Rymdstyrelsen
Swedish National Space Agency

KTH VETENSKAP OCH KONST

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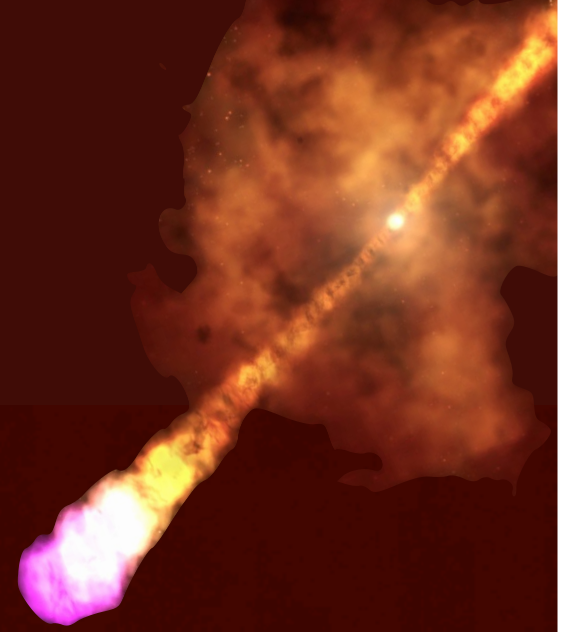
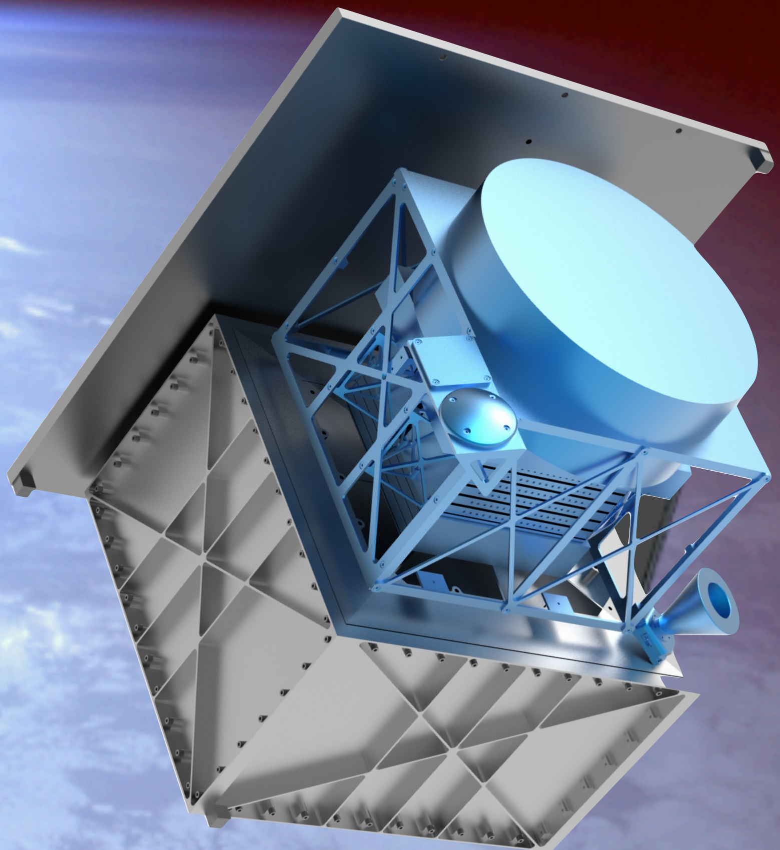
SPHiNX

