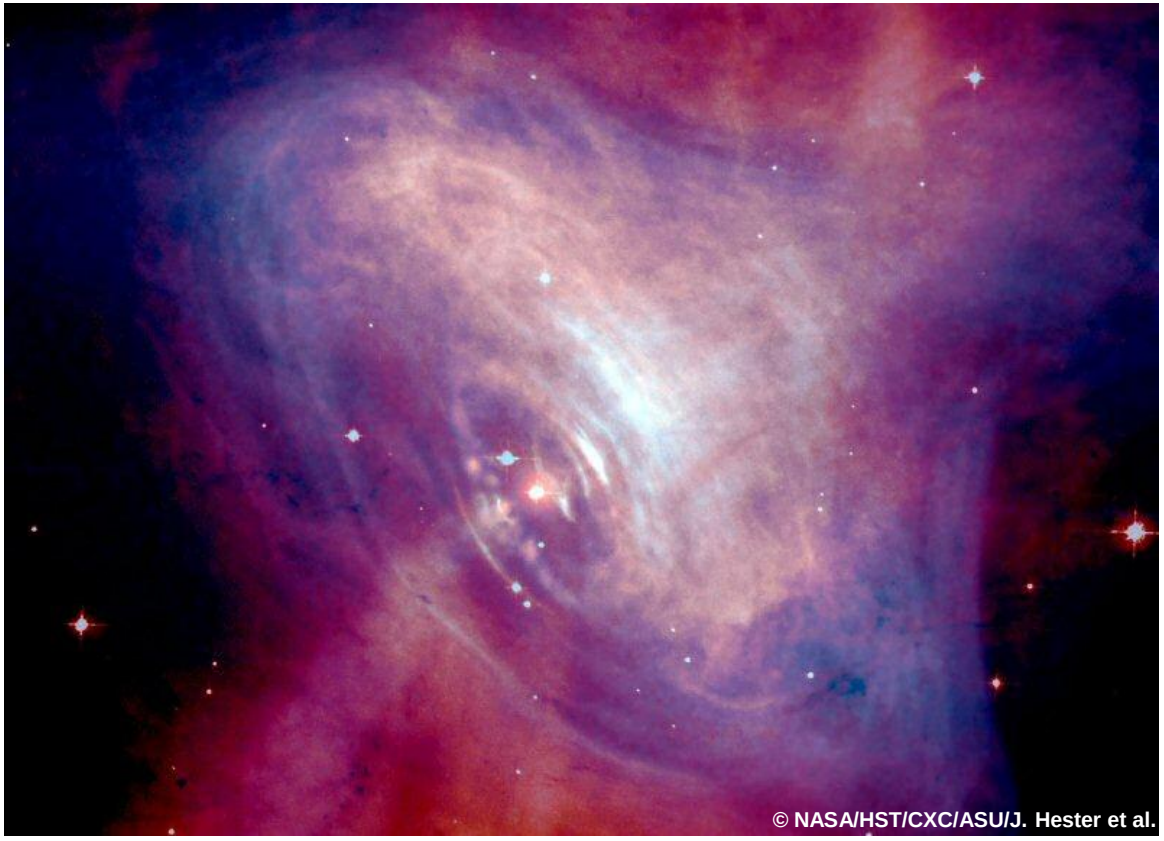
The PoGOLite balloon-borne soft gamma-ray polarimeter



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PoGOLite

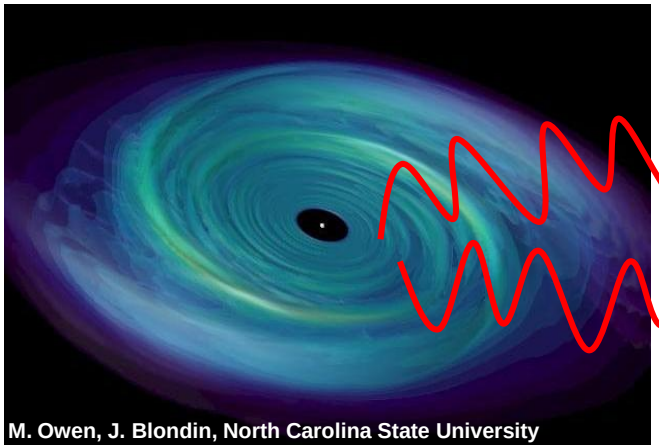
The Polarized Gamma-ray Observer

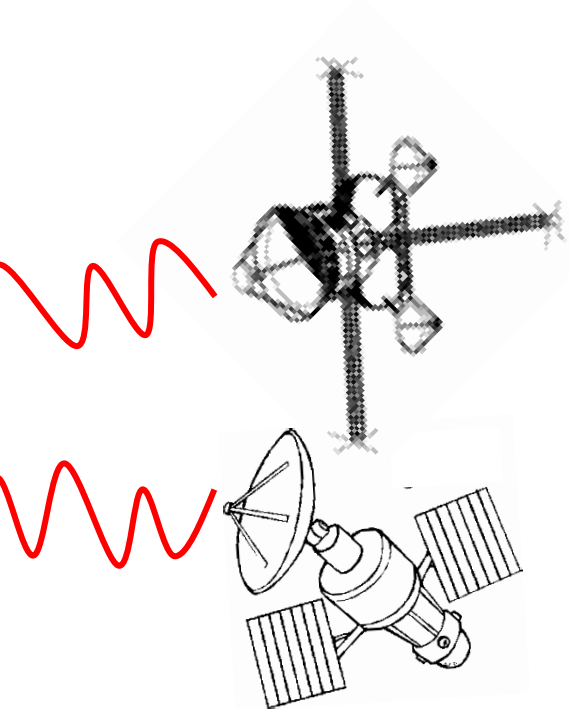
Outline

- Polarization – a new window on the universe
- The PoGOLite instrument
- Performance: prototype testing and simulation results
- The PoGOLite Pathfinder and plans for the future

Polarization – a new window on the universe

- Photons can be characterized by their energy, direction, time of detection and polarization, but polarization is usually not measured. So far, only one significant measurement in the X-ray/gamma-ray band, from 1976: photons up to ~5 keV from the Crab (M. Weisskopf et al., ApJ 208 L125, 1976)
- Measuring polarization gives two new observational parameters: polarization angle and degree
- X-ray polarimetry can be used to probe sources ➔ new information about the emission mechanisms, geometries and magnetic fields of the observed sources





"Most instruments":

