Polarization studies in the MeV range

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Polarimetry measurements

- Compton polarimetry principles
- Present and future γ-ray polarimeters
- Science objectives of γ-ray polarisation measurements

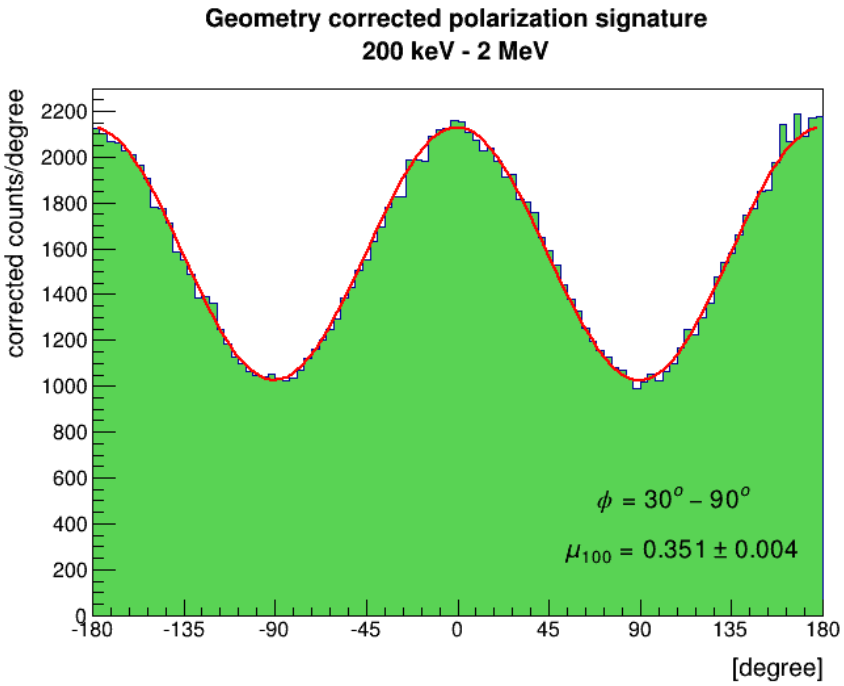
COMPTON POLARIMETRY PRINCIPLES

Compton polarimetry principles

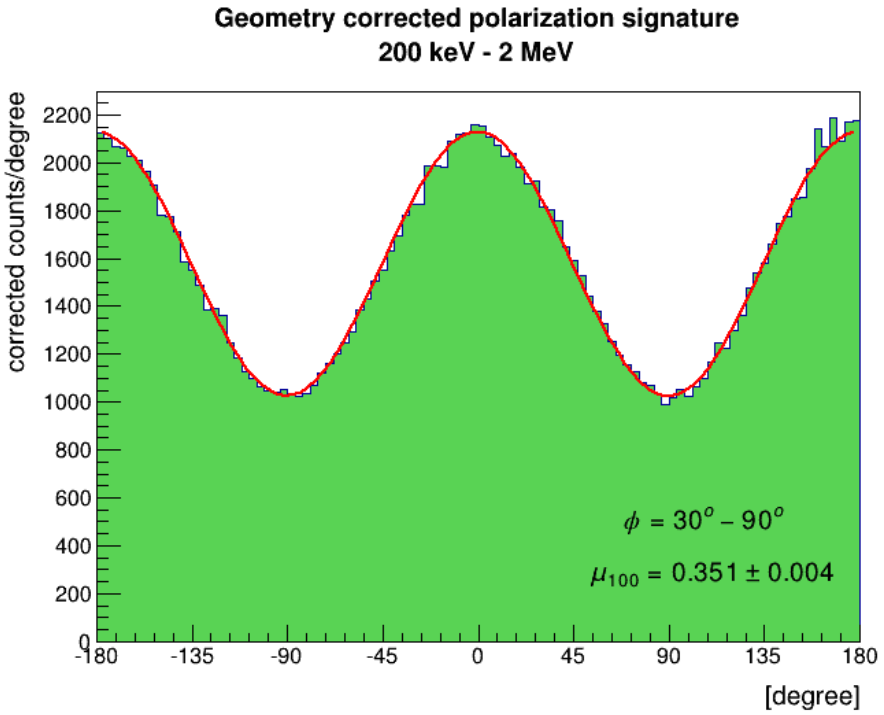
Compton scattering cross section is maximum for photons scattered at right angle to the direction of the incident electric vector $\Rightarrow$ asymmetry in the azimuthal profile S of scattered events.

$$S = \bar{S}\left[1 + a.\cos(2(\varphi - \varphi_0))\right]$$

- modulation
  - a = modulation factor
  - polar. fraction = PF = a/a_{100}
  - a_{100} = modulation for a 100 % polarized source.
  - polar. angle = PA = $\varphi_0 - \pi/2 + n\pi$



An excellent Compton polarimeter



Energy range (MeV)	Selections	Modulation m_{100}
0.2 – 2	2+ events, θ_{EHC}=20° , θ_{ARM}=3.5° , F_C=30° - 90°	0.351