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



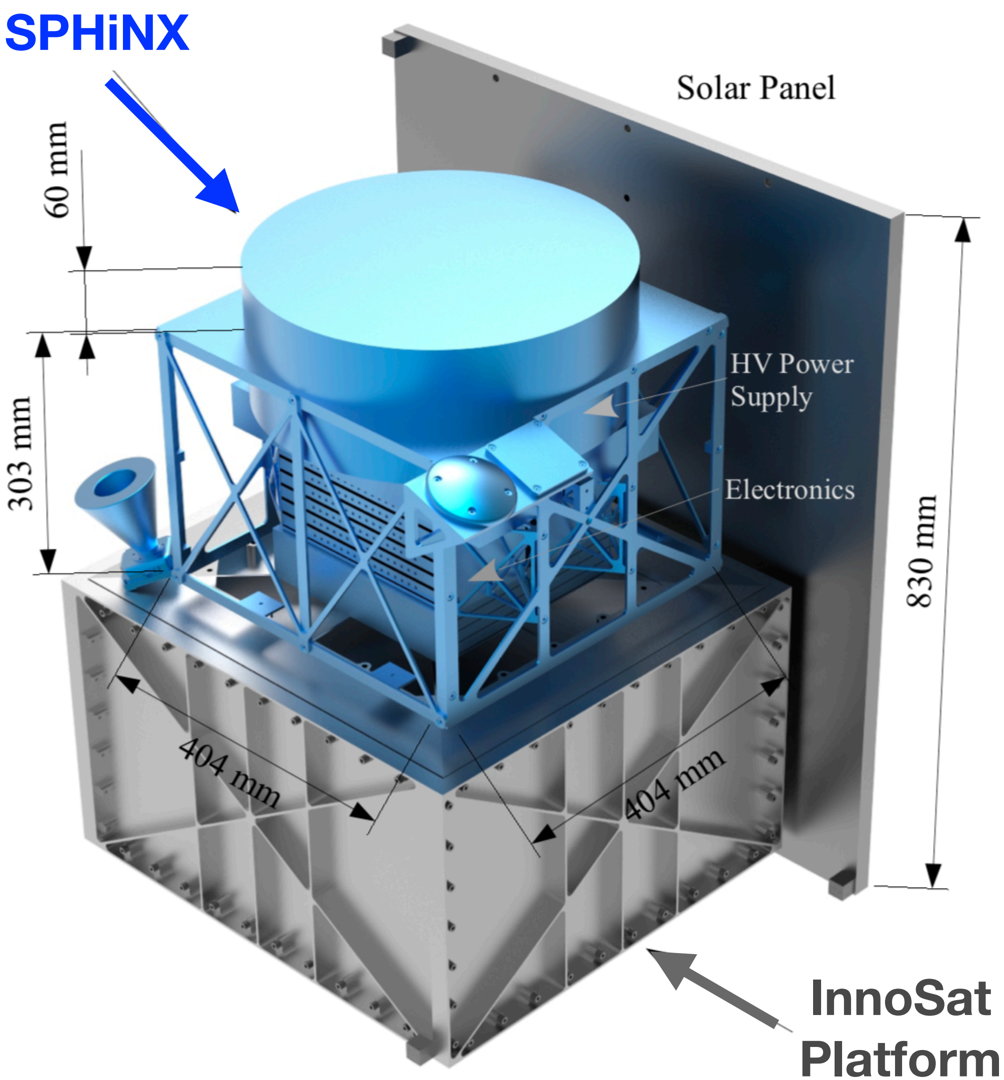


Mark Pearce
KTH, Sweden
on behalf of the SPHiNX team

2018-09-13

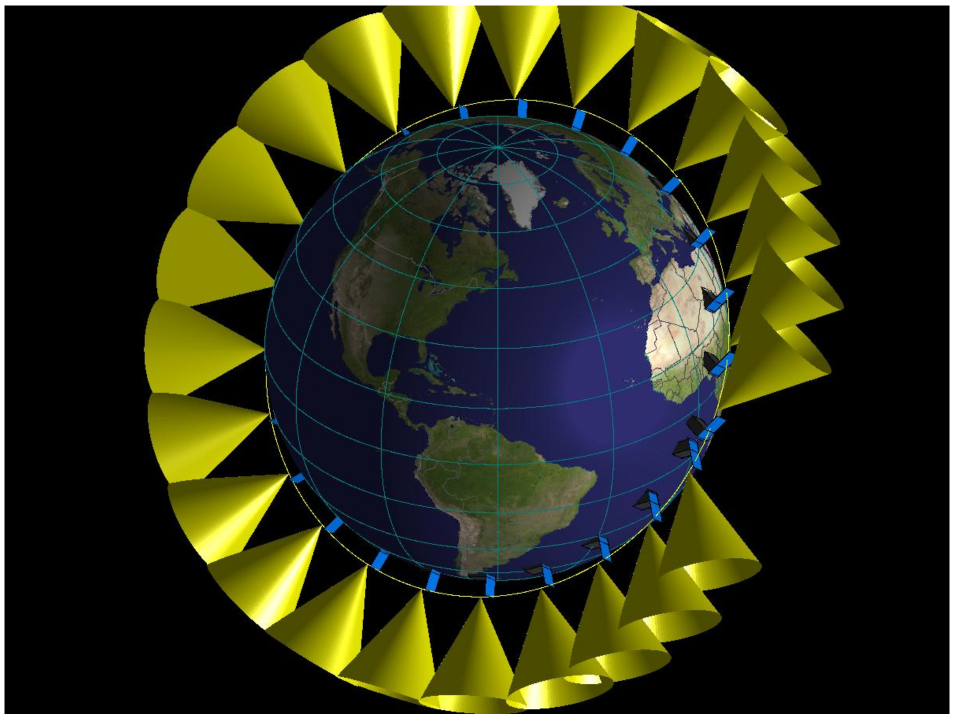
Towards a Network of GRB Detecting Nanosatellites
Budapest / 13-14 September 2018

Mission overview



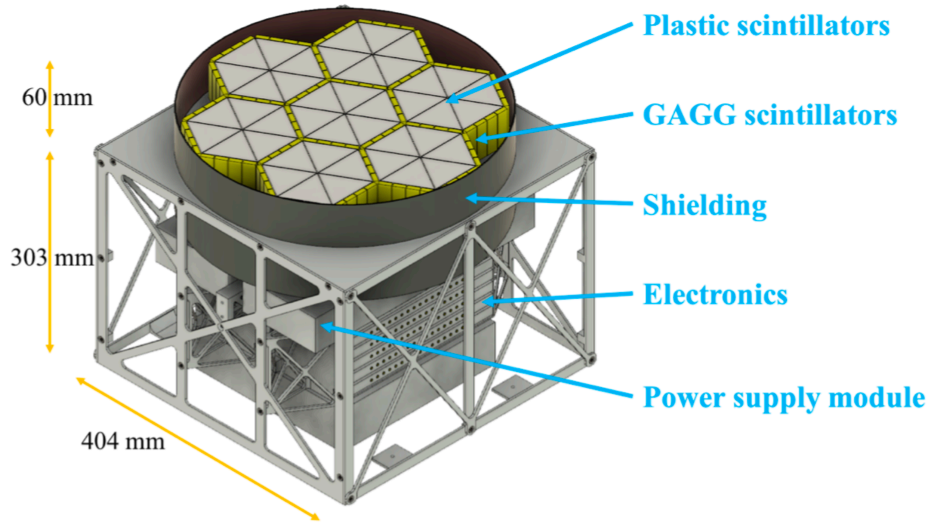
Phase A baseline design

Orbit inclination/altitude	53° / 500 km
Launch type	Piggy-back (e.g. PSLV)
Duration	2 years
Payload mass	25 kg
Payload volume	48×53×70 cm^3
Payload power	30 W
Downlink (S-Band)	150 MB/pass. 1 pass/day.
Pointing	Quasi-zenith, 3-axis stabilised, 0.1° precision