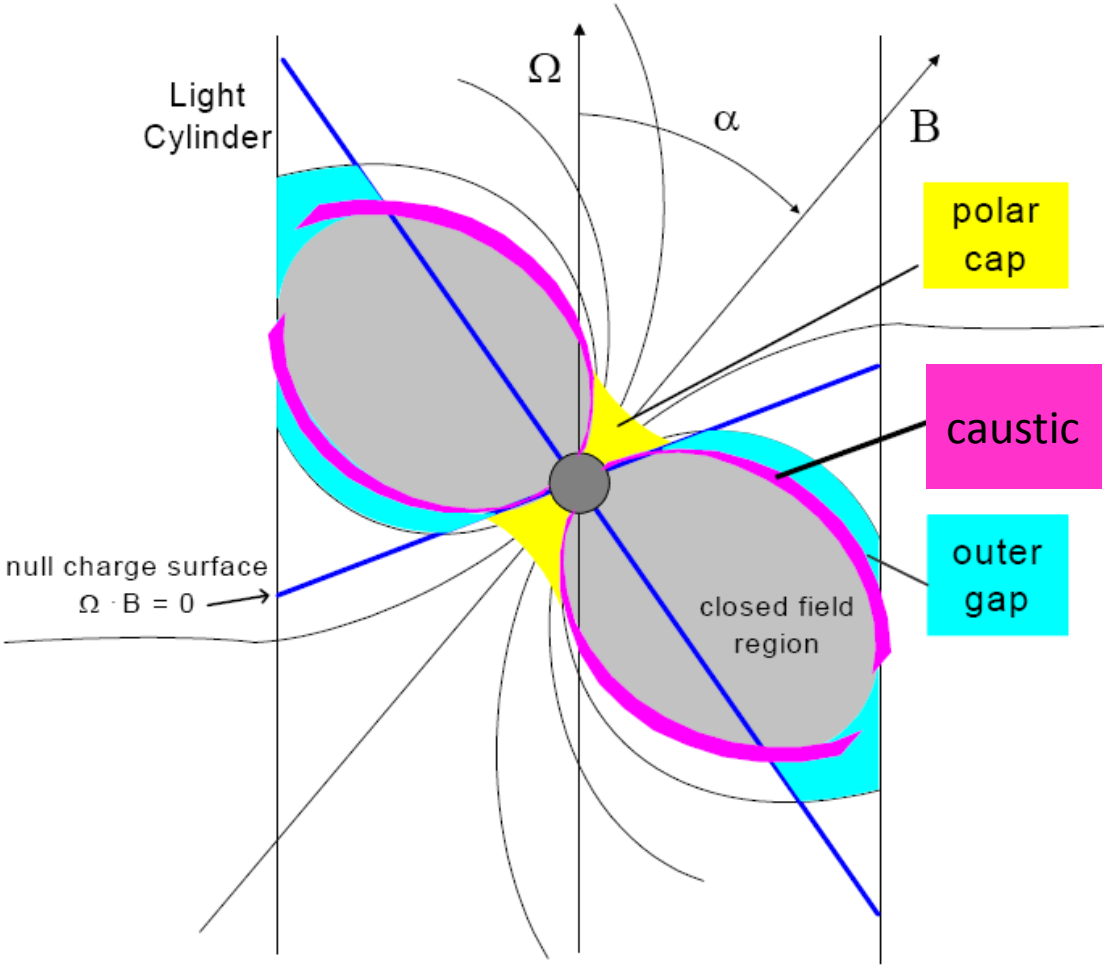
$$E, \hat{r}, t$$

Polarimeters:

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

Polarization – the Crab pulsar

- One of the prime targets for polarimetry
- Three main emission models: polar cap, outer gap, caustic
- Models predict different emission mechanisms and location of emission



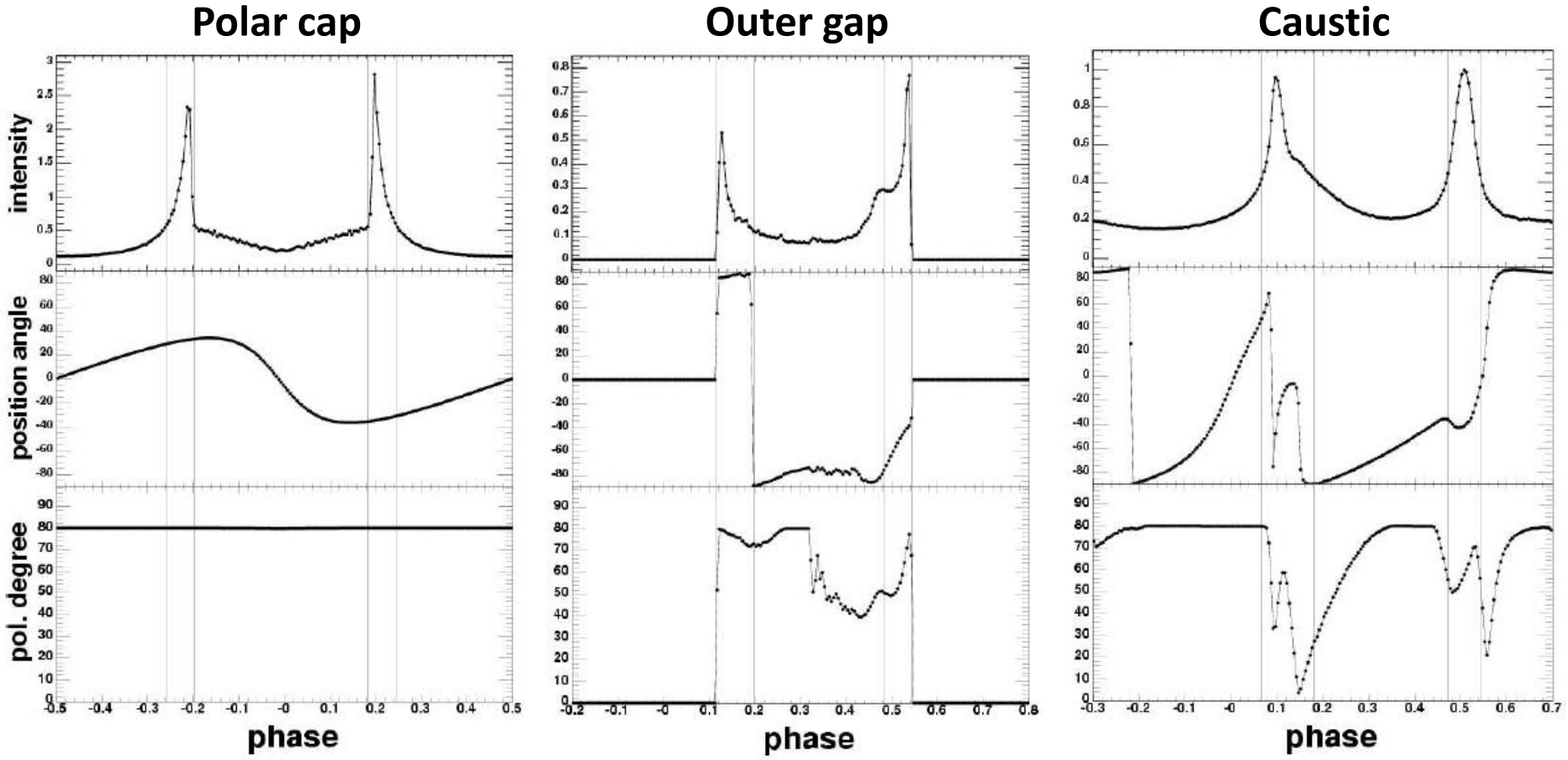
A. Harding, NASA Goddard Space Flight Center (2004)

Charged particles near surface emitting synchrotron radiation

Charged particles confined between last open B-field lines

Acceleration in outer magneto-sphere ➔ pair prod. cascades

Polarization – Crab pulsar emission models



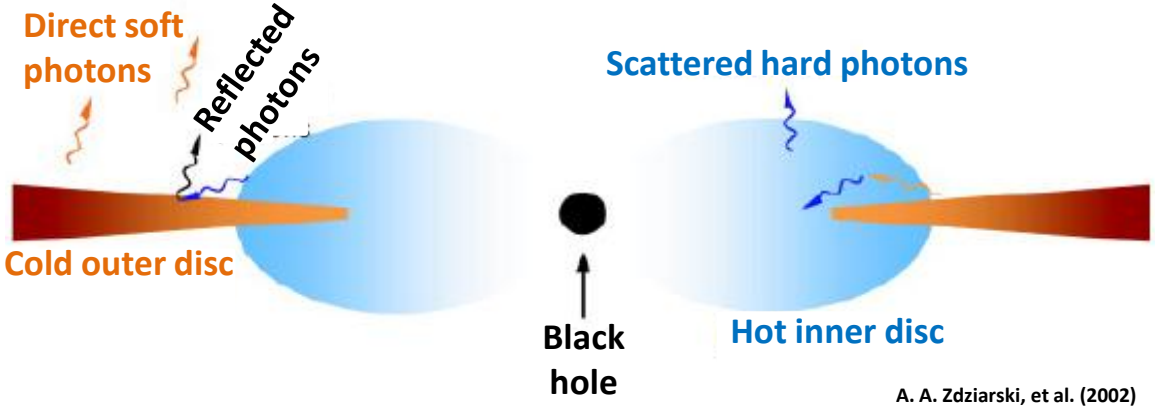
PoGOLite collab.