Source (s^{-1})	Atm. bkg (s^{-1})	CGB (s^{-1})	Cosmic-ray induced bkg (s^{-1})
5.7	3.4	8.4	2.7

Minimum detectable polarization for **T_{obs}= 1 Ms:**

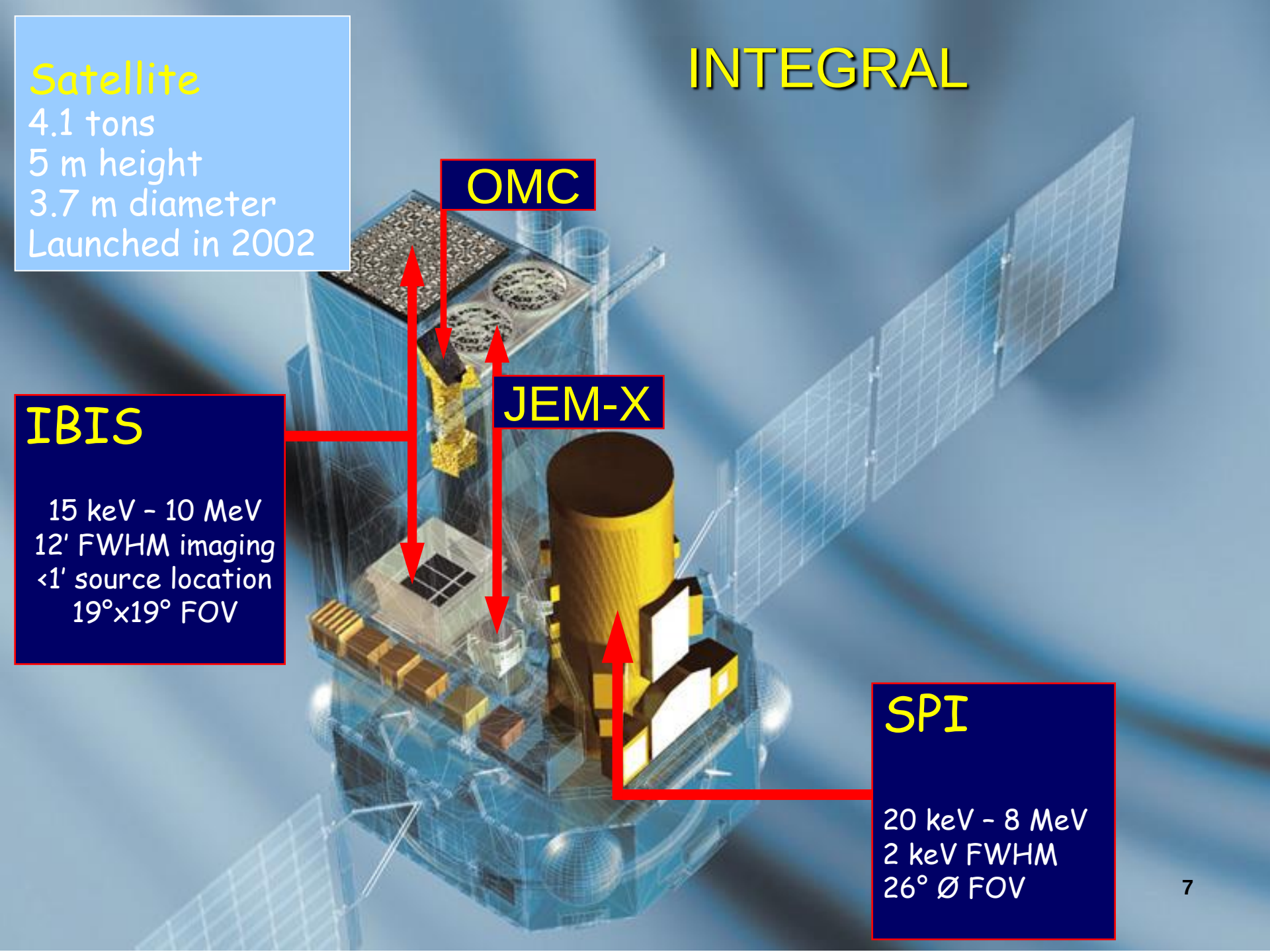
$MDP_{3\sigma}$ 1 Crab	$MDP_{3\sigma}$ 100 mCrab	$MDP_{3\sigma}$ 10 mCrab
0.67%	**5.8%**	**57.2%**