Instrument performance

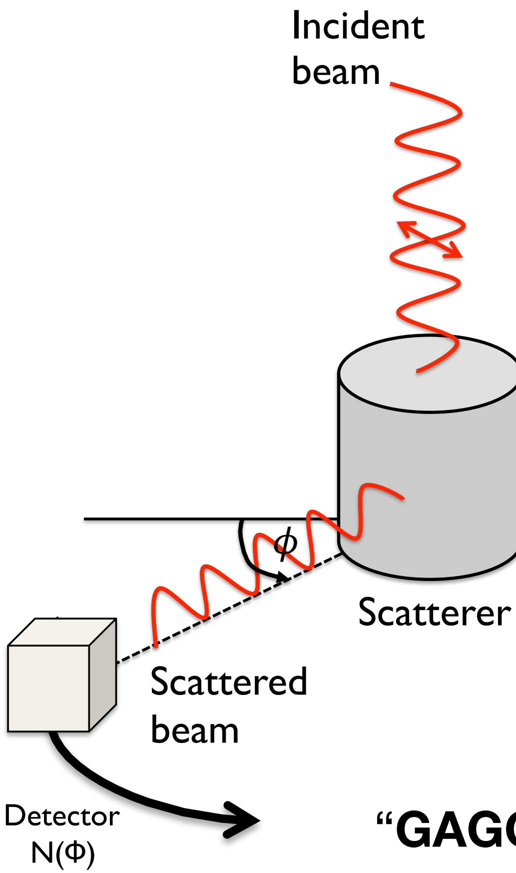
- **Observe ~200 GRBs / 2 years**
  - Field-of-view ~120°
  - Geometric area ~800 cm^2
- **Determine light-curve and spectral shape (<10-600 keV)**
  - dE < 30% (60 keV)
- Timing to ~1 ms (UT synchronised)

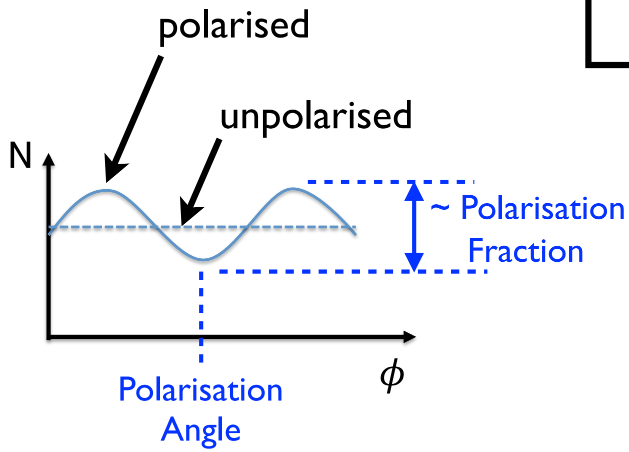


- **Instrument design is optimised for polarimetry**
  - Determine Polarisation Fraction (PF) and Polarisation Angle (PA) with ~10% (MDP<0.3) precision for **~50 (long) GRBs / 2 years**
  - Energy range: **50-600 keV**