- All models have similar predictions for the intensity
- Different predictions for polarization angle and degree ➔ polarimetry can be used to identify the correct model

Polarization – Other sources of interest

Accretion discs

- Primary component of photons directly from the accretion disc – unpolarized
- Secondary component of photons reflected in the accretion disc – polarized
- Polarization ➔ information about the geometry and inclination of the disc
- Prime target: Cygnus X–1



Neutron stars

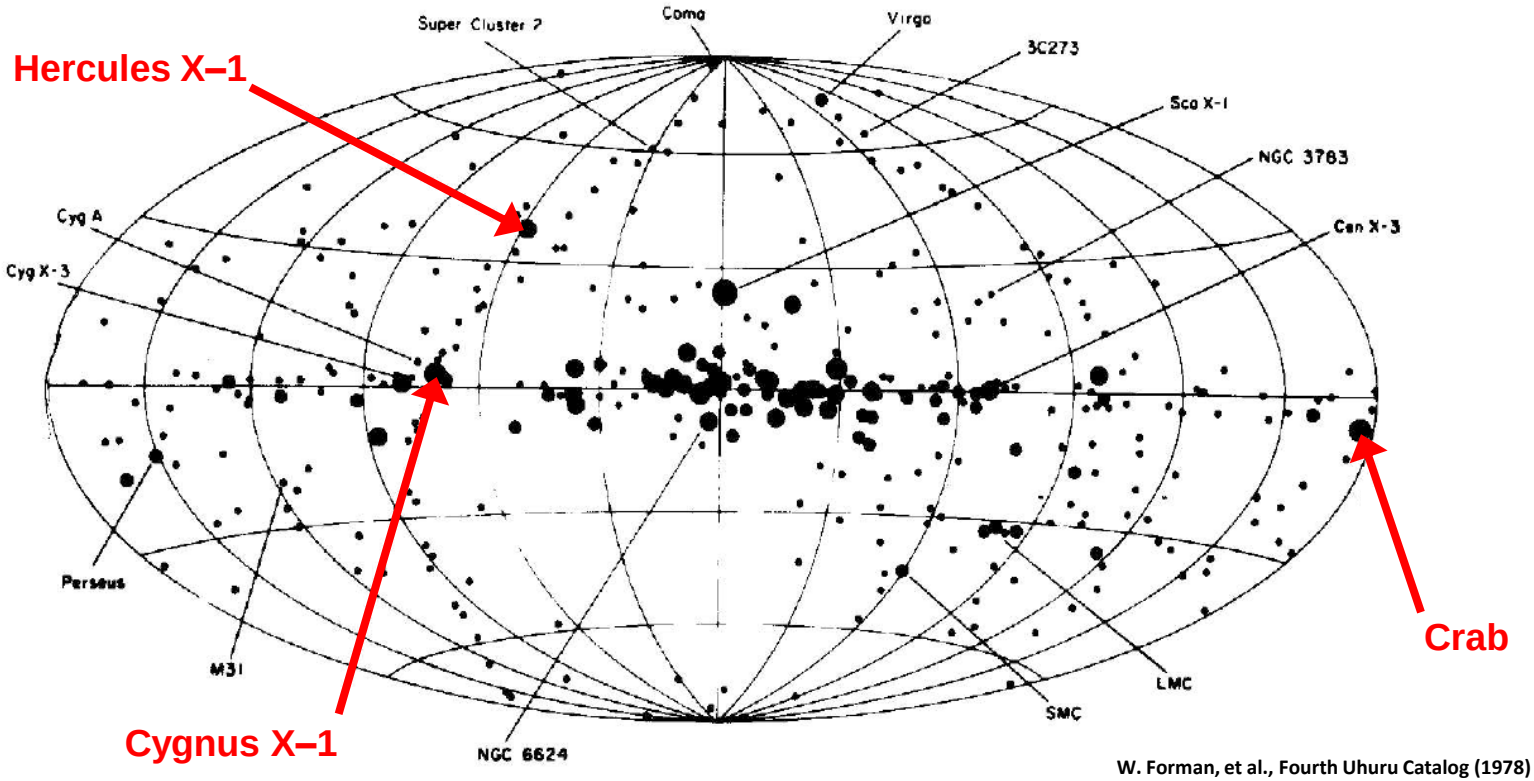
- QED predicts absorption of photons polarized perpendicular to the magnetic field lines ➔ reconstruct the geometry of the magnetic fields
- Prime target: Hercules X–1

Astrophysical jets

- Polarization observed in radio and UV range, polarization of HE emission unknown ➔ study emission mechanisms and magnetic field of the host galaxy
- Prime target: Markarian 501

Polarization – List of potential targets

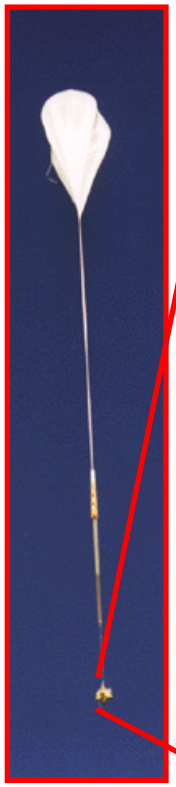
- The Crab (pulsar) ➔ identify HE emission mechanism
- Cygnus X–1 (accreting BH) ➔ study geometry and inclination of accretion disc
- Hercules X–1 (accreting NS) ➔ orientation of rotation axis and B-field lines
- Markarian 501 (blazar) ➔ study jets during high state
- V0332+53 (accreting X-ray pulsar) ➔ study cyclotron features during outburst
- 4U0115+63 (accreting NS) ➔ study physical processes under extreme conditions
- GRS 1915+105 (microquasar) ➔ study direction of the magnetic field during burst

