
# A Balloon-borne Soft Gamma-ray Polarimeter

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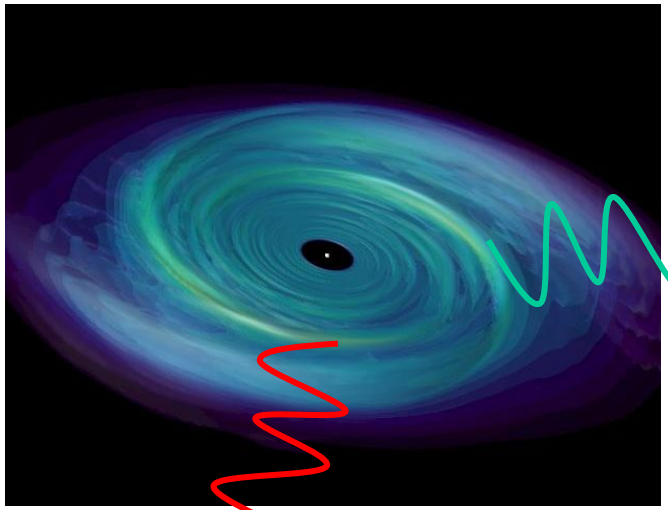
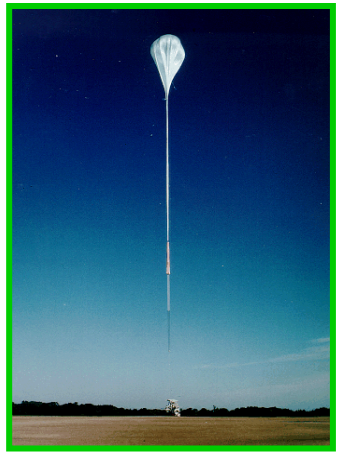
Mérida, México



$\gamma$

$E, t, \hat{r}, \hat{P}$

**P o G OLite**



[25 – 80 keV]

SLAC / Stanford- KIPAC, Hawaii

KTH, Stockholm University

Tokyo Institute of Technology, Hiroshima University, ISAS/JAXA, Yamagata University.

Ecole Polytechnique

$E, t, \hat{r}$

$\gamma$

e.g. G L A S T

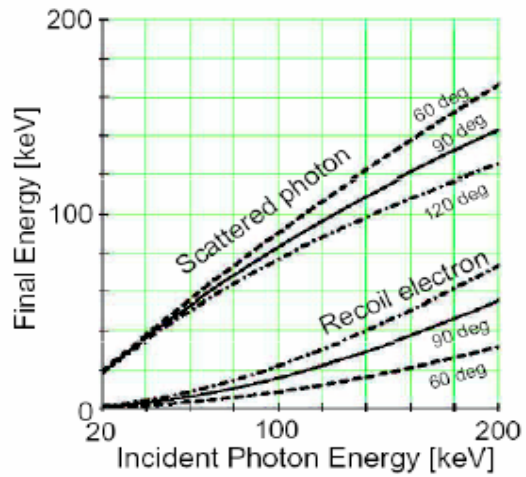
[10 keV – 300 GeV]

- Gamma- / X-rays can be characterised by their **energy**, **direction**, **time of detection** and **polarisation**
- **Polarisation** only measured once (OSO-8, 2.6 & 5.2 keV,1976)
- Measuring the **polarisation** of gamma-rays provides a **powerful diagnostic** for source emission mechanisms
- **Polarisation** can occur through **scattering / synchrotron processes**, interactions with a **strong magnetic field**

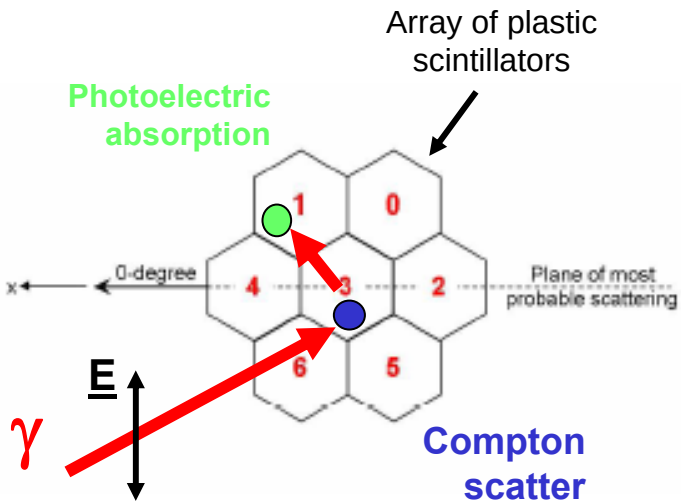
$\Rightarrow$ sensitive to the ‘history’ of the photon

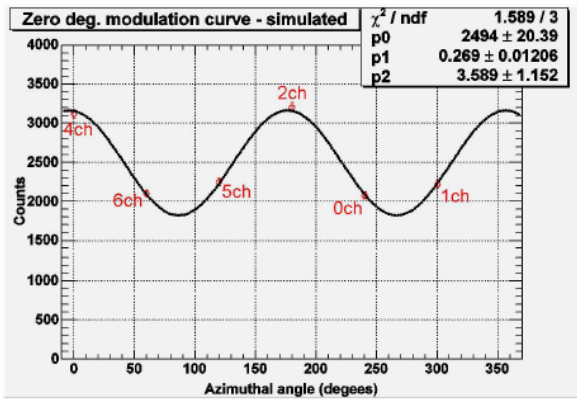
# Measuring polarisation

- γ from a **polarised** source undergo **Compton scattering** in a suitable detector material
- Higher probability of being **scattered perpendicular** to the **electric field vector** (polarisation direction)
- Observed **azimuthal scattering angles** are therefore **modulated by polarisation**