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

X-ray polarimetry



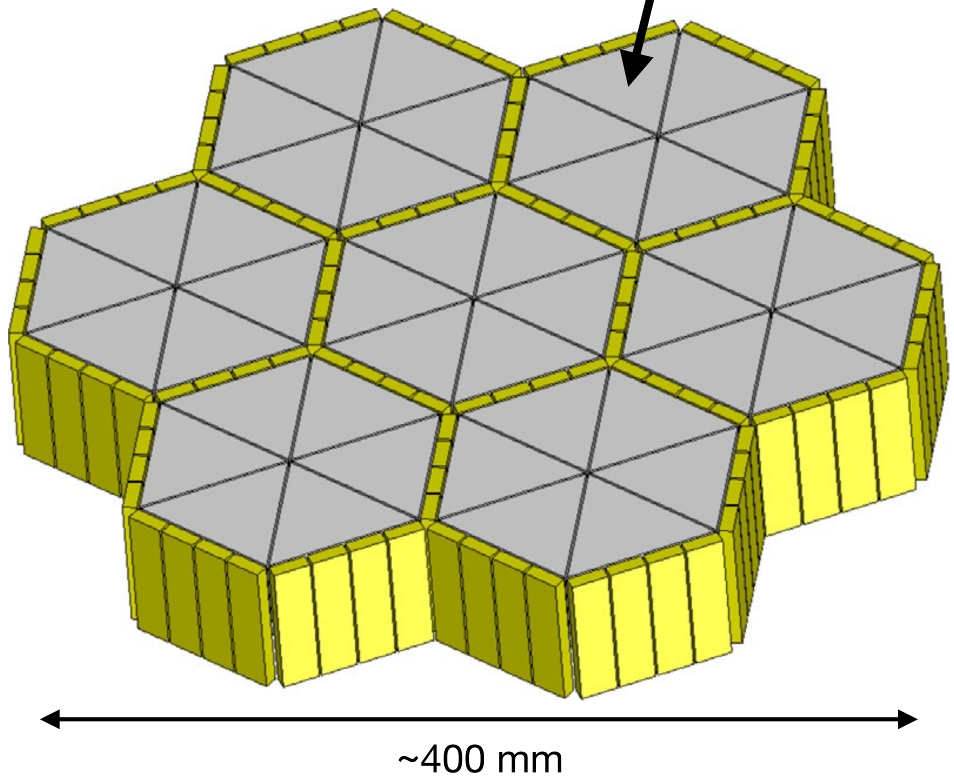


Klein-Nishina relationship

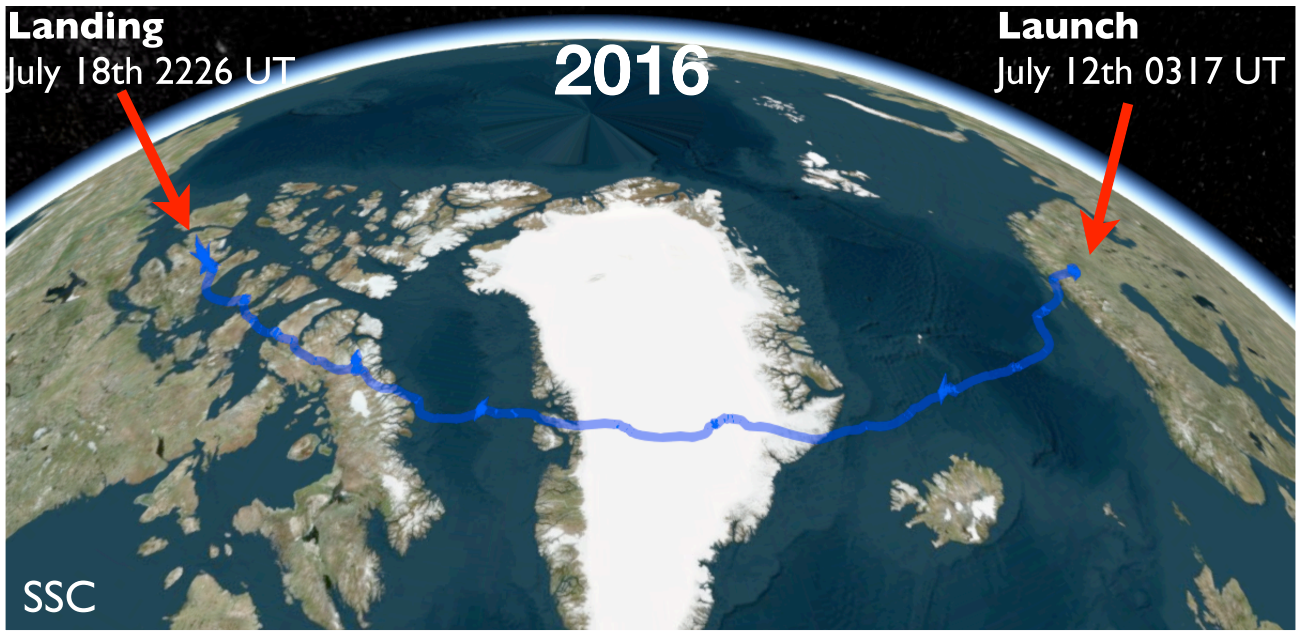
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_e^2 \frac{k^2}{k_0^2} \left(\frac{k}{k_0} + \frac{k_0}{k} - 2 \sin^2\theta \cos^2\phi \right)$$

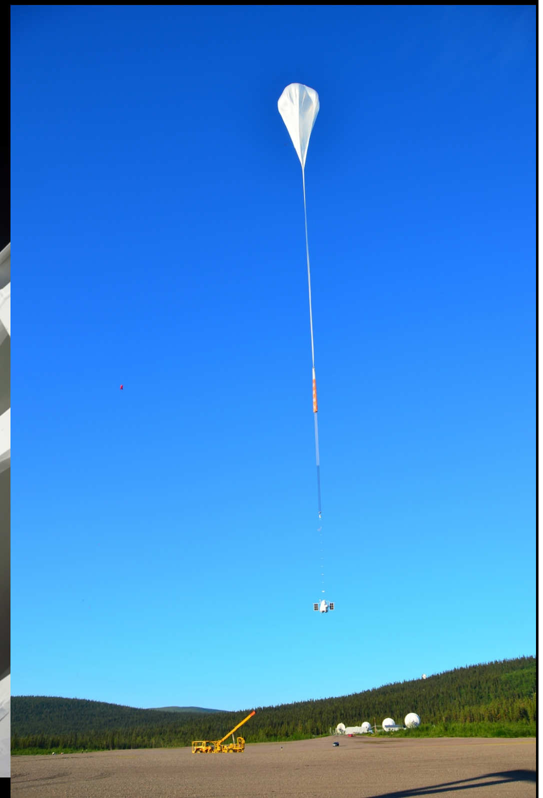
EJ-204 **plastic scintillator**
(low Z)

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



- Fast (88 ns decay)
- High density (6.6 g/cm^3)
- High light-yield (LY=5.6×10^4 γ/MeV)
- Low LY dose dependence/activation
- Self-luminescence issue? (SAA)