ASTROGAM polarigram in 0.2 - 2 MeV for a Crab-like source on axis

PRESENT AND FUTURE γ–RAY POLARIMETERS

INTEGRAL

Satellite
4.1 tons
5 m height
3.7 m diameter
Launched in 2002



IBIS

15 keV – 10 MeV
12′ FWHM imaging
<1′ source location
19°x19° FOV

SPI

20 keV – 8 MeV
2 keV FWHM
26° Ø FOV

ASTROGAM vs INTEGRAL/IBIS

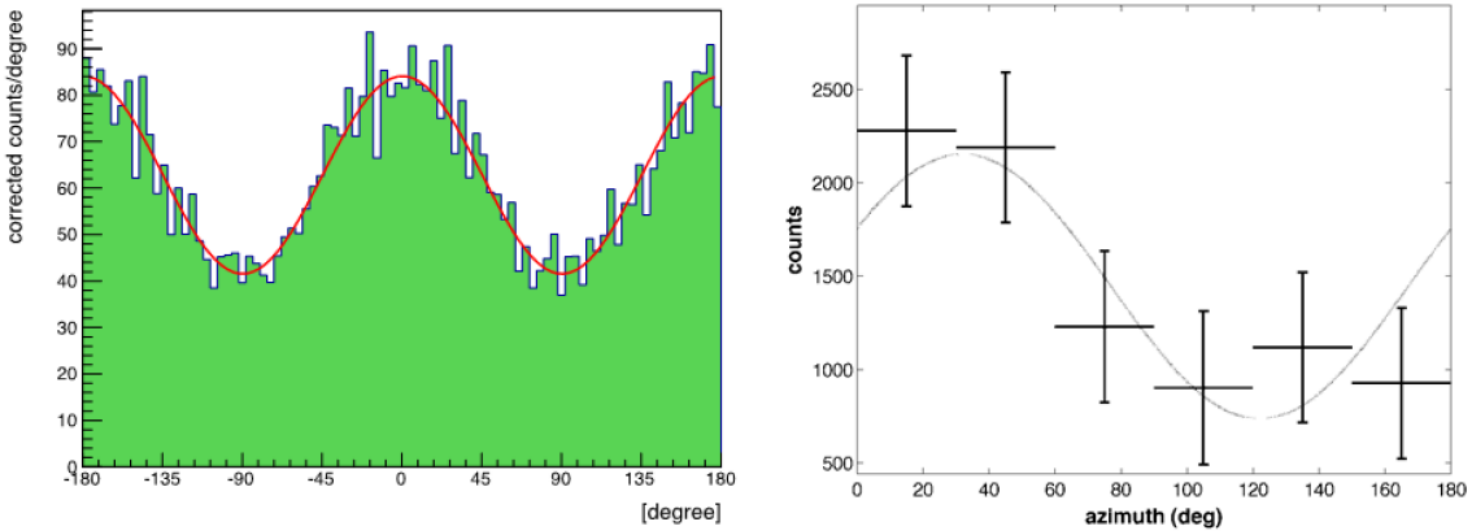


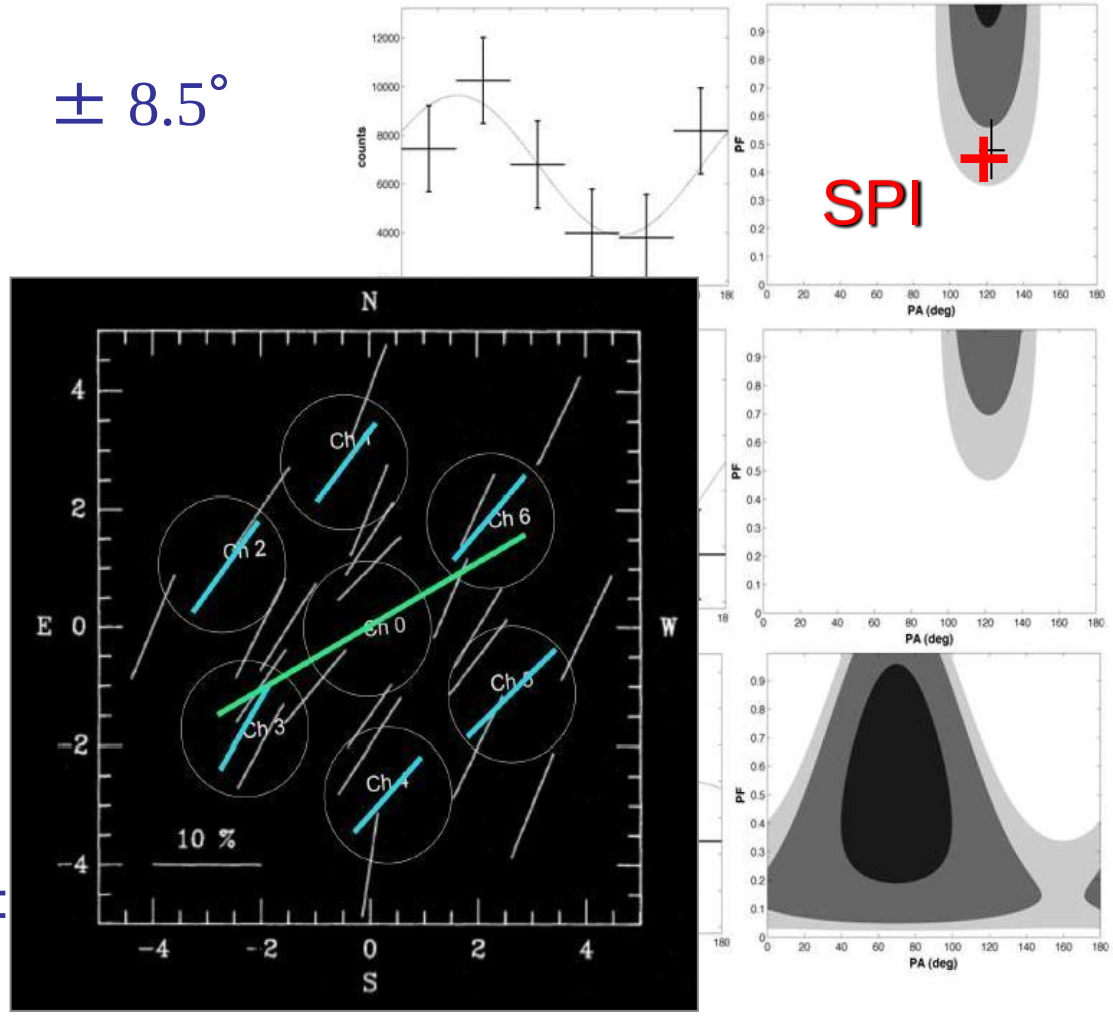
Figure 2.13 Left panel *– ASTROGAM polarization response (polarigramme) in the 0.2 – 2 MeV range for a 100% polarized, 10 mCrab-like source observed on axis for 10^6 s. The corresponding modulation is $\mu_{100} = 0.34$.* ***Right panel*** *– Polarigramme measured with INTEGRAL/IBIS (1σ error bars) for the Crab emission between 200 and 800 keV in the off-pulse and bridge phase intervals (Forot et al. 2008). The measured polarization fraction is >88%.*