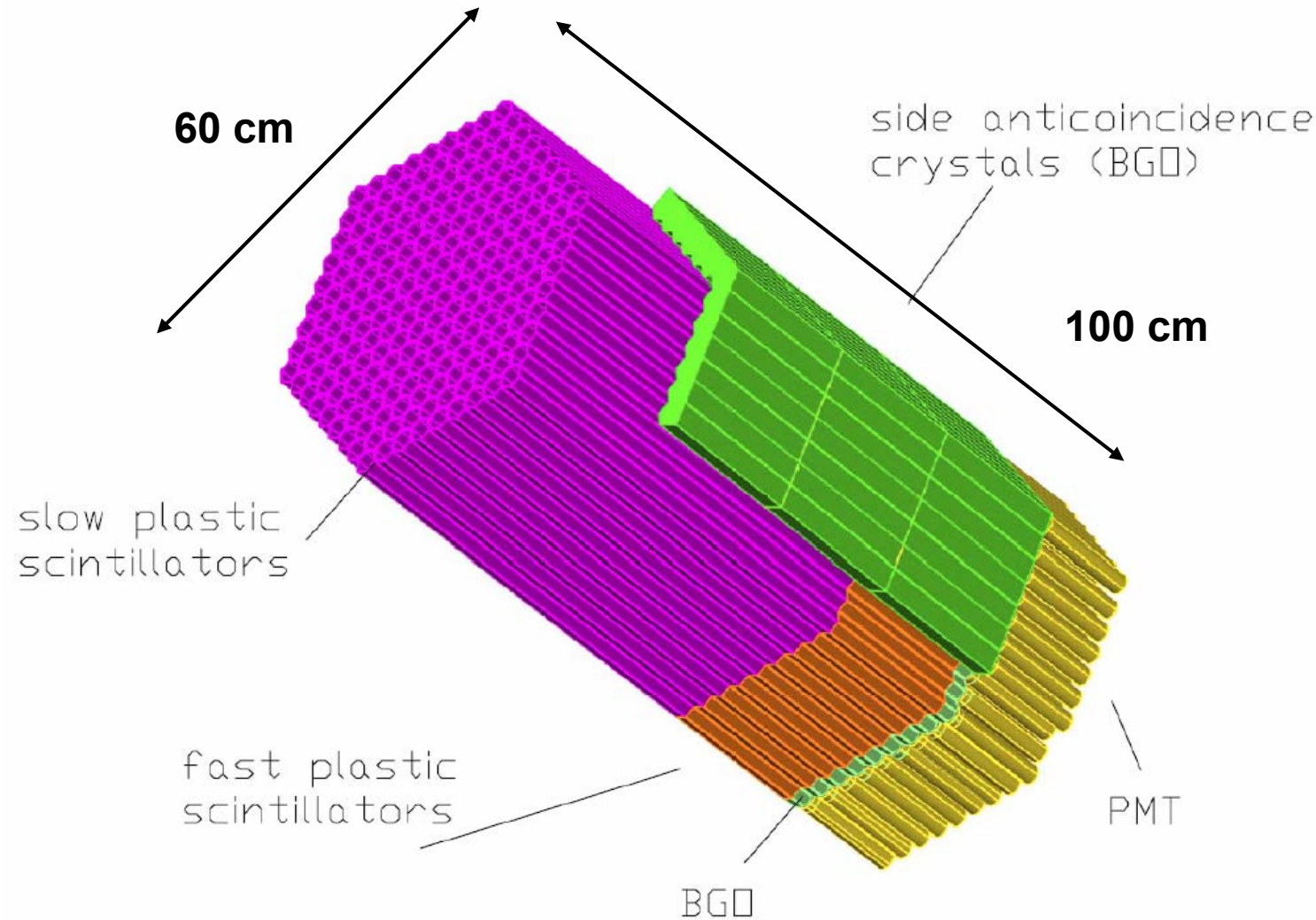



- Incident γ deposits **little energy** at **Compton** site
- **'Large' energy** deposited at **photoelectric absorption** site
- ⇒ **large energy difference**
- Can be distinguished by simple plastic scintillators (despite poor intrinsic energy resolution)