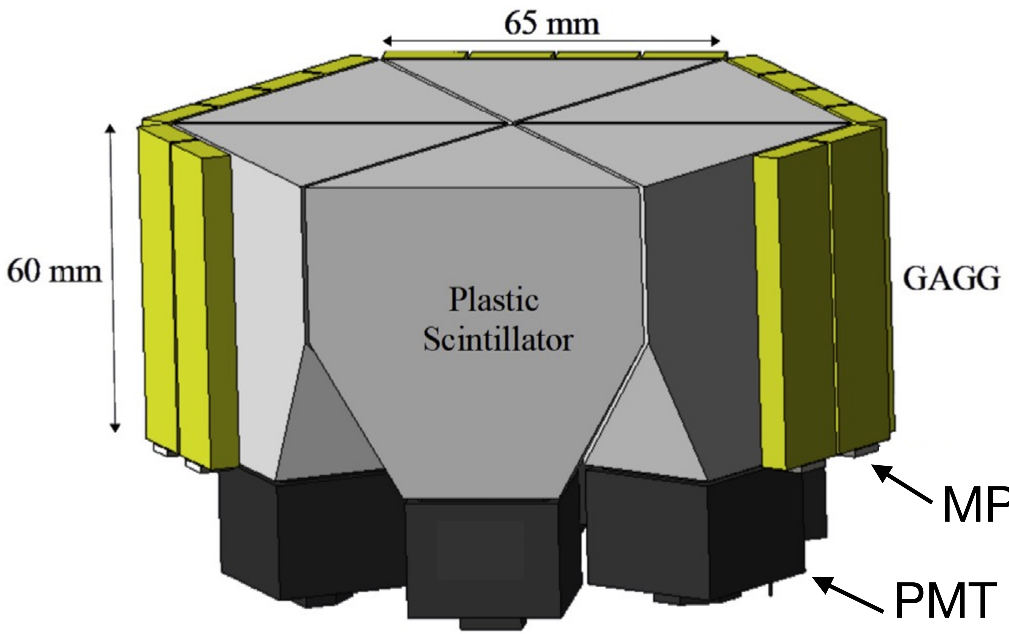




Crab: *M. Chauvin et al., Nature Sci Rep 7 (2017) 7816, MNRAS 477 (2018) L45*

Cyg X-1: *M. Chauvin et al., Nature Astronomy 2 (2018) 652*

Future? Stratospheric balloon flights for testing Cubesats



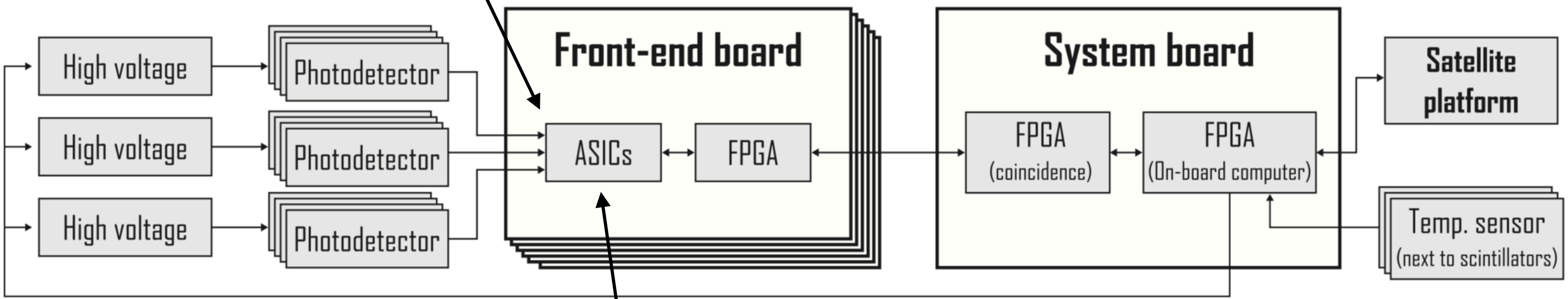
MPPC = Hamamatsu S13360-6050

PMT = Hamamatsu R7600U-200.
Aim to transition to MPPC

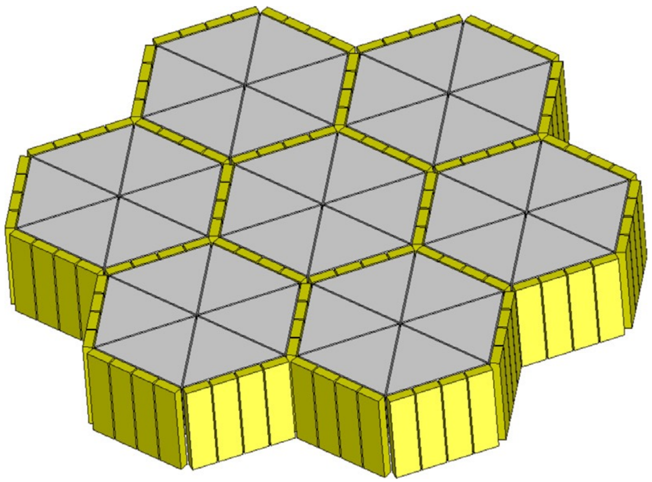
But…

Challenge: *50 keV polarisation requires 5 keV Compton scatter detection in plastic*