INTEGRAL/IBIS Crab observations

Off Pulse: PA = 120.6° ± 8.5°, PF > 0.72

Off Pulse + Bridge: PA = 122.0°, PF > 0.88

$Peak_1$ + $Peak_2$: PA = 70.0°, PF = 0.42 ±



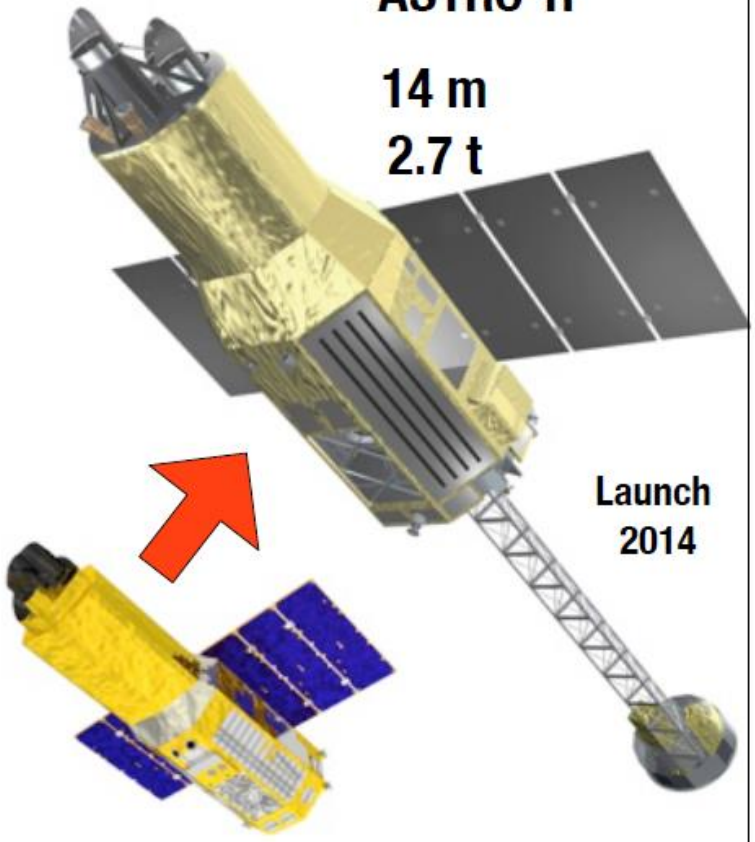
Forot et al. 2008, PRD

2. ASTRO-H

- Launch site:

  Tanegashima Space Center, Japan
- Launch vehicle: JAXA H-IIA rocket
- Orbit Altitude: 550km
- Orbit Type: Approximate circular orbit
- Orbit Inclination: ~31 degrees
- Orbit Period: 96 minutes
- Launch : 2014