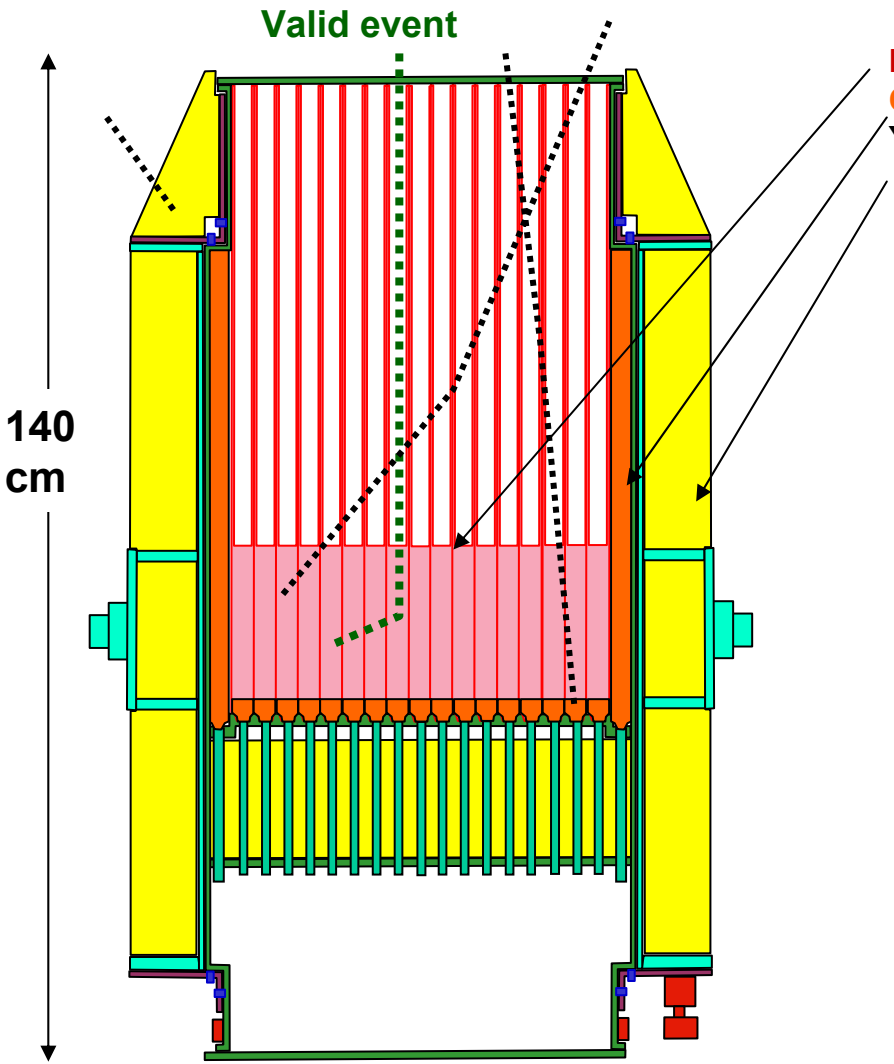
# PoGOLite polarimeter – schematic



# Well-type phoswich detector

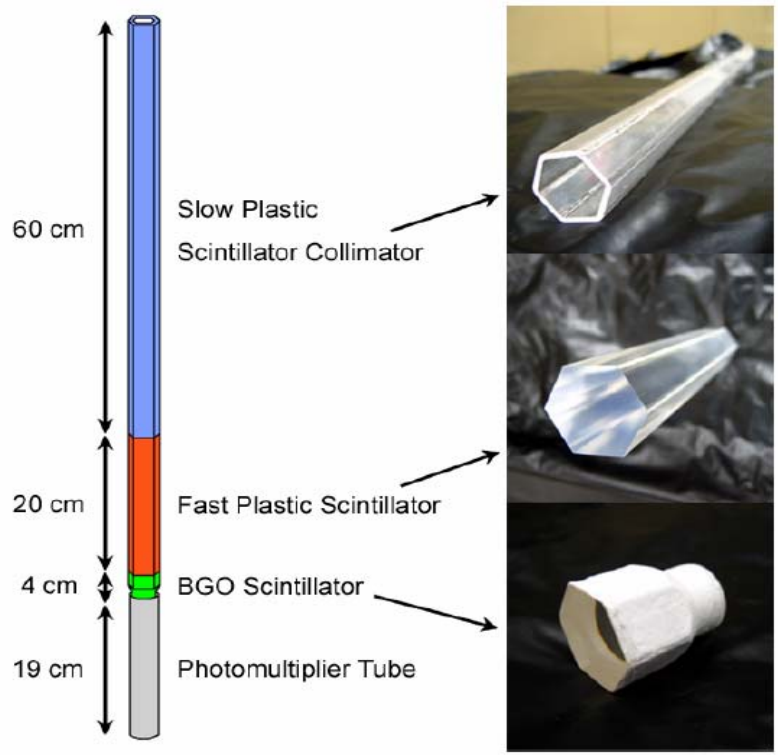
A narrow field-of-view and low background instrument

**See:** C. Marini-Bettolo. OG 1.5 poster




**Pink: Phoswich Detector Cells (total 217units)**
**Orange: Side Anti-counter Shield (total 54 BGO)**
**Yellow: Neutron Shield (polyethylene)**

## Phoswich Detector Cell



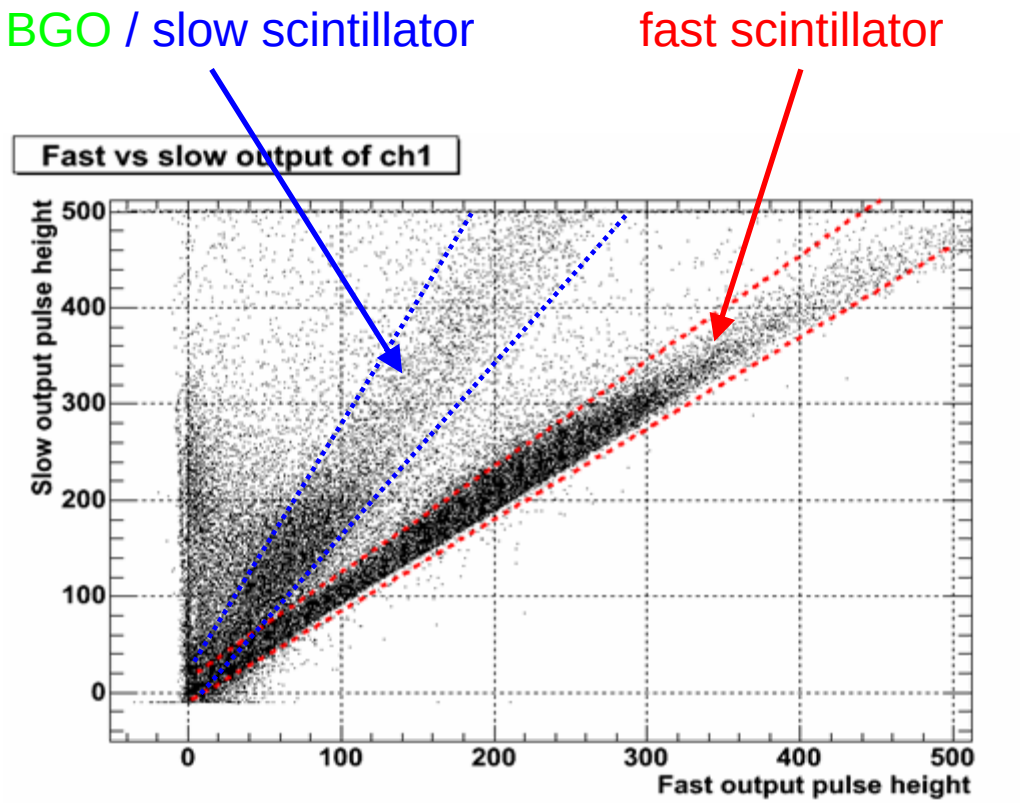
# Selecting fast scintillator events

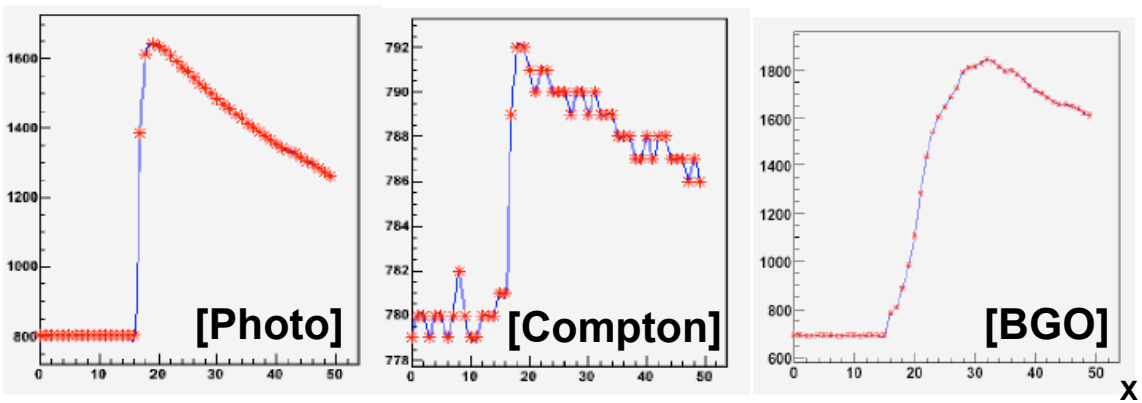
- Pulse shape discrimination

| Decay times | |
|---|---|
| Fast scintillator | 1.8 ns |
| Slow scintillator | 285 ns |
| BGO | ~300 ns |

- Clear separation between signals from fast scintillator and BGO/slow scintillator

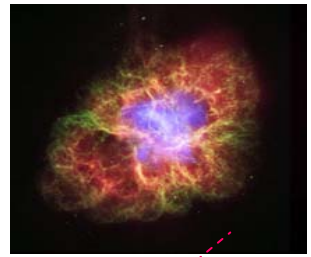
- Fast scintillator branch is chosen for analysis