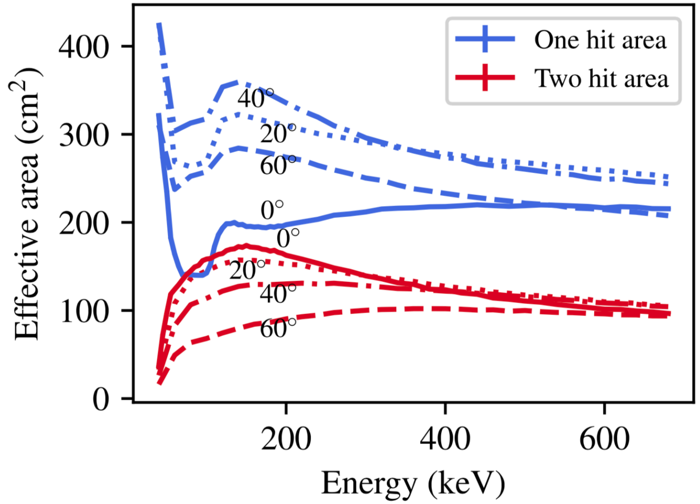
ASIC = IDEAS “SIPHRA”
Weeroc Citiroc



preamp/shaper/peak det/(digitise)



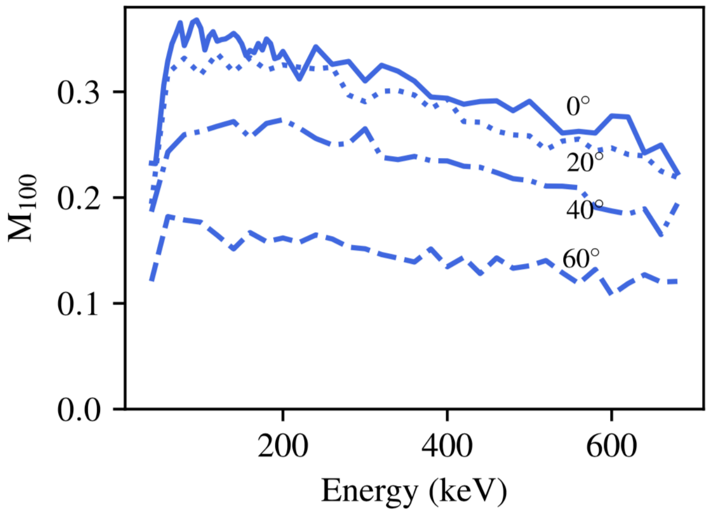
Background mitigation
- Periphery of scintillator array covered in Pb/Sn/Cu shield
- 1 mm CFRP shell covers sides/top of array
- Albedo attenuated by InnoSat

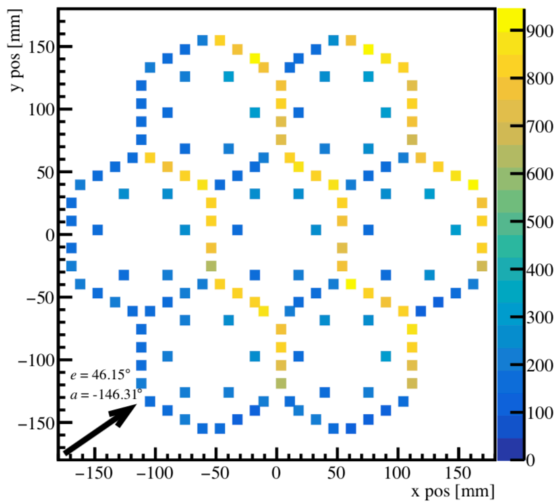


Geant4 simulations

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)