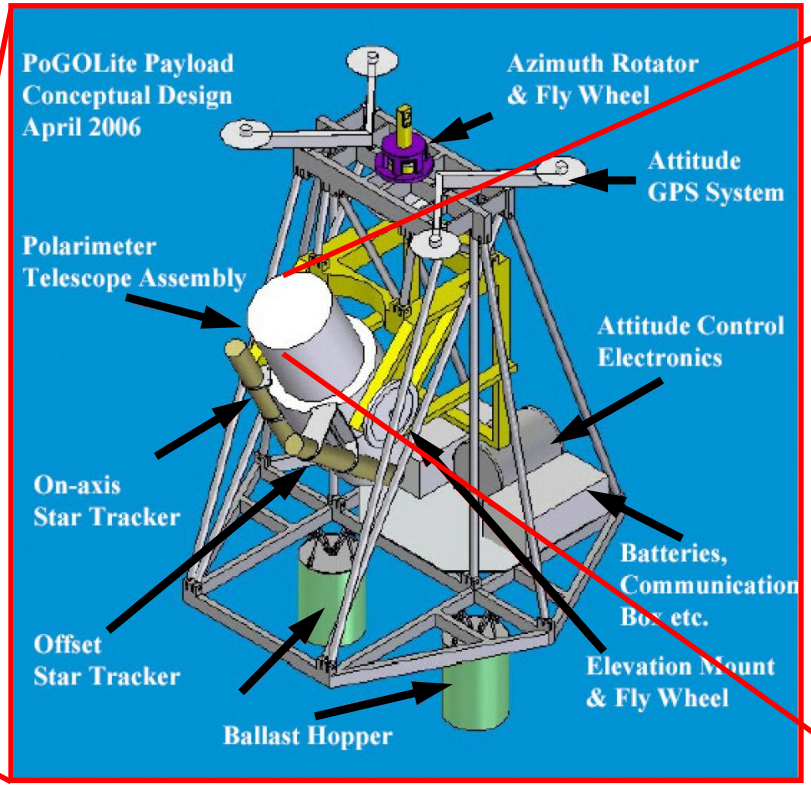


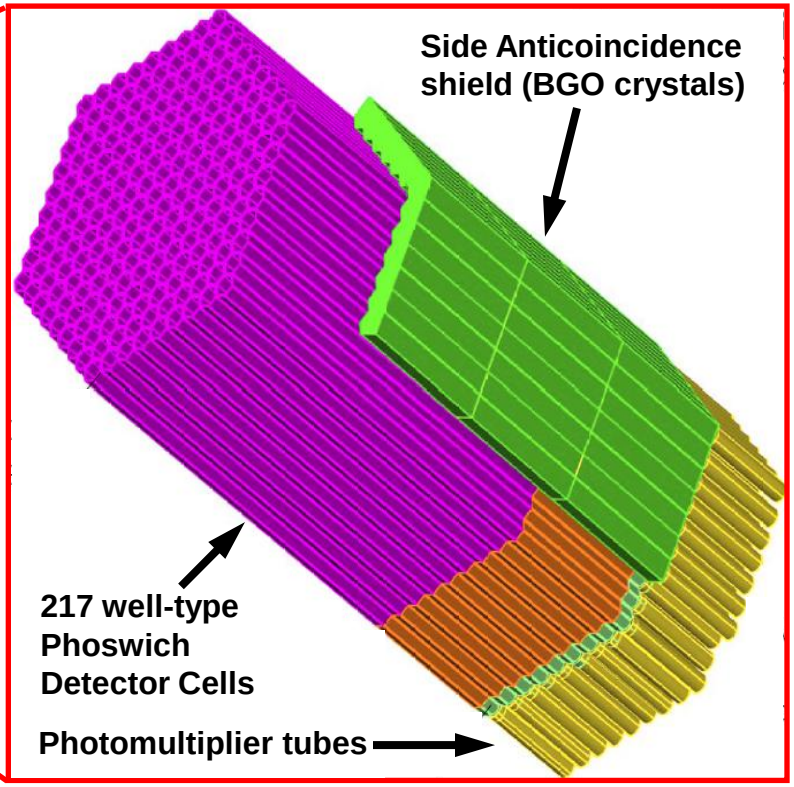
W. Forman, et al., Fourth Uhuru Catalog (1978)

PoGOLite – The Polarized Gamma-ray Observer

- Currently under construction to address these questions
- Balloon-borne experiment – measure polarization of hard X-rays/soft gamma-rays 25–80 keV
- International collaboration: United States, Japan, Sweden, France
- Excellent background reduction: active collimation, active and passive shielding
- PoGOLite uses coincident detection of Compton scattering and photoabsorption in an array of plastic scintillators (low cost, low weight, prototype successfully tested in beam tests)







PoGOLite – Performance characteristics

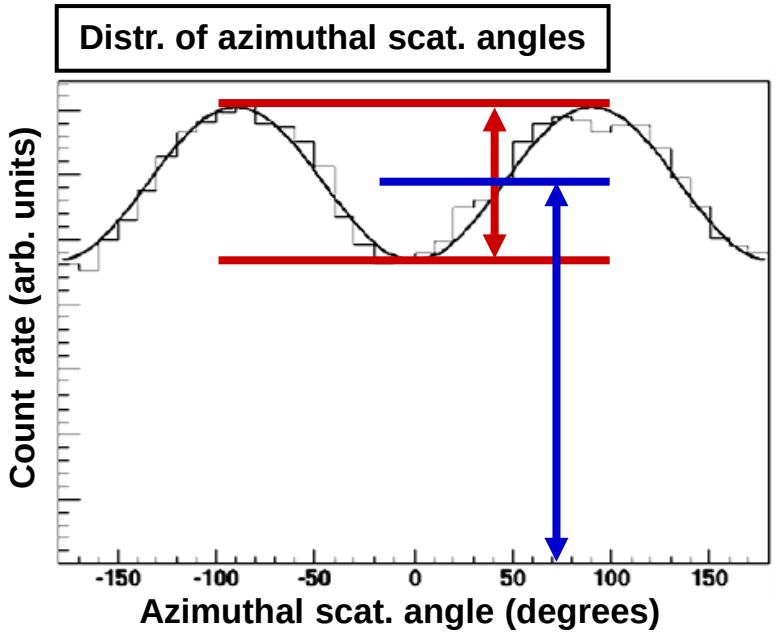
- Measure 10% polarization from a 200 mCrab source in a 6 h flight
- Field of view: 1.25 msr (2.0 degrees x 2.0 degrees)
- Pointing accuracy: better than 5% of the field of view
- Geometric area of detector: 994 cm^2
- Effective area for polarimetry: 228 cm^2 at 40 keV
- Energy range 25–80 keV

Polarization – detection principle

The Compton scattering process is governed by the Klein-Nishina formula ➔ photons have a higher probability to scatter perpendicularly to the incident polarization vector

Distribution of observed azimuthal scattering angles modulated by the polarization

Modulation factor:
M = difference / average

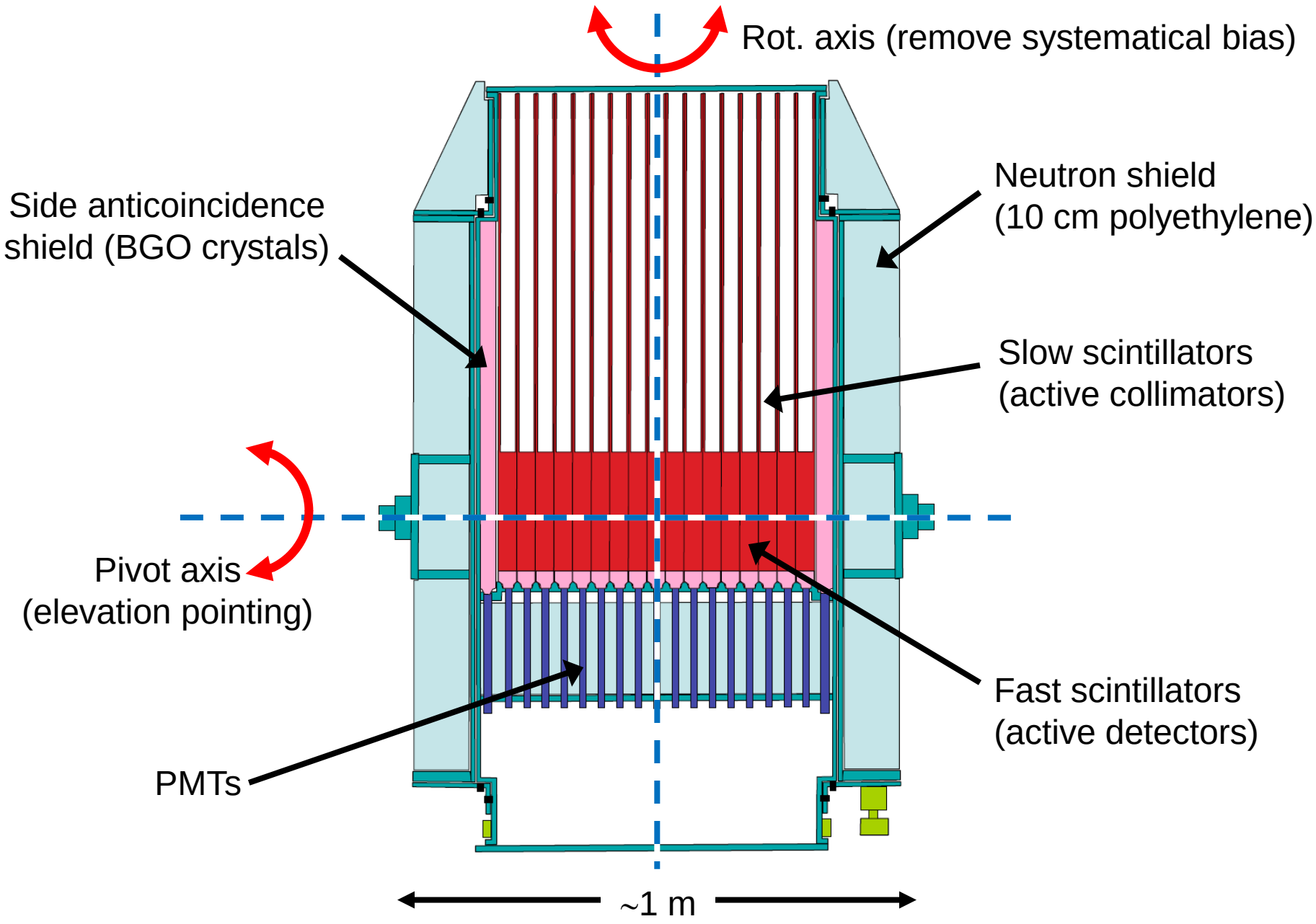


Polarization angle and degree can both be determined from the modulation:

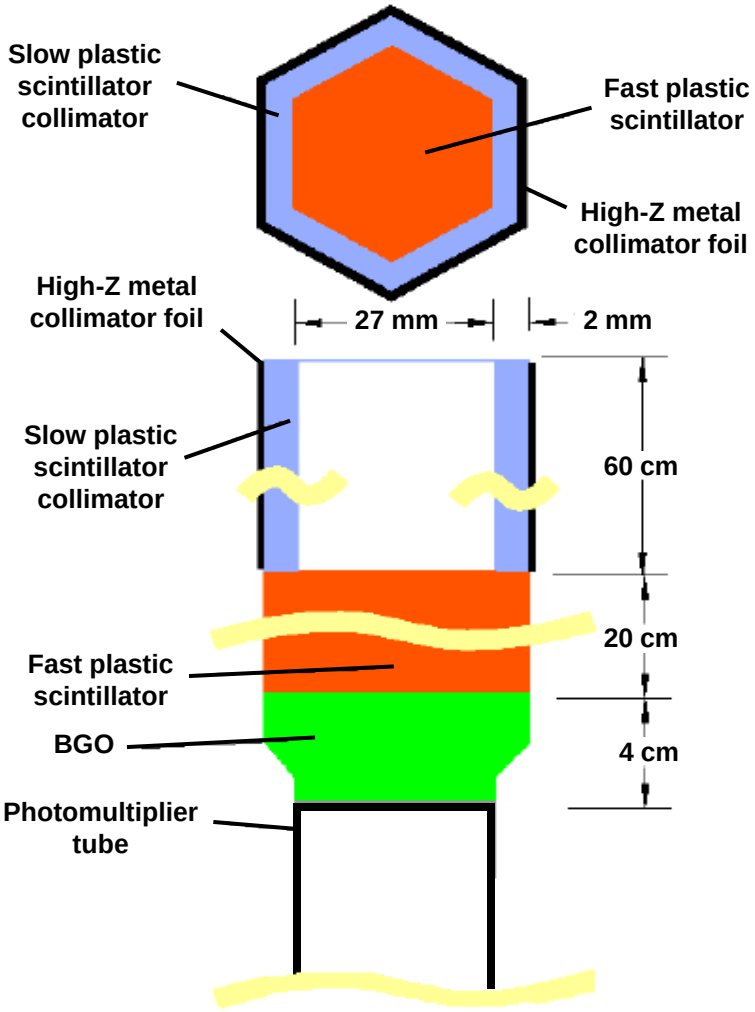
Polarization degree: $P_{source} = M / M_{100}$
(M_{100}: modulation factor for a 100% polarized source, obtained using a beam with a known polarization degree)

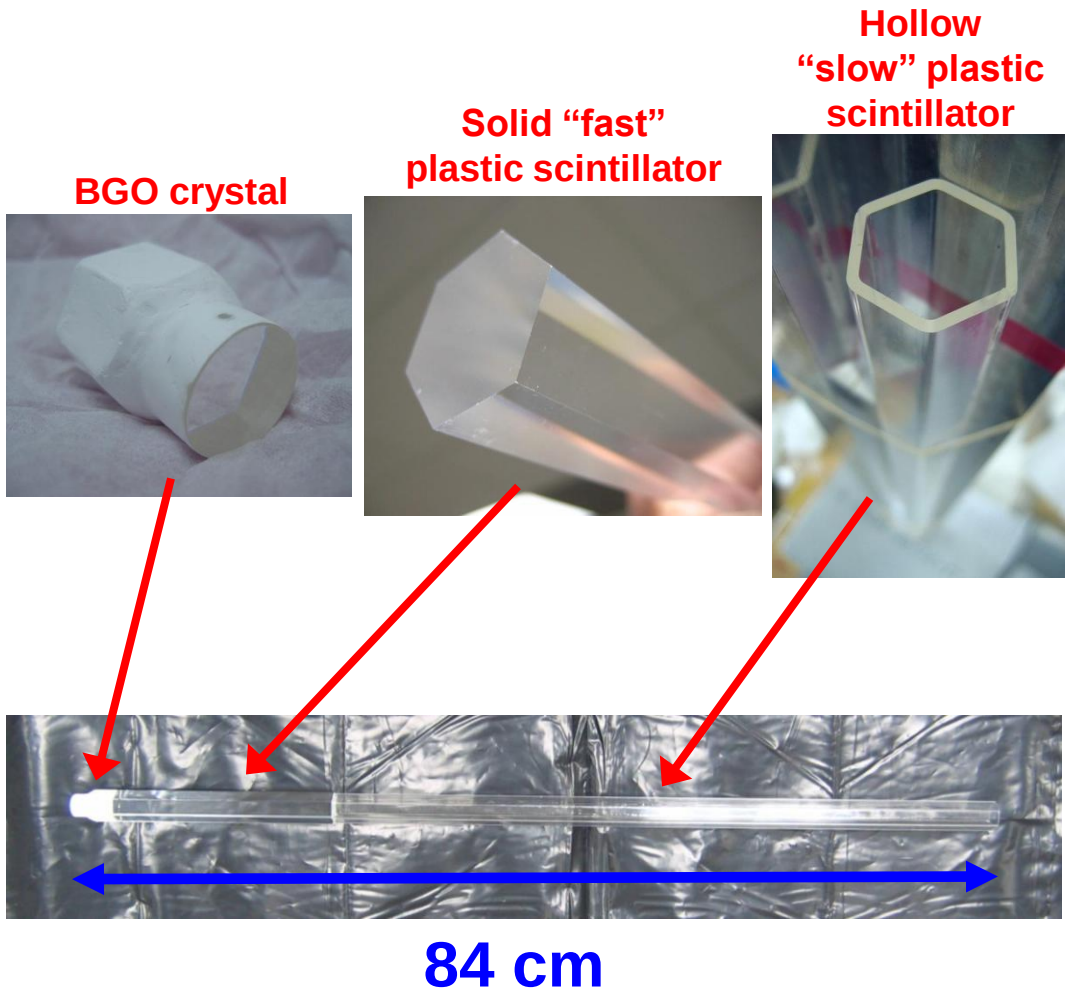
Polarization angle: phase of the fitted modulation curve

The PoGOLite instrument (1)



The PoGOLite instrument (2)