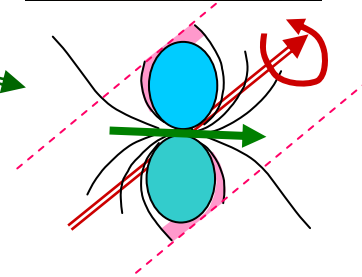


# Polarisation in soft γ-ray emission

- **Synchrotron emission**:
  - **Rotation-powered neutron stars** (eg. the Crab pulsar)
  - **Pulsar wind nebulae** (eg. the Crab nebula)
  - **Jets in active galactic nuclei**
- **Compton scattering**:
  - **Accreting disk around black holes** (eg. Cygnus X-1)
- **Propagation in strong magnetic field:**
  - **Highly magnetised neutron stars**



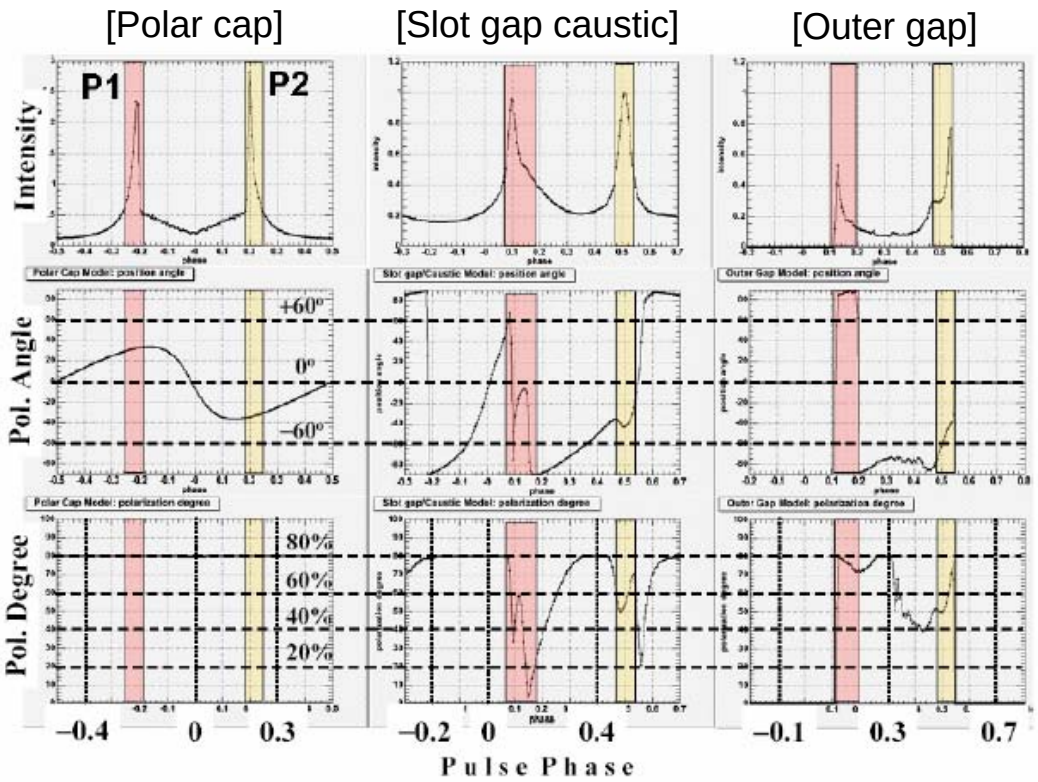


**Expected polarization is a few % - ~20%**

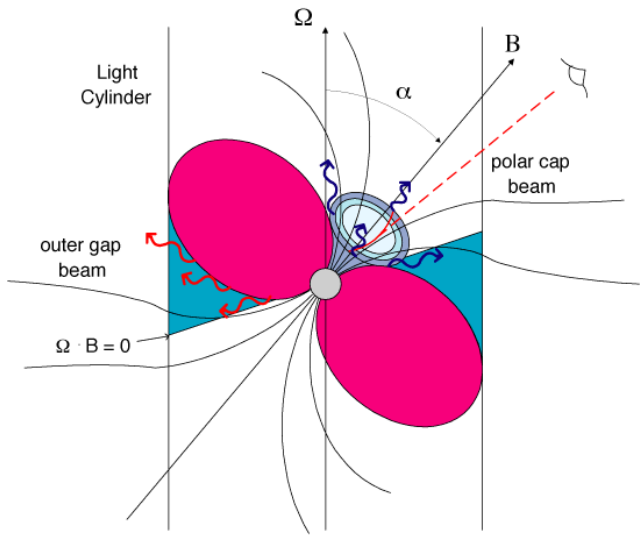
→ **Need a very sensitive polarimeter**

**PoGOLite is optimised for point-like sources**
**covers 25-80 keV range and**
**detects 10% pol in 200 mCrab sources**
**in a 6 hour balloon observation**