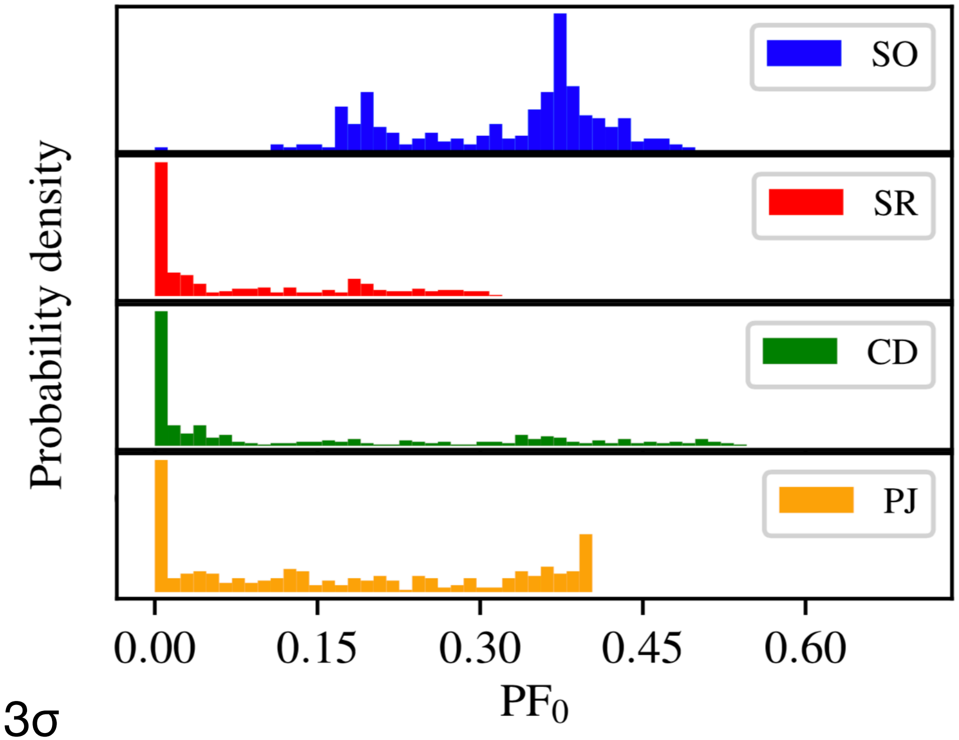


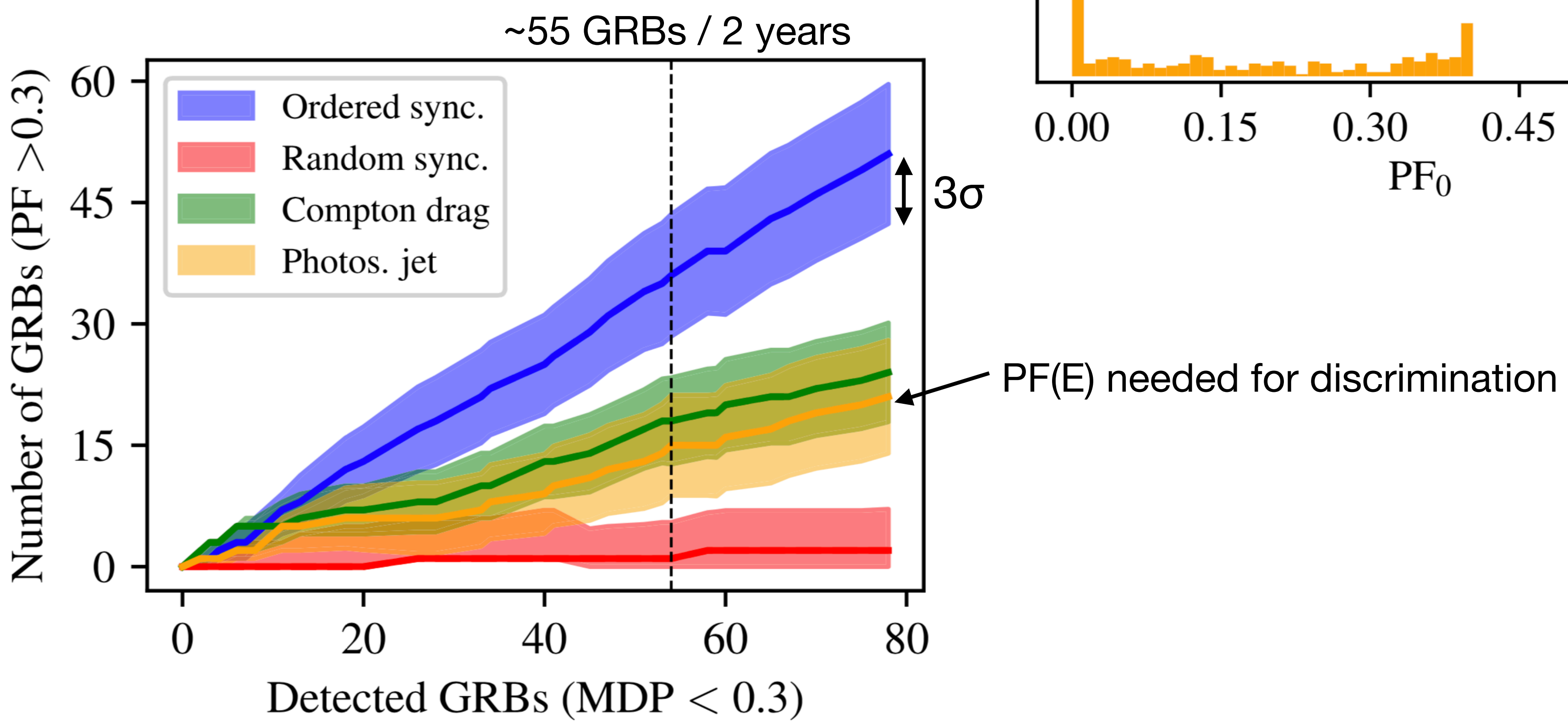


Segmented design

- Stand-alone localisation accuracy ≲5°
- Important for polarimetric response

Example: emission model discrimination





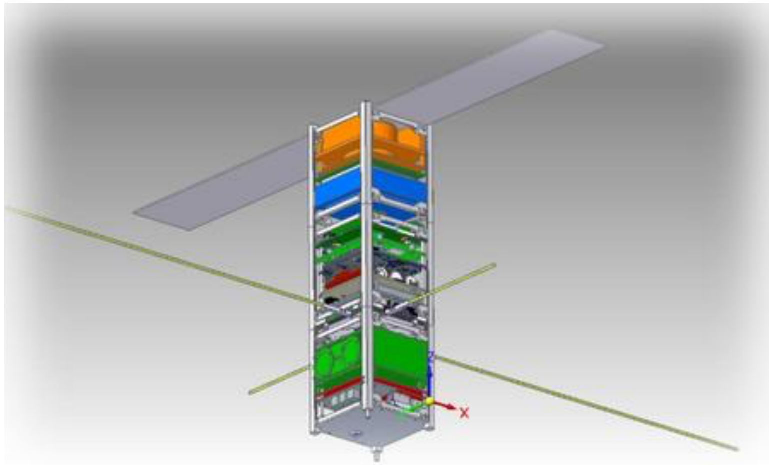
Outlook

- SPHiNX is a **small satellite** payload for GRB polarimetry proposed for the Swedish InnoSat platform