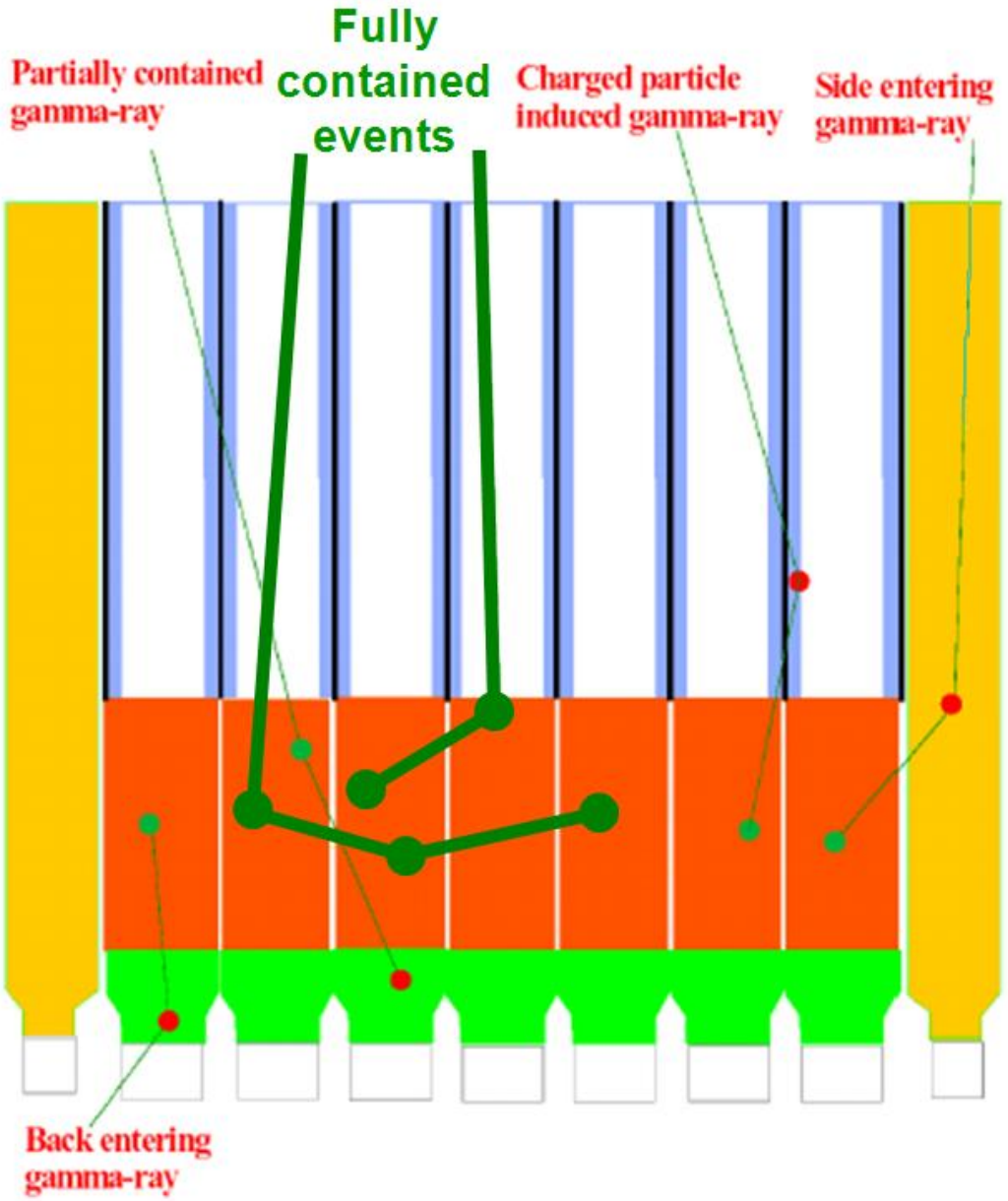




The well-type Phoswich Detector Cell (PDC). 217 of these cells in PoGOLite.
Pulse shape discrimination used to identify signals from different components

The PoGOLite instrument (3)

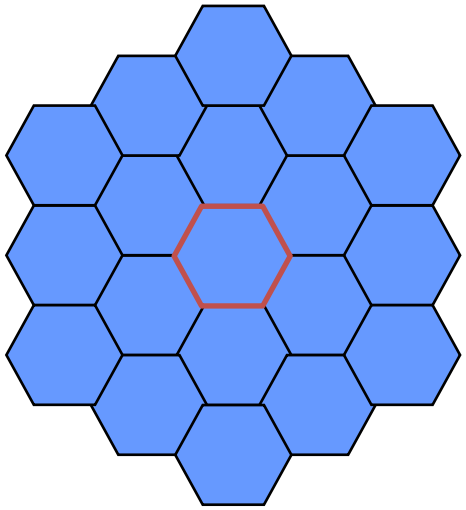
- Fully contained events: Compton scattering and photoelectric absorption
- Relative energy deposition used to reconstruct the path of the photons
- Polarization ➔ modulation in observed distribution of azimuthal scattering angles
- Off-axis events give signal in slow scintillator, SAS or BGO and are rejected

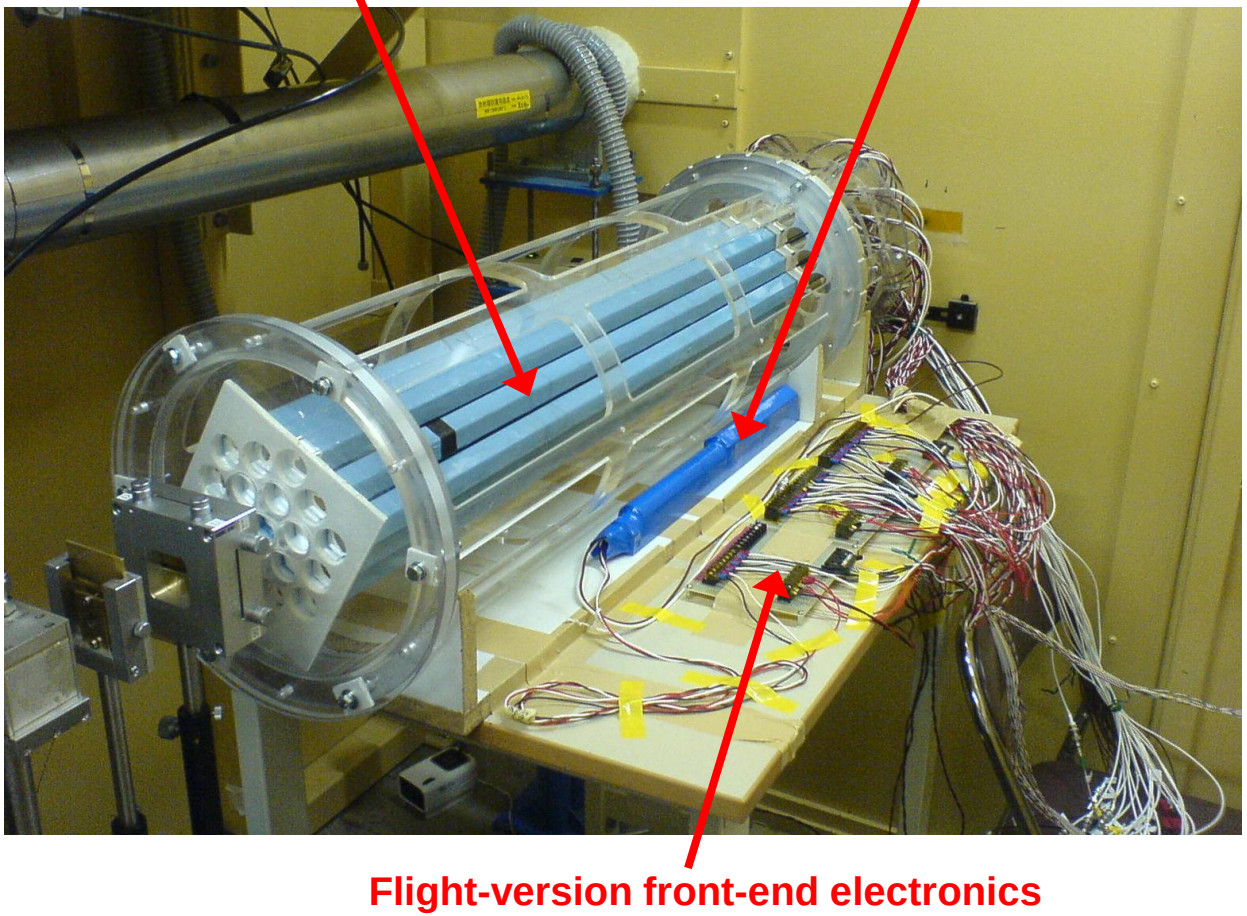


Simplified sketch of the detector array

The PoGOLite prototype (1)