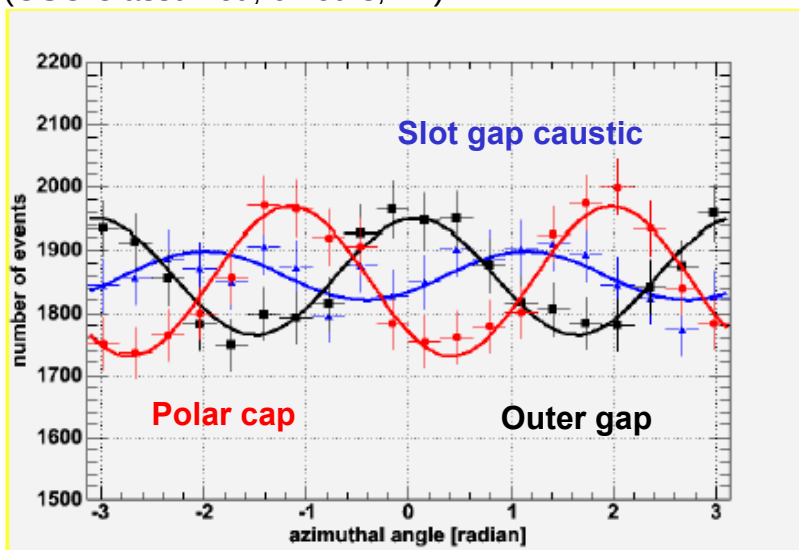
# Crab Pulsar emission models




Numerical data: Alice Harding

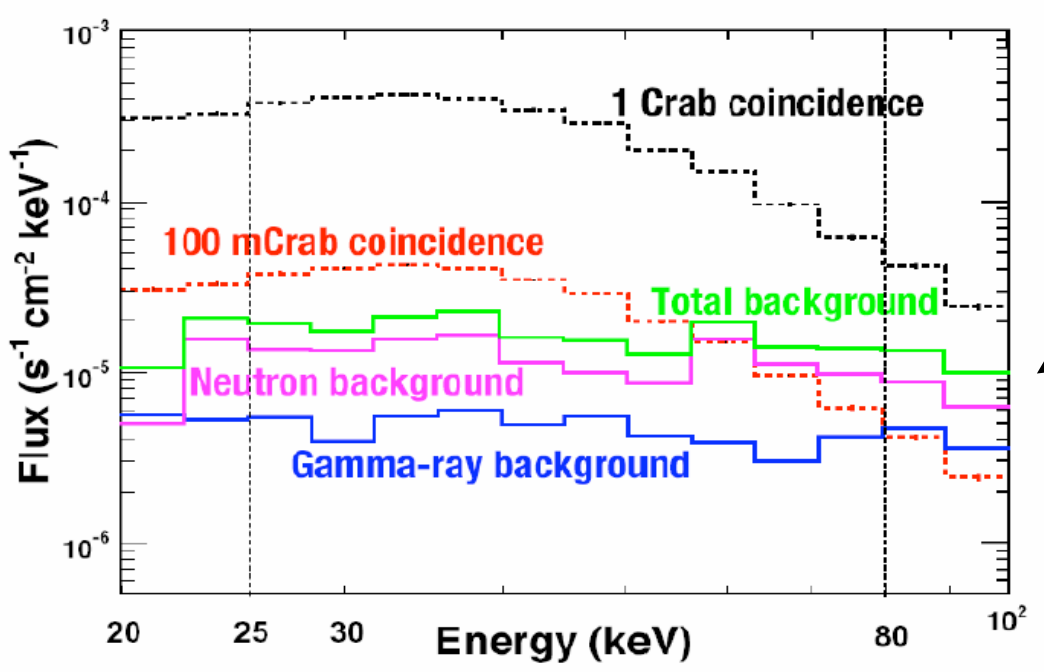



(OSO-8 assumed, 6 hours, P1)



# Background reduction

PoGOLite




**Dominant backgrounds:**
- Atmospheric neutrons (mostly albedo)
- CXB / atmospheric gamma-ray (down, up)

• Excellent **background suppression** with **narrow aperture well-type phoswich** design

• GLAST-BFEM (CSBF) data used to provide background model

**Low** (~100 mCrab) **background**

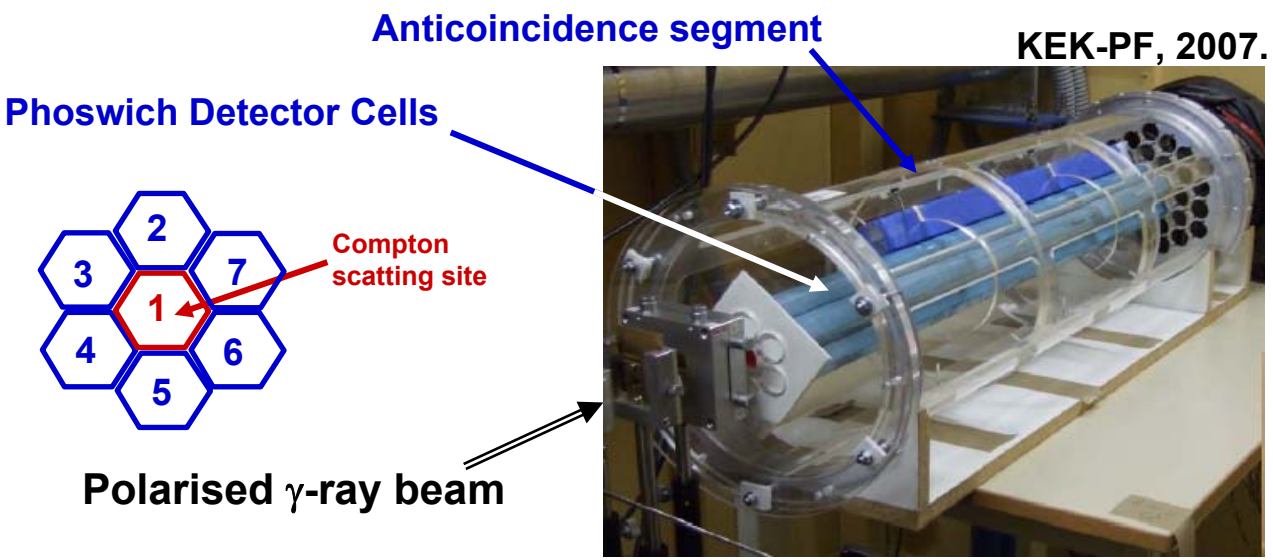
**Large** (115-250 cm$^2$) **effective area**

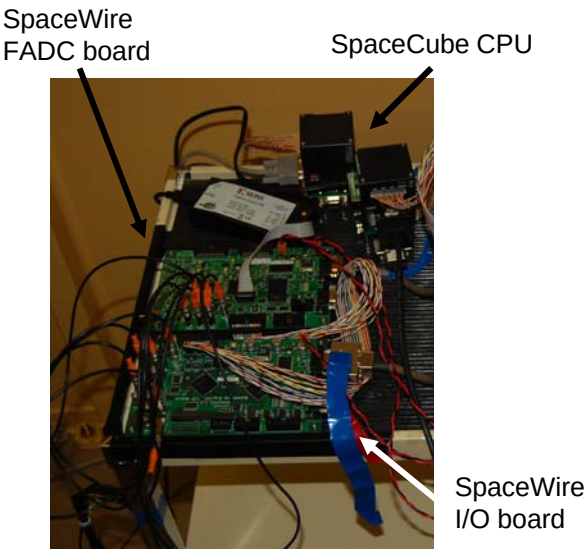
⇒ PoGOLite can detect 10% plane polarised signal from 200 mCrab source in a single 6 hour balloon flight

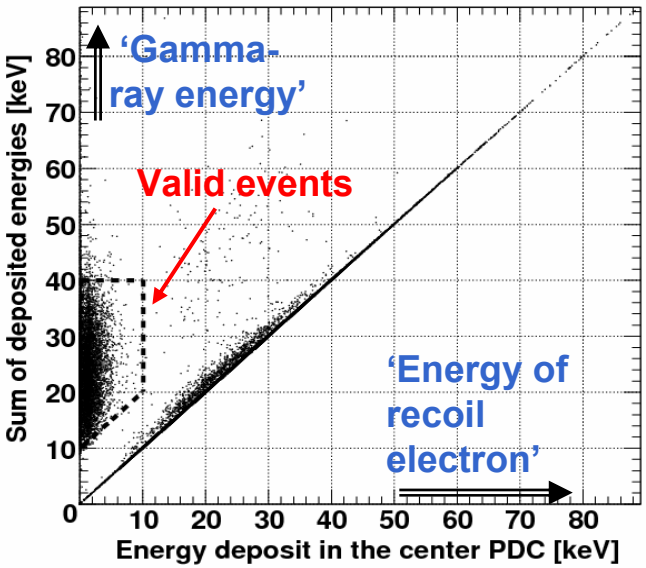
• Cosmic ray and gamma background rejection by BGO shields and active collimators