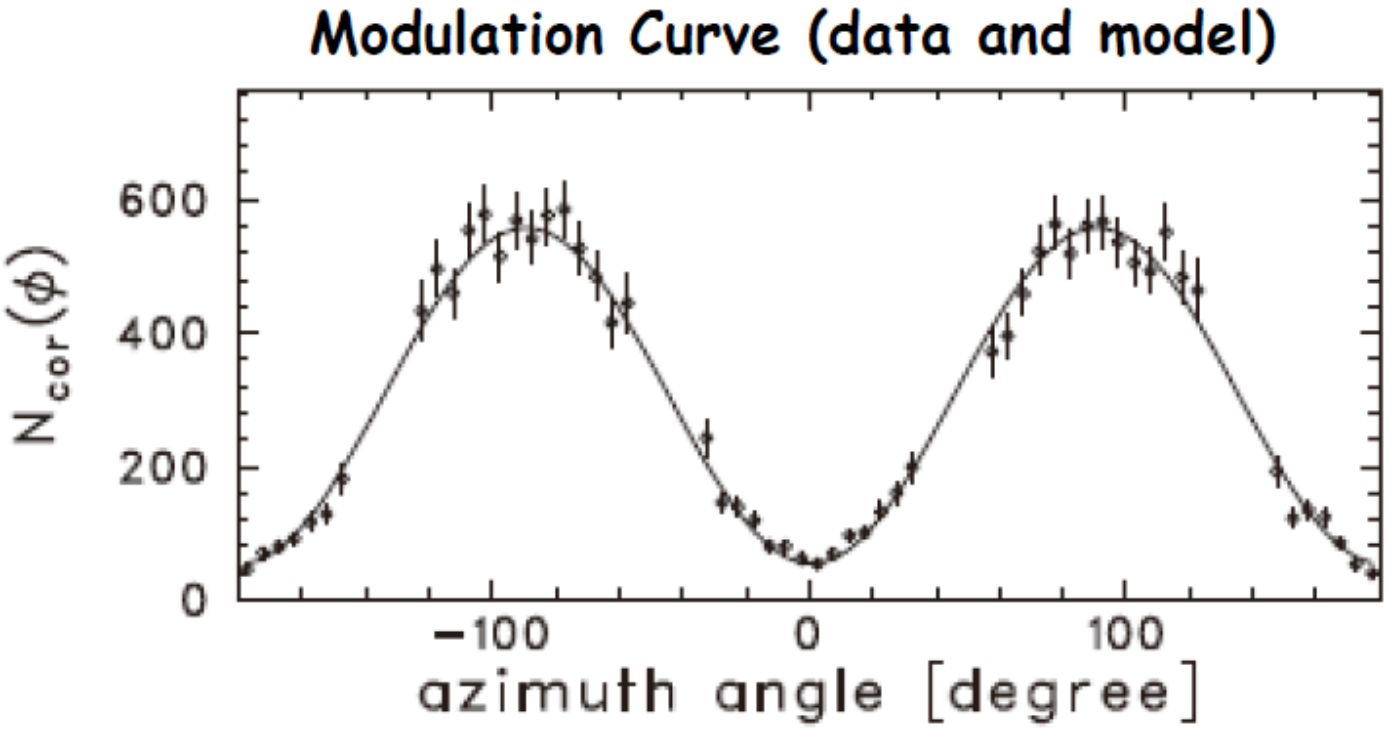
1. Micro-calorimeter + XRT
   0.3-12 keV , ΔE=5eV , FOV=3', Δθ=1.3'
2. Soft X-ray CCD + XRT
   0.4-12 keV, ΔE=150eV, FOV=38', Δθ=1.3'
3. Hard X-ray imager + Hard XRT
   5-80 keV ΔE<2keV , FOV=9', Δθ=1.7'
4. Soft Gamma-ray detector
   100-600 keV no imaging capability