19 units



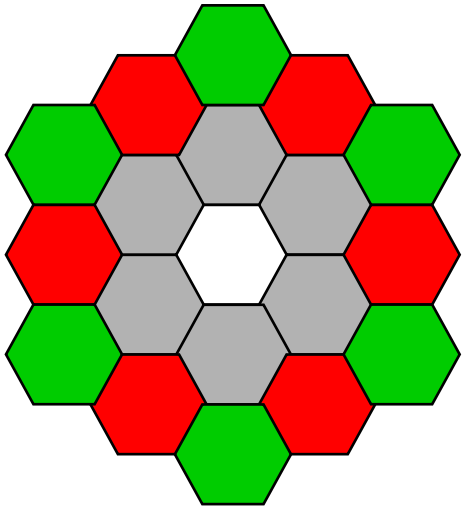


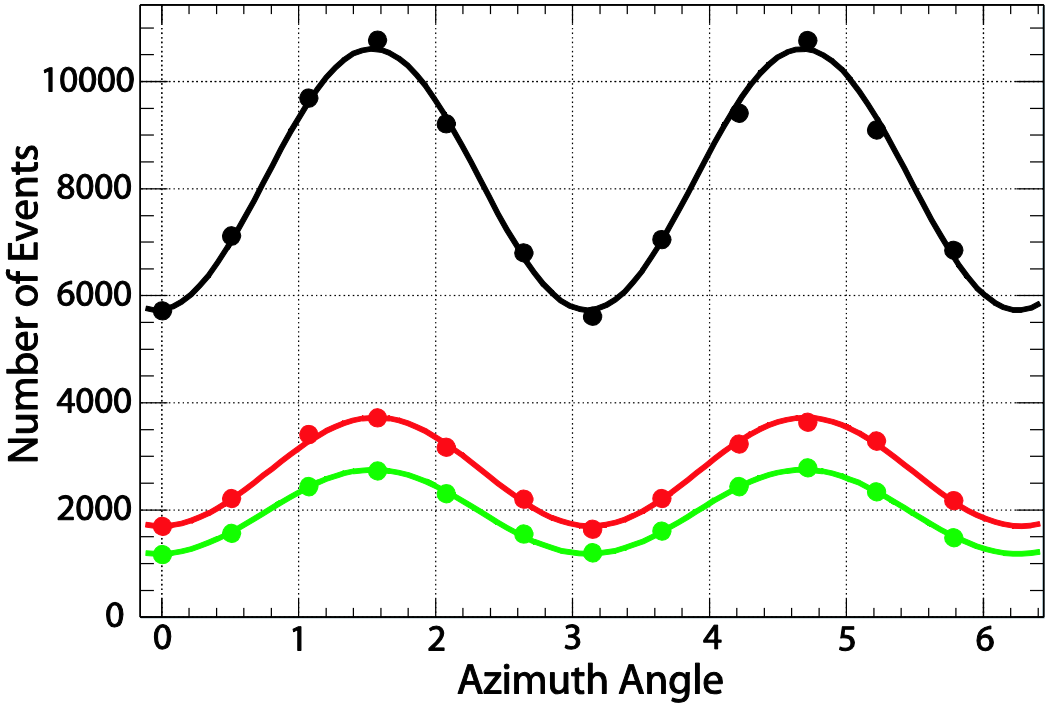
Several prototype tests to date: synchrotron photons, radioactive sources, accelerator protons, neutrons…

The PoGOLite prototyope (2)

- Latest test: Feb. 2008, KEK “Photon Factory” in Tsukuba, Japan
- Synchrotron photons, 50 keV, (90 ± 1)% linear polarization
- Array rotated in 30 degree steps (like flight-version)
- Observed modulation factor consistent with simulations

19 units





MF

Inner 6 units

29.8 +- 0.4%

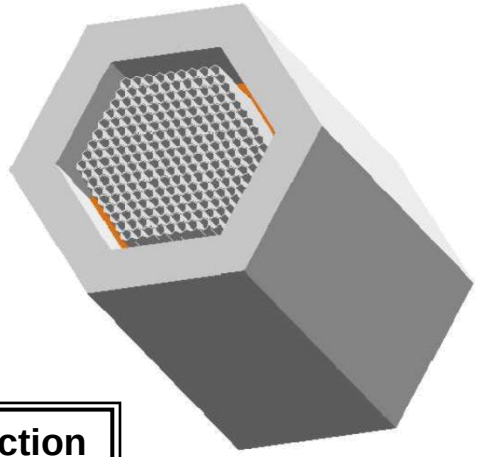
Outer 12 units

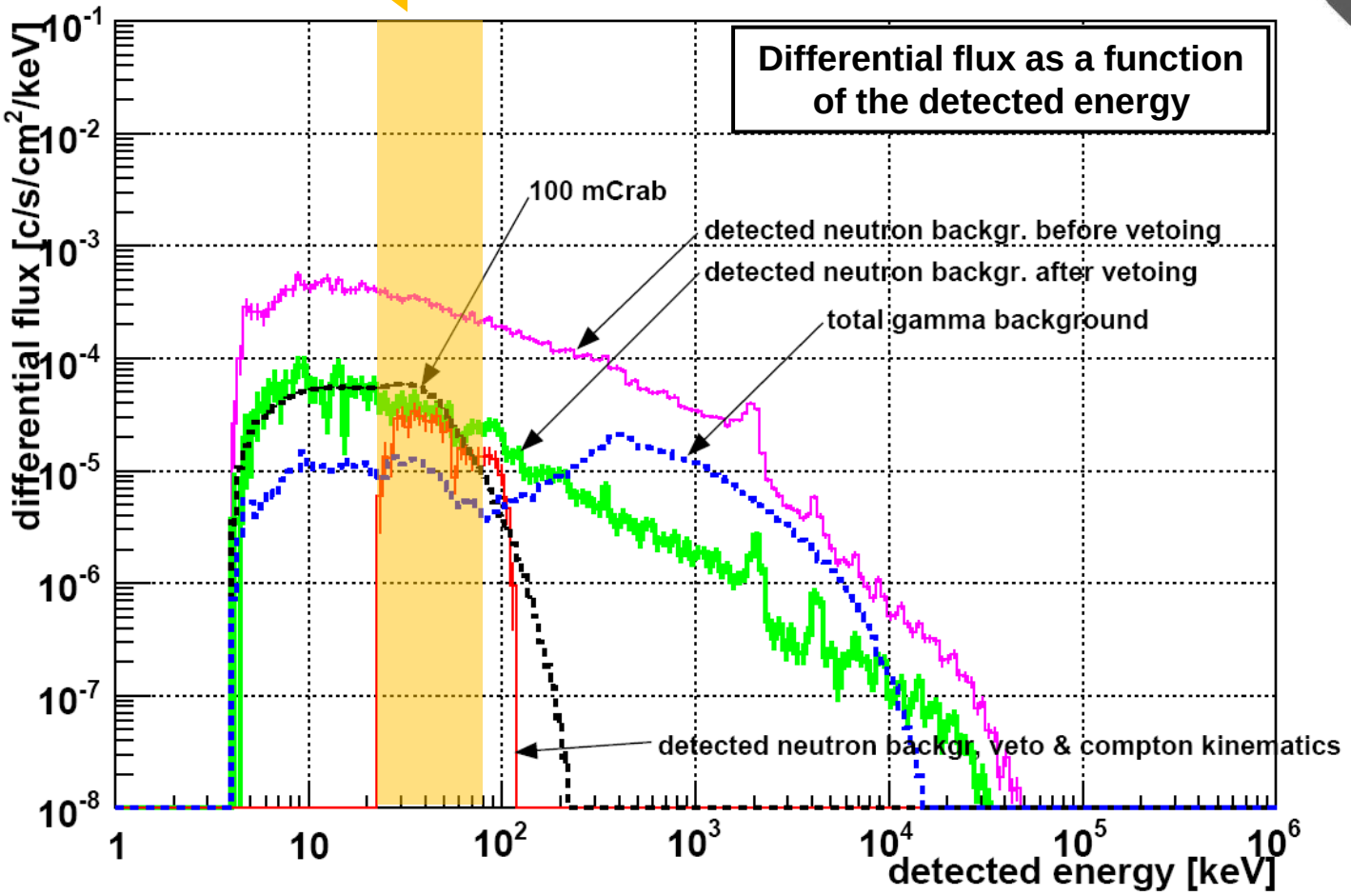
37.1 +- 0.7%

39.5 +- 0.8%

Simulated observation data

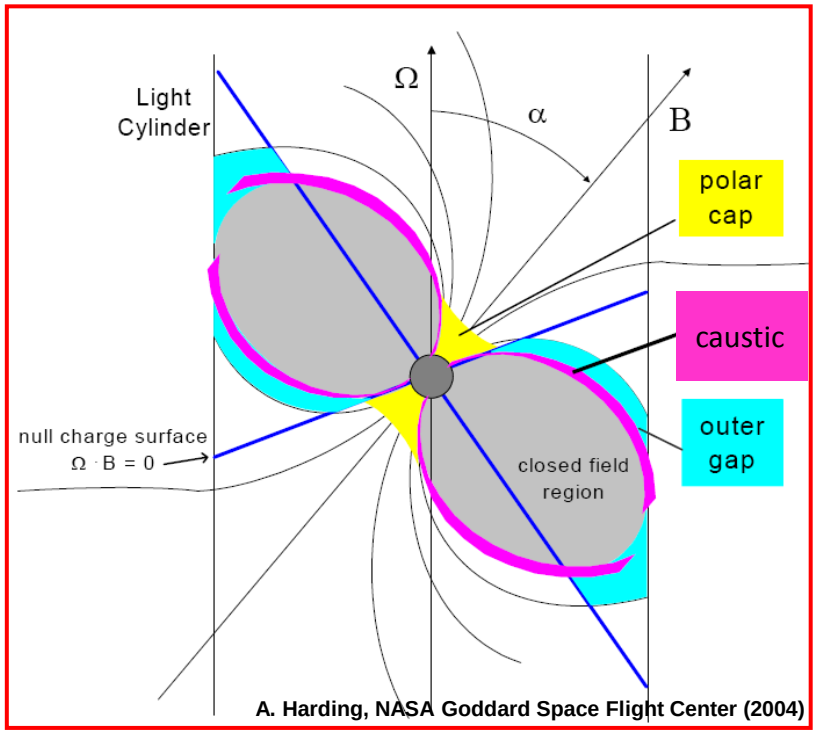
- Monte Carlo simulations show that atmospheric neutrons dominate the background. **The PoGOLite model in Geant4**
- With the 10 cm thick polyethylene shield, the background can be reduced to less than a 100 mCrab level in the **PoGOLite energy range (25–80 keV)**