• Neutron background reduced with Compton kinematics and polyethylene shield

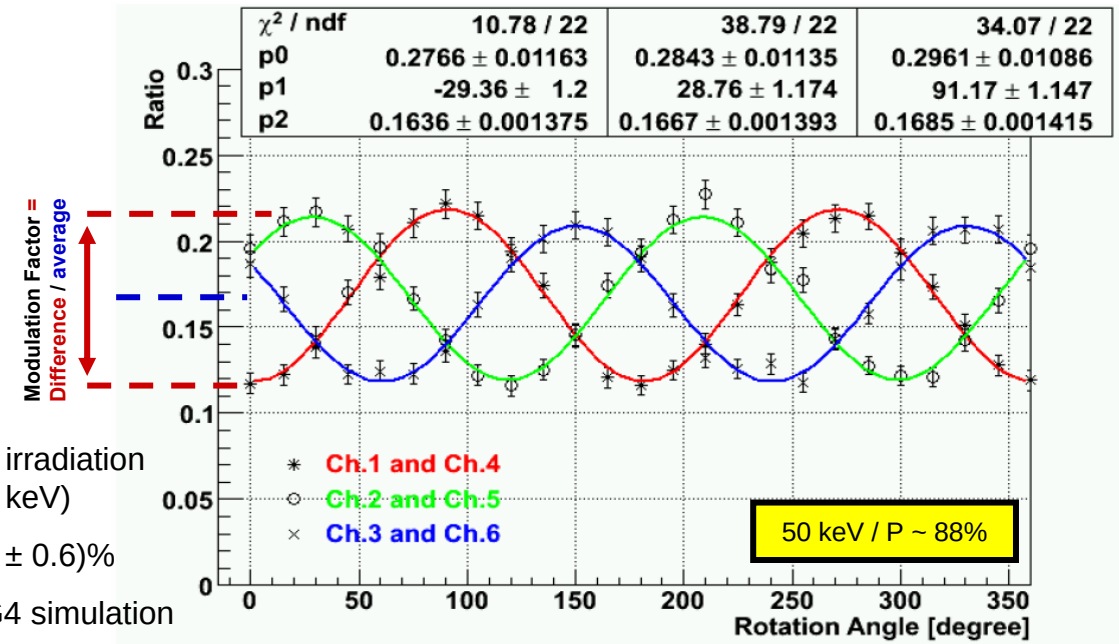
# Tests with polarized soft γ-ray beams



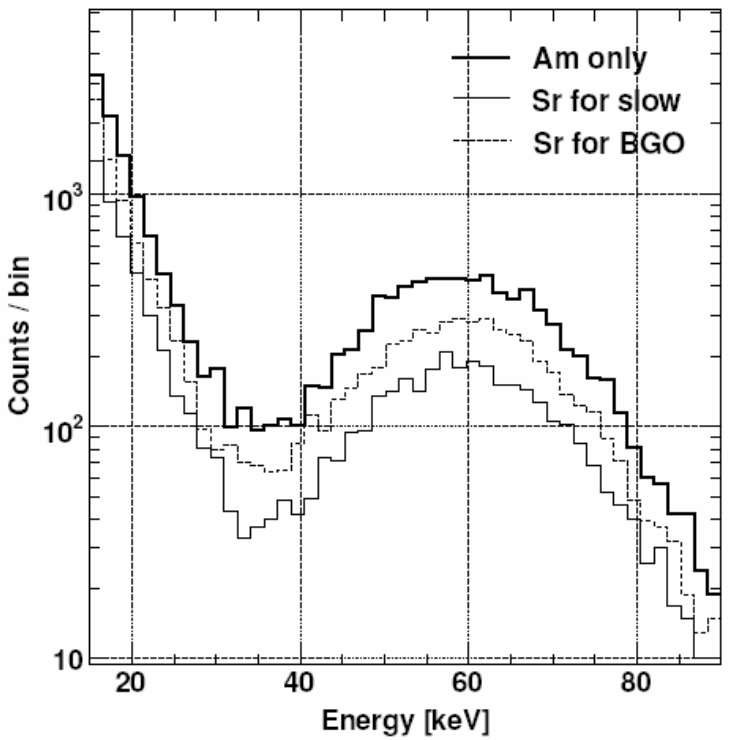




$$P_{source} = \frac{MF_{obs}}{MF_{100}}$$



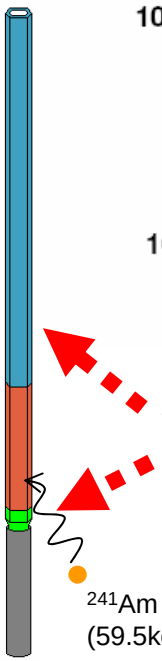

- Simultaneous irradiation with $^{137}$Cs (661 keV)
- <MF> = (28.6 ± 0.6)%
- Agrees with G4 simulation

# Charged particle background rejection




FWHM

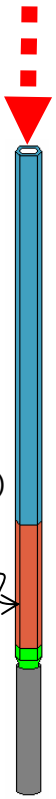
(42±1)%
(44±1)%
(42±1)%



$^{90}$Sr ($e^-$, <2.3 MeV, 10 kHz)
**NB:** x10 expected!

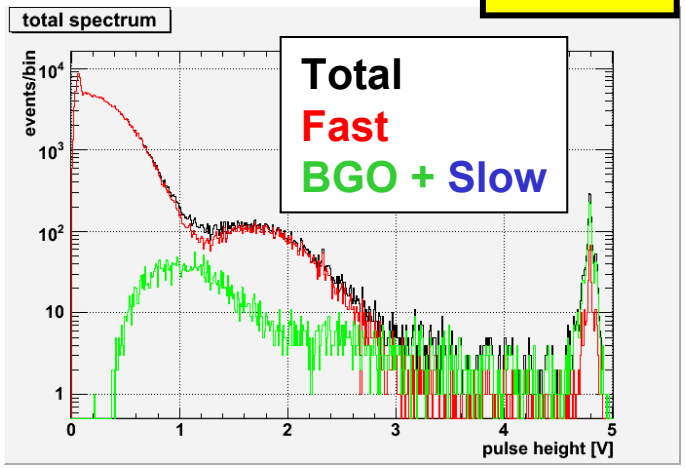
$^{241}$Am
(59.5keV)

392 MeV p

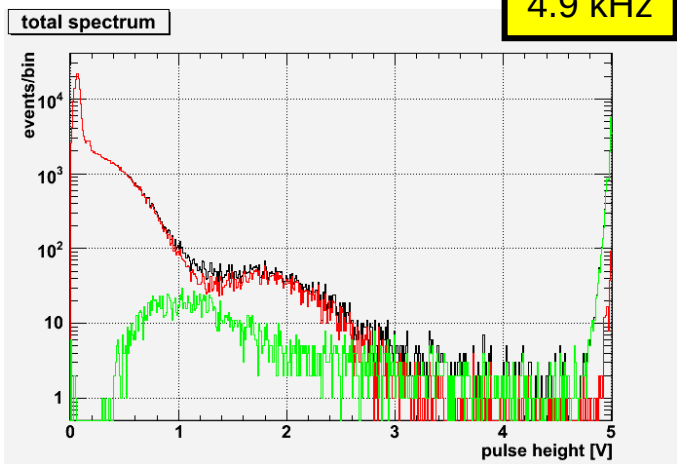


$^{241}$Am
(59.5keV)