Suzaku (ASTRO-E2)
(6m, 1.7t)
Launch 2005

Compton polarimeter - SGD

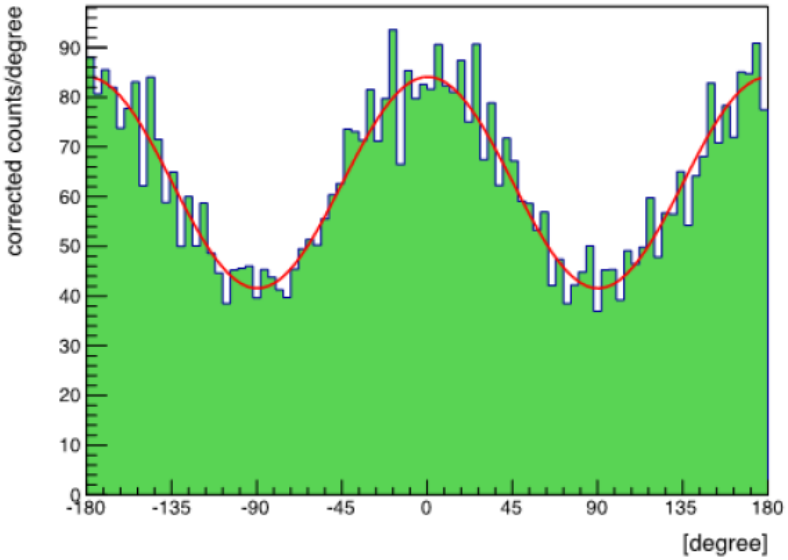
- **Beam test at Spring-8**



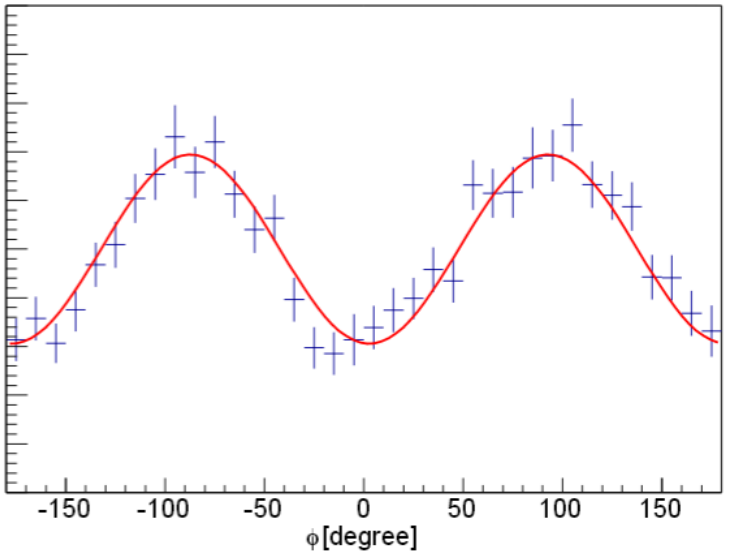
Takeda+ 10, NIMA

m_{obs}=0.82 agrees with the expectation (0.855) within 3%
=> verifying the detector concept and simulation

ASTROGAM vs ASTRO-H/SGD



200 keV – 2 MeV



300 keV – 600 keV

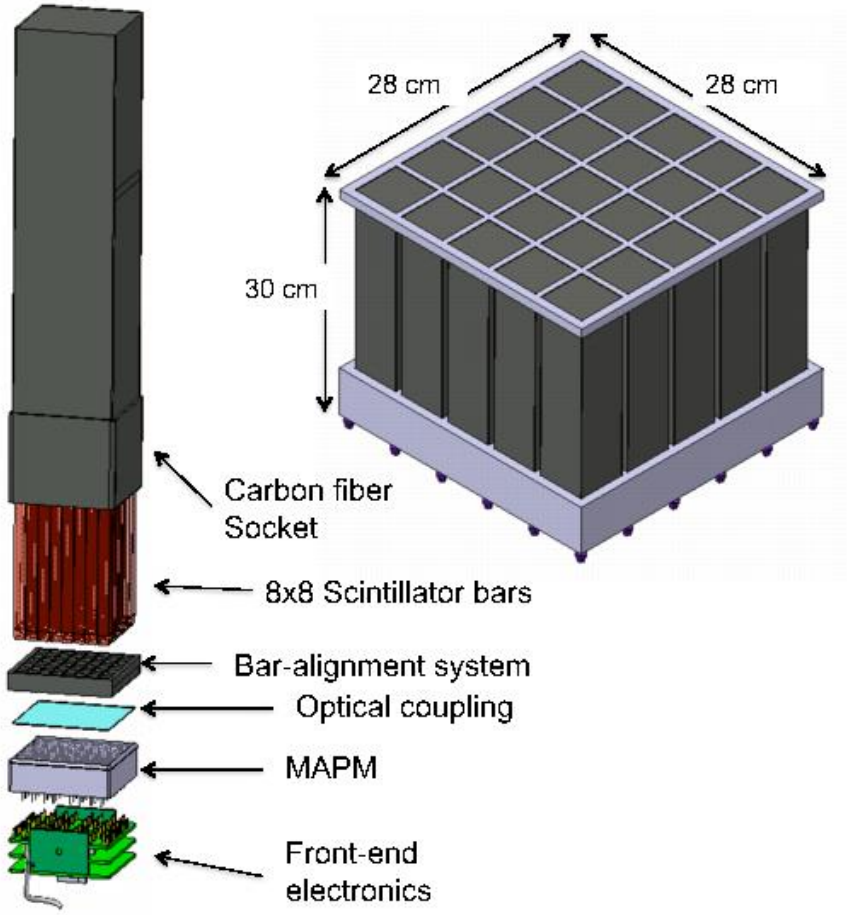
ASTROGAM and ASTRO-H polarigram for a Crab-like source observed during 100 ks.
Left: ASTROGAM **100 mCrab** source;
Right: SGD **1 Crab** source

SGD	ASTROGAM
MDP_{99} 1 Crab 50 ks 300-600 keV	
40%	6%

http://arxiv.org/pdf/1412.1190v1.pdf

POLAR (2015 -)

