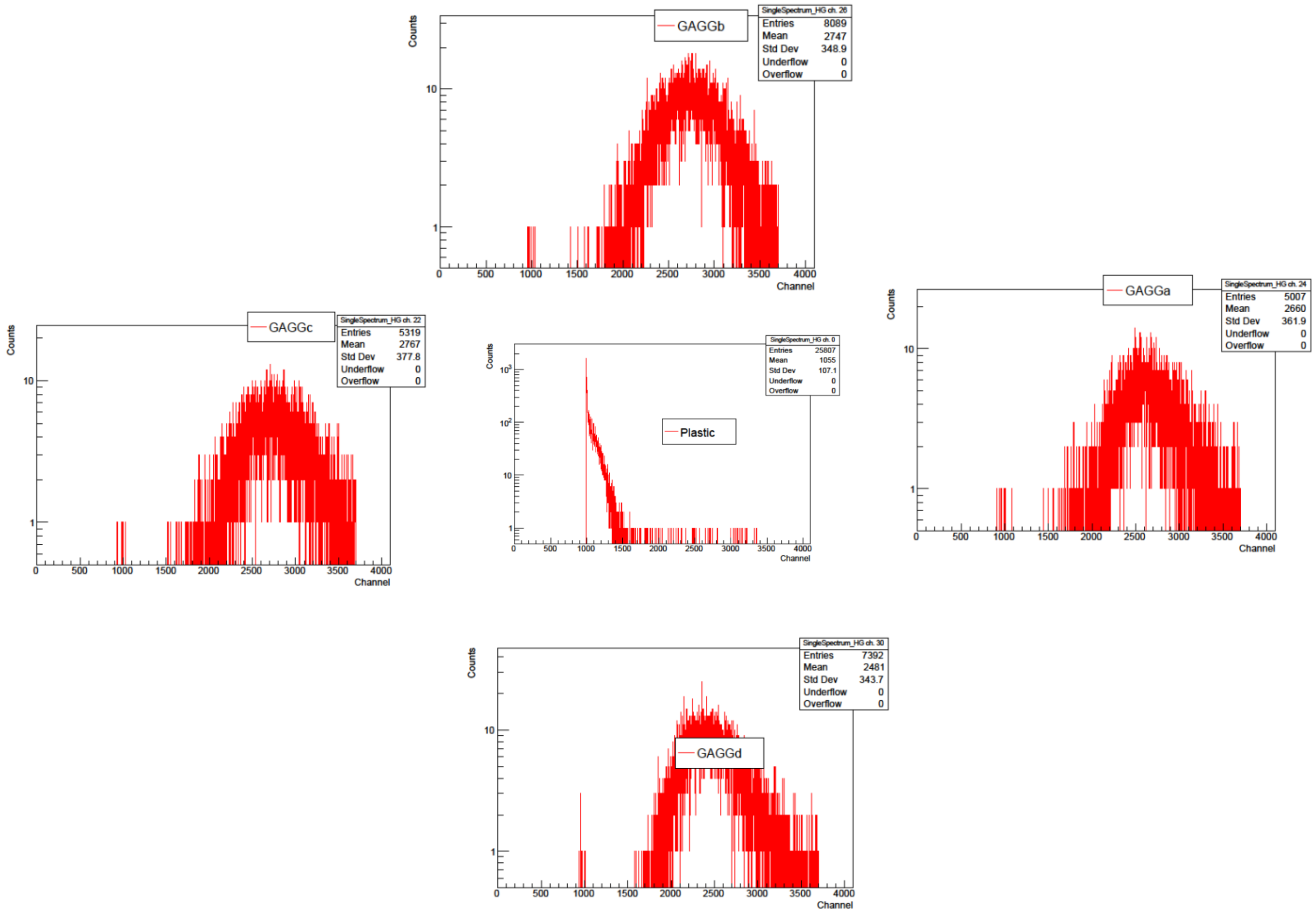


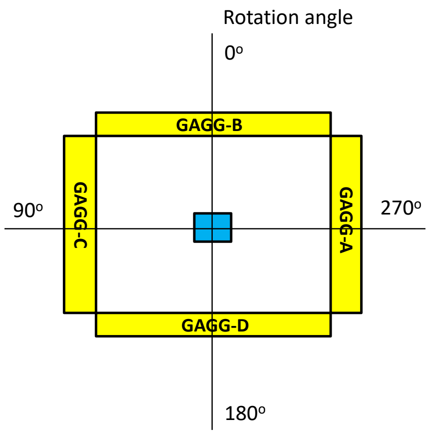
MPPC array is under study…

**Thanks to Merlin Kole.*

Toy polarimeter





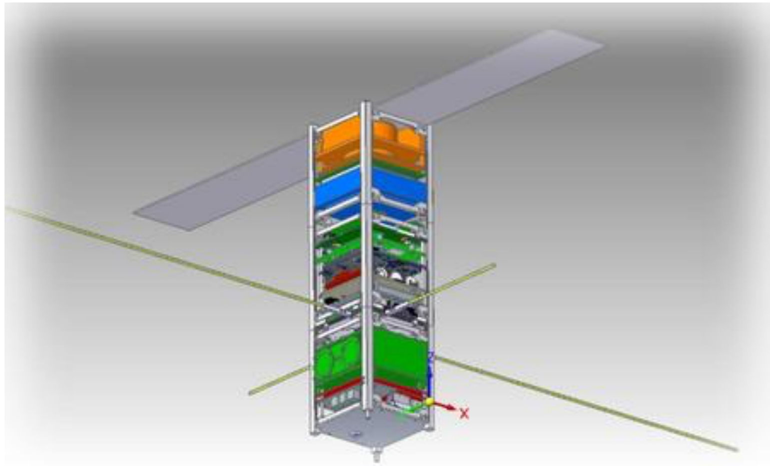


- **Scatterer:** POLAR plastic scintillator (6×6 mm)
- **Absorber:** GAGG scintillator
- **Read out:** CITIROC

- Can we align our developments with POLAR-2?

Summary & outlook

- SPHiNX is a hard X-ray GRB polarimeter proposed for the Swedish InnoSat platform
- Phase A studies completed in 2018
- Swedish Space Agency selected atmospheric/climate-related missions for InnoSat-1 (launch 2019) /-2 (launch 2022)
- So, what next? Wait for InnoSat-3? Very interested in POLAR-2.
- **Last, but not least:** Congratulations on the impressive first results from POLAR!



KTH student satellite ("MIST")
3U CubeSat
GAGG/MPPC/Citiroc-based
X-ray monitor
Launch: *NET 2020*