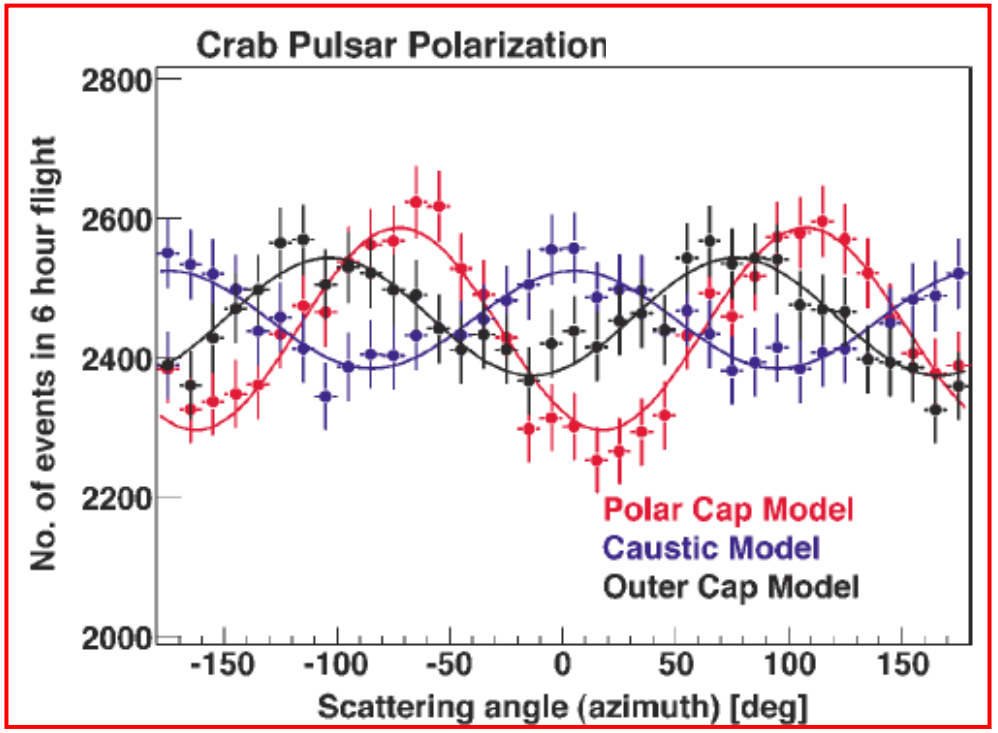




The Crab pulsar – Observation with PoGOLite

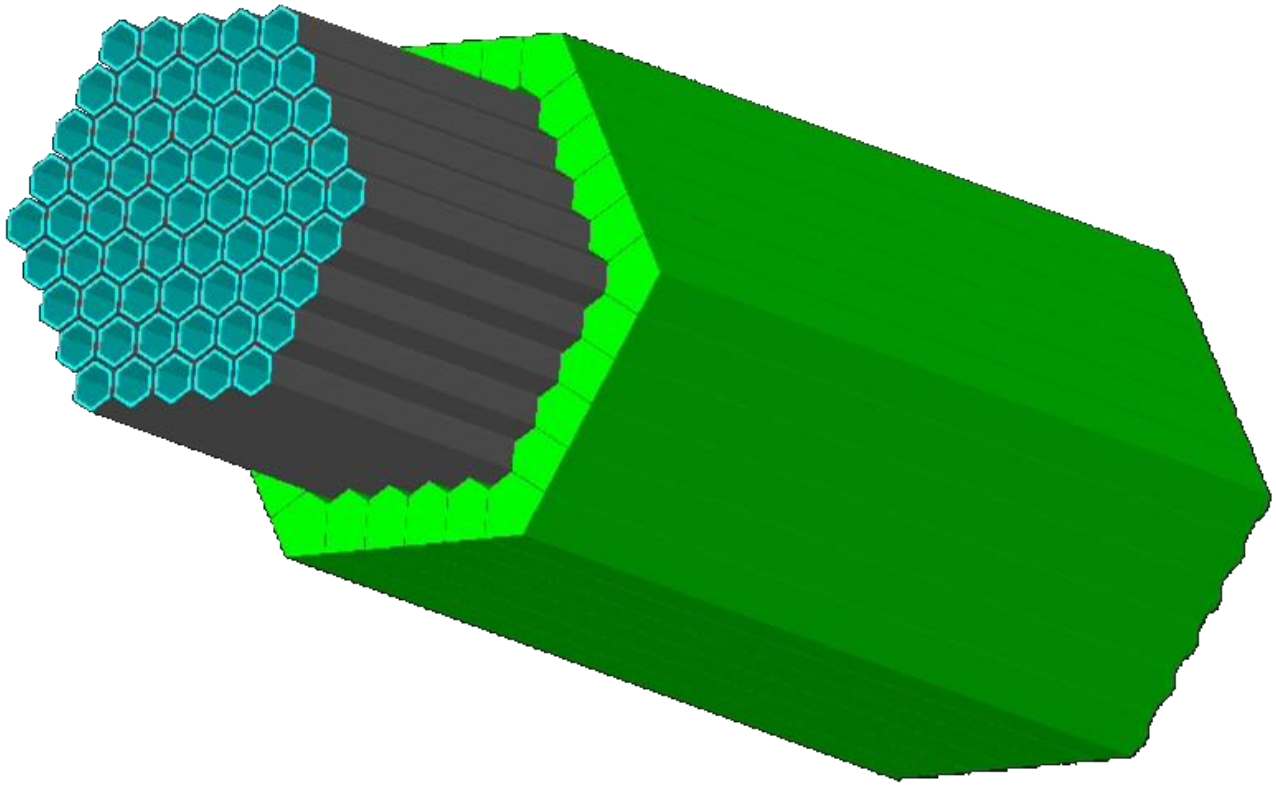
- Three main emission models: the polar cap model, outer gap model and the caustic model
- Six hour measurement with PoGOLite enough to identify correct model or to put severe constraints on future models if all three models turn out to be incorrect





The PoGOLite Pathfinder

- 61 unit proof-of-principle “pathfinder” instrument currently under construction
- Measure polarization from the Crab nebula at a 7σ level
- Detect as low as 10% polarization from Cygnus X–1 in the hard state
- Study in-flight background from neutrons, cosmic rays, gamma-rays
- First flight from Esrange in Sweden in August 2010



Outlook

- Next step after the Pathfinder mission: 217-unit full-scale instrument
- Numerous interesting targets – pulsars, accreting black holes, active galaxies, etc.
- Different flight types foreseen:

<u>Short flights (6 – 8 hours)</u>
- E.g. from Sweden or the US
- Proof-of-principle, evaluate background
- Observe the Crab pulsar

<u>Long duration flights (~5 days)</u>
- From Esrange (Sweden) to western Canada
- Better statistics. Time variation.
- Multiple targets: the Crab, Cyg X-1, Her X-1...

<u>Flights of opportunity</u>
- No consumables ➔ can be launched when an interesting event is detected by GLAST or SWIFT