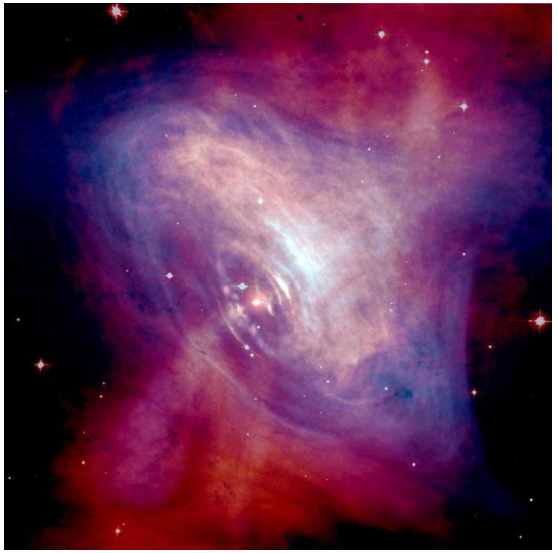
- **POLAR** is a Swiss – Chinese mission to be placed on the Chinese space station Tiangong 2 (2015).
- It is a Compton telescope dedicated to GRB polarization measures between 50 and 500 keV.



ASTROGAM POLARIMETER SCIENCE OBJECTIVES

Astrophysics : Jets

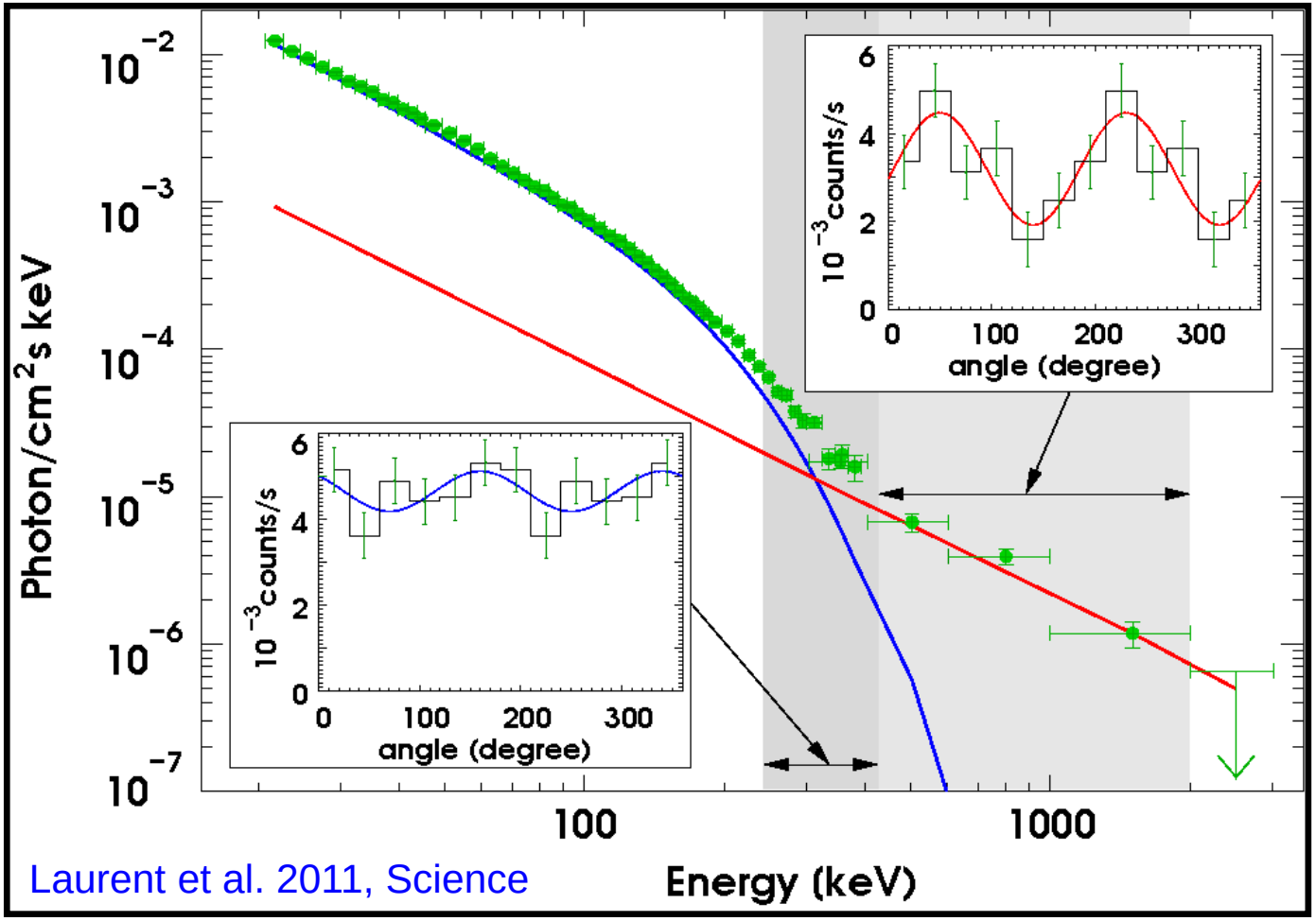
- γ-ray polarization in **objects emitting jets** (Blazars, GRBs, X-ray binaries) or with **strong magnetic field** (pulsars, magnetars) poses strong constraints on the magnetic field structure and the nature of the γ-ray emission process.