Beam off

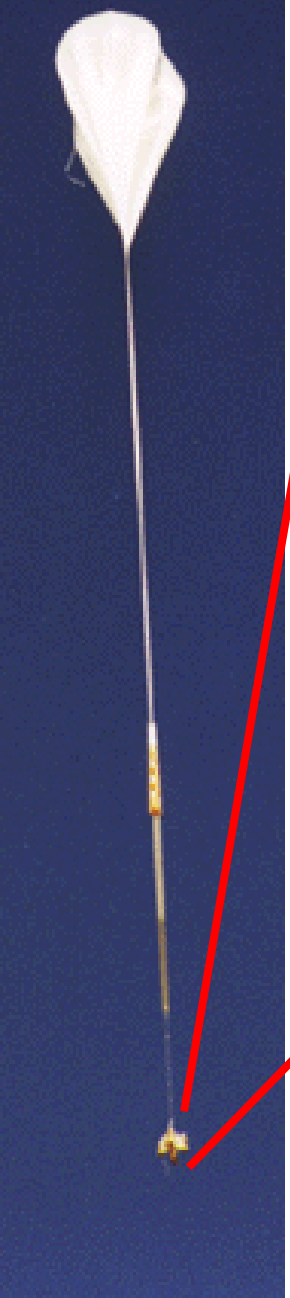


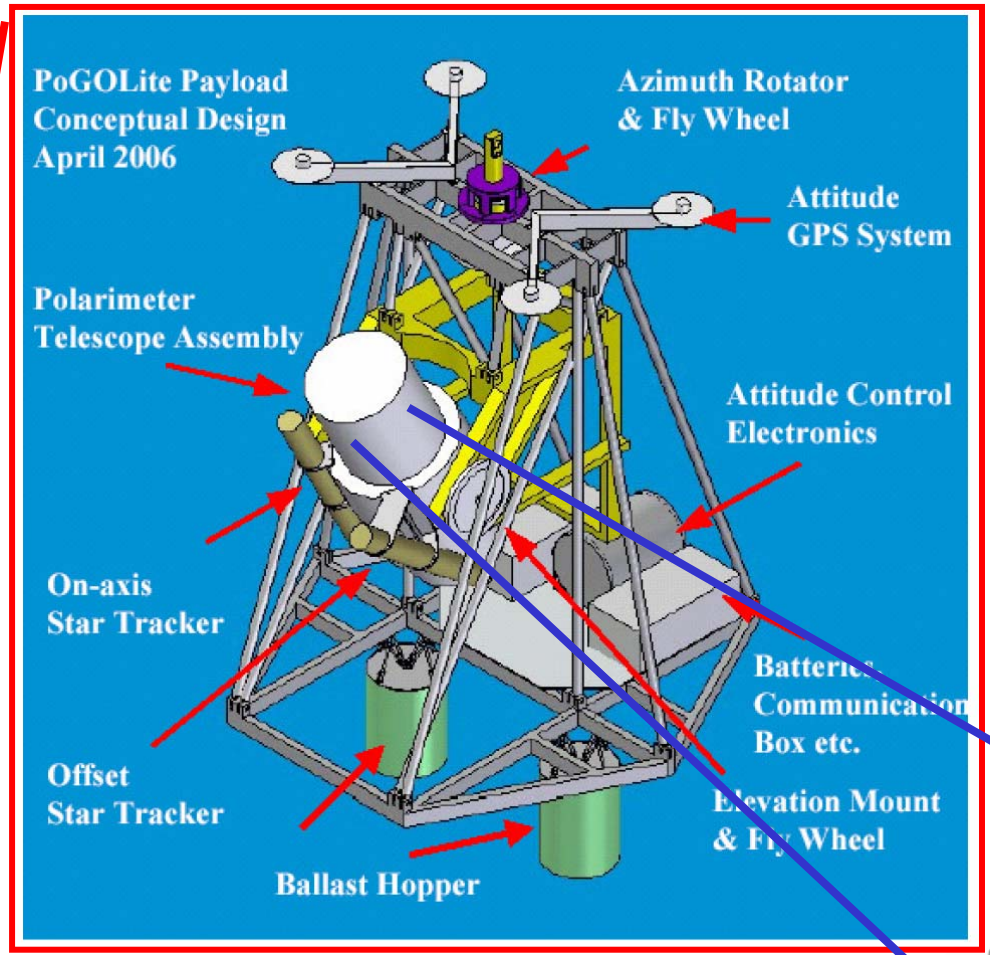

4.9 kHz




Proton beam test at RCNP Osaka, July 2006

# PoGOLite payload



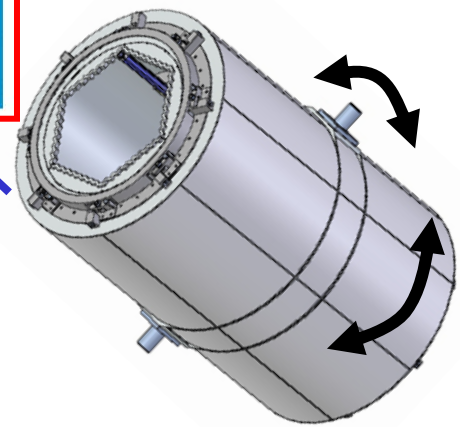



**DAQ system**

- Dimensioned for long duration flights
- No HV supply lines
- Flash ADC recording of all non-zero waveforms
- Memory stick storage

**Attitude control**

- Design adapted from HEFT.
- Goal: 5% of F.O.V. = ~0.1 degrees
- 2 star cameras, DGPS, 2 gyroscopes, 2 magnetometers, accelerometer. Axial and elevation flywheels.
- Star cameras are primary aspect sensors. Acquires 8th mag. stars in daylight at 40 km.