- Phase A studies were completed in 2018
- Space Agency selected atmospheric/climate-related missions for InnoSat-1 (launch 2019) /-2 (launch 2022)

- SPHiNX technology developments are applicable to CubeSats

- We will try again for InnoSat-3! Call expected later this year.
  - Background is manageable but challenging
  - Lower inclination orbit beneficial but launch opportunities are rare



KTH student satellite ("MIST")
3U CubeSat
GAGG-based X-ray monitor
Launch ~2020
UHF ground station at KTH

References

Background studies

MDPI MDPI

Article

A Study of Background Conditions for Sphinx—The Satellite-Borne Gamma-Ray Burst Polarimeter

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Received: date; Accepted: date; Published: date

Abstract: SPHiNX is a proposed satellite-borne gamma-ray burst polarimeter operating in the energy range 50–500 keV. The mission aims to probe the fundamental mechanism responsible for gamma-ray burst prompt emission through polarisation measurements. Optimising the signal-to-background ratio for SPHiNX is an important task during the design phase. The Geant4 Monte Carlo toolkit is used in this work. From the simulation, the total background outside the South Atlantic Anomaly (SAA) is about 323 counts/s, which is dominated by the cosmic X-ray background and albedo gamma rays, which contribute ~60% and ~35% of the total background, respectively. The background from albedo neutrons and primary and secondary cosmic rays is negligible. The delayed background induced by the SAA-trapped protons is about 190 counts/s when SPHiNX operates in orbit for one year. The resulting total background level of ~513 counts/s allows the polarisation of ~50 GRBs with minimum detectable polarisation less than 30% to be determined during the two-year mission lifetime.

Keywords: polarimeter; Compton scattering; GRB; background

1. Introduction

The Satellite Polarimeter for High eNergy X-rays (SPHiNX) is a proposed mission for a Swedish scientific satellite based on the InnoSat platform[1], which supports a maximum payload mass of 25 kg and provides a payload power budget of 30 W.

SPHiNX is a dedicated polarimeter for gamma-ray bursts (GRBs), the most luminous explosions in the Universe [1]. Long GRBs are generated by the collapse of massive stars [2], while short GRBs come from the merger of binary neutron stars or neutron star–black hole binary systems [3]. The recent

Xie et al., Galaxies 2 (2018) 50

Mission design & science prospects

Astroparticle Physics 104 (2019) 54–63

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

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Science prospects for SPHiNX – A small satellite GRB polarimetry mission

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ARTICLE INFO

Article history:
Received 16 May 2018
Revised 14 August 2018
Accepted 16 August 2018
Available online 17 August 2018

Keywords:
Polarimetry
X-ray
Gamma-ray burst
Small satellite,

ABSTRACT

Gamma-ray bursts (GRBs) are exceptionally bright electromagnetic events occurring daily on the sky. The prompt emission is dominated by X-/γ-rays. Since their discovery over 50 years ago, GRBs are primarily studied through spectral and temporal measurements. The properties of the emission jets and underlying processes are not well understood. A promising way forward is the development of missions capable of characterising the linear polarisation of the high-energy emission. For this reason, the SPHiNX mission has been developed for a small-satellite platform. The polarisation properties of incident high-energy radiation (50–600 keV) are determined by reconstructing Compton scattering interactions in a segmented array of plastic and $Gd_3Al_2Ga_3O_{12}$(Ce) (GAGG(Ce)) scintillators. During a two-year mission, ~200 GRBs will be observed, with ~50 yielding measurements where the polarisation fraction is determined with a relative error ≲ 10%. This is a significant improvement compared to contemporary missions. This performance, combined with the ability to reconstruct GRB localisation and spectral properties, will allow discrimination between leading classes of emission models.

1. Introduction

Gamma-ray bursts (GRBs) are the brightest electromagnetic events in the universe, occurring randomly on the sky approxi-

such as relativistic jets, relativistic magneto-hydrodynamics, aberration of light, relativistic shock waves, and Lorentz invariance violation [7,8].

During the process of collapse and merger, two highly relativis-

Pearce et al., Astroparticle Physics 104 (2019) 54. (astro-ph/1808.05384)

Localisation

Gamma-ray burst localisation strategies for the SPHiNX hard X-ray polarimeter

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Abstract. SPHiNX is a proposed gamma-ray burst (GRB) polarimeter mission operating in the energy range 50-600 keV with the aim of studying the prompt emission phase. The polarisation sensitivity of SPHiNX reduces with increasing uncertainty on the GRB sky position. The stand-alone ability of the SPHiNX design to localise GRB positions is explored via Geant4 simulations. Localisation at the level of a few degrees is possible using three different algorithms. This results in a large fraction (> 80%) of all observed GRBs having a negligible (< 5%) reduction in polarisation sensitivity due to the uncertainty in localisation.

Keywords: polarimeters, x-rays, gamma ray bursts, Monte-Carlo simulations, analysis techniques .

*Nirmal Kumar Iyer, nkiyer@kth.se

1 Introduction

Gamma-ray bursts (GRB) were serendipitously discovered over 50 years ago by Vela satellites deployed to monitor the ban on nuclear tests in space.[1] They are now known to be the brightest events in the electromagnetic universe, occurring approximately once per day at random locations on the sky.[2,3] GRBs are thought to be formed during the collapse of a massive object into a black

Heckmann et al., SPIE JATIS. In review (2018)

In preparation: paper describing lab developments