- **10 - 100 MeV γ-ray polarization** will be a key observation to prove (or disprove) that hadrons are accelerated in blazar jets (Zhang & Böttcher 2013)

INTEGRAL polarization observation of Cygnus X-1

Strong polarization in the MeV component ⇒ signature of the jet?

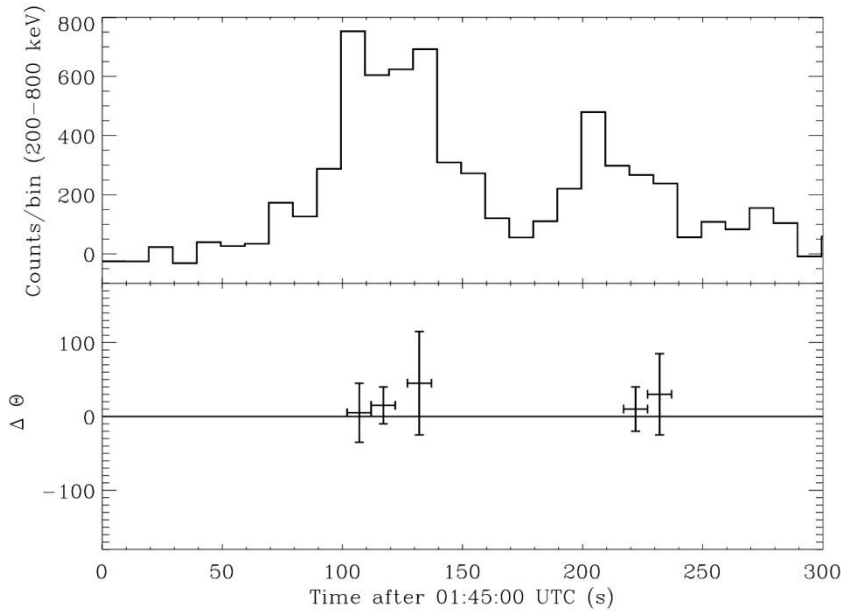


Laurent et al. 2011, Science

Fundamental Physics

- Polarization from **cosmological sources** (Blazars, GRBs) can provide strong constraints on theories aimed at unifying General Relativity and quantum mechanics ⇒ Lorentz invariance violation

INTEGRAL measurement of GRB 041219A polarimetry
Comparison of Polarization Angle between two energy bands
⇒ Helicity dependence of cosmological photon propagation

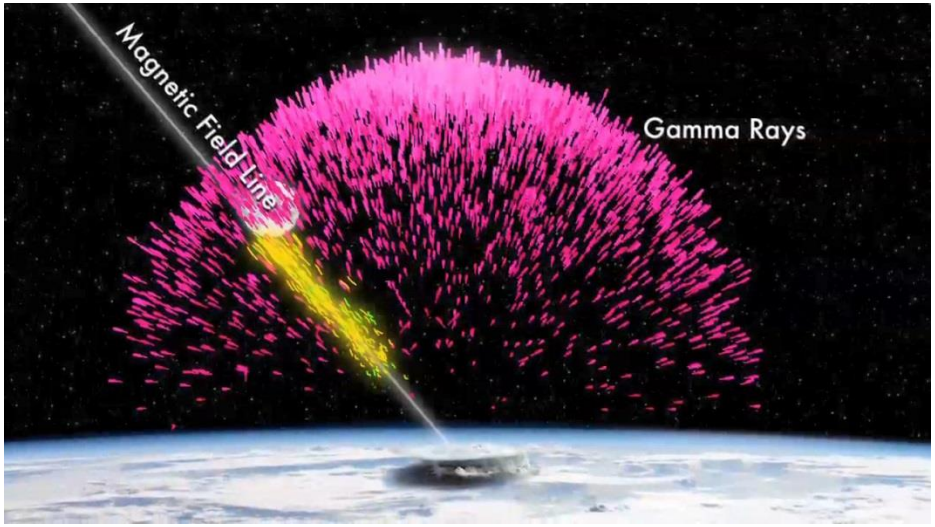


Evolution during the γ-ray burst duration of the polarimetric angle shift measured between the energy ranges [200-250 keV] and [250-325 keV]. The mean value, 21 ± 47° is consistent with zero ⇒ Strong limit on vacuum birefringence ($\xi < 4\times10^{-15}$)

Laurent et al. 2011, PRD

Earth observations : Terrestrial γ-ray flashes

ASTROGAM may discover γ-ray polarization from Terrestrial γ–ray flashes (TGF). γ–ray are thought to be produced from accelerated electrons by Bremsstrahlung. If they are Compton scattered on the atmosphere afterward ⇒ polarization



THANK YOU !