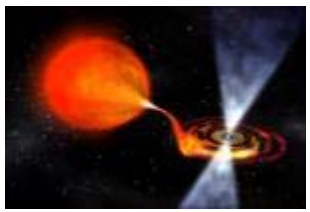


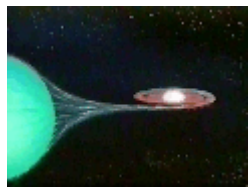
# Engineering flight: 2009 / Science flight: 2010

Primary Northern-sky targets (6h)

| Object | Counting Rate | MDP (3σ) |
|---|---|---|
| Crab (total) | 13.7/s | 3% |
| Cyg X-1 | Hard 13.3/s, Soft 4.6/s | Hard :3%, Soft: 5% |
| Her X-1 | 2.5/s | 8% |
| Mkn 501 (Flare) | 0.65/s | 14% |
| V0332+53 (burst) | ~4/s | 5% |
| 4U0115+63 (burst) | ~4/s | 5% |
| GRS 1915 (burst) | ~4/s | 5% |

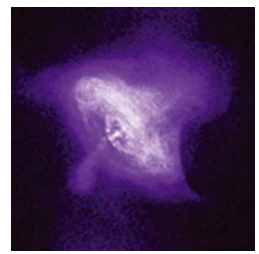
- Proposed location: **NASA Columbia Scientific Balloon Facility**, Palestine, Texas
- Nominal ~6 hour long maiden flight
- Total payload weight ~1000 kg
- $1.11 \times 10^6$ $m^3$ balloon
- Target altitude ~40 km
- **Engineering flight from Sweden planned for 2009**. Long duration Sweden to Canada also proposed.

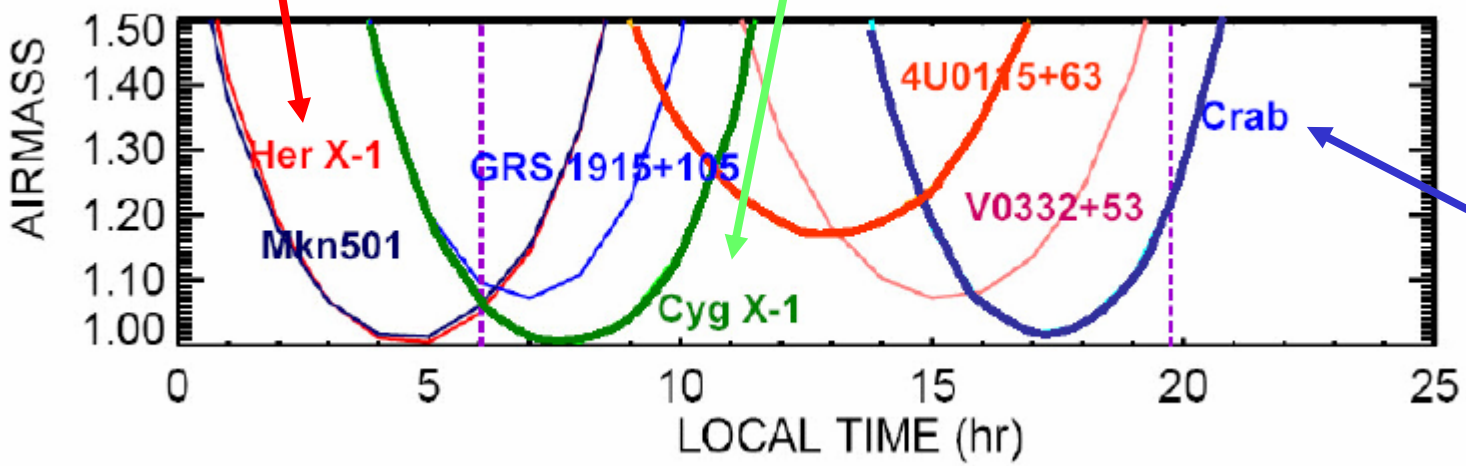




Accreting X-ray pulsar

High-mass X-ray binary

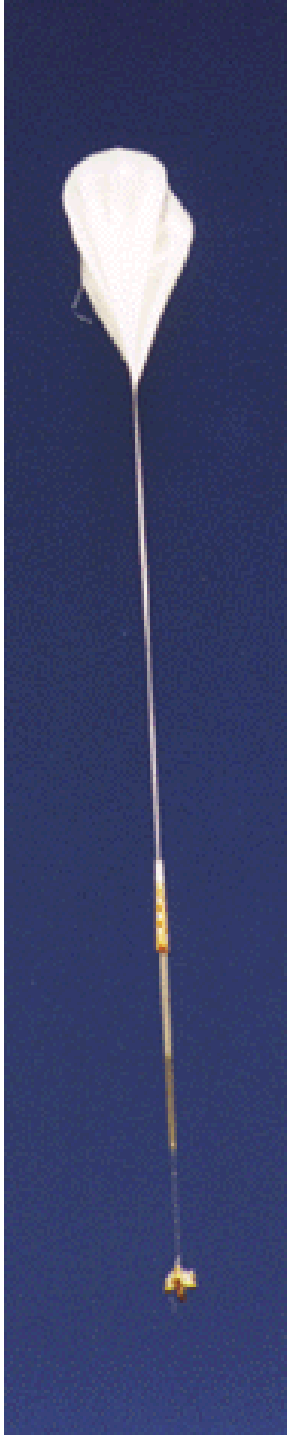





Pulsar / SNR

# Summary

- **PoGOLite** stands to open a **new observation window** on sources such as **rotation-powered pulsars and accreting black holes** through a measurement of the **polarisation** of soft gamma rays (25-80 keV).
- **Well-type Phoswich** detectors are used to significantly **reduce aperture and cosmic ray backgrounds**.
- A **prototype Phoswich system** and **waveform sampling electronics** has been tested with **photon and proton beams** and the **design and simulation validated**.
- **Construction of flight hardware** is currently **in progress**
- **Engineering flight** proposed for **2009** from Sweden. **Maiden science flight** from USA proposed for **2010**.
- **Long duration flights** and **flights of opportunity** (GLAST, SWIFT) will extend the **rich scientific program**.




# The Polarized Gamma-ray Observer

M. Pearce[1], M. Arimoto[2], M. Axelsson[3], C.-I. Björnsson[3], G. Bogaert[4], P. Carlson[1], W. Craig[6], Y. Fukazawa[5], S. Gunji[7], L. Hjalmarsdotter[3], T. Kamae[8], Y. Kanai[2], J. Kataoka[2], J. Katsuta[10], N. Kawai[2], J. Kazejev[1], M. Kiss[1], W. Klamra[1], S. Larsson[3], G. Madejski[8], C. Marini Bettolo[1], T. Mizuno[5], J. Ng[8], M. Nomachi[9], H. Odaka[10], F. Ryde[1], H. Tajima[8], H. Takahashi[5], T. Takahashi[10], T. Tanaka[5],T. Thurston[11], M. Ueno[2], G. Varner[12], H. Yoshida[5], T. Yuasa[13].

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[6]*Lawrence Livermore National Laboratory, USA.*
[7]*Yamagata University, Japan.*
[8] *Stanford Linear Accelerator Center, USA.*
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[10]*JAXA, Institute of Space and Astronautical Science, Japan.*
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[12]*University of Hawaii,USA.*
[13]*University of Tokyo, Japan.*