Compton Gamma-ray Polarimeter Development

SLAC Annual Program Review

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Collaboration: Goddard Space Flight Center, SLAC(Research Div Accel. Div.), Princeton (USA);
Royal Inst. of Tech (Sweden);
ISAS, Tokyo Inst. of Tech., Hiroshima Univ., Yamagata Univ. (Japan);
Ecole Polytechnique (France);
Nicolas Copernicus Astronomical Center (Poland)

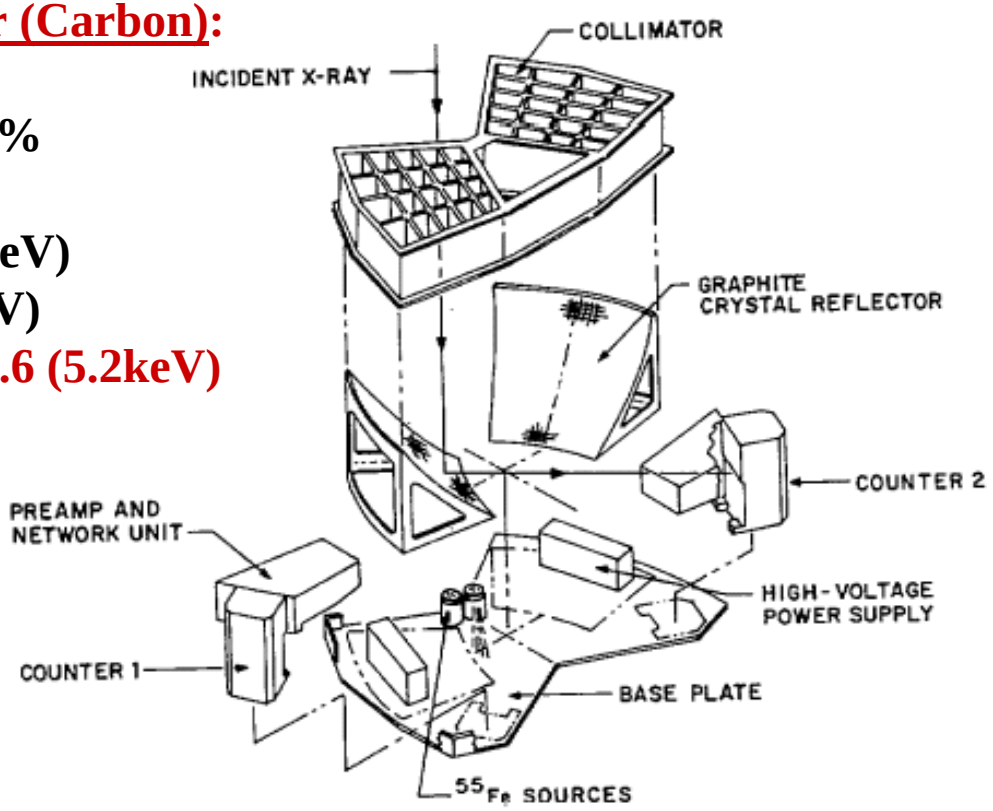
- **History: linear pol. meas. is the last frontier in the EM wave astrophys.**
- **New science: X/γ polarization senses B-field and geometry at sources**
- **R/D done: key ideas come from us over the past 15 years (1987-2003)**
- **Goal of this R/D: prototype instrument for balloon flights**
- **Path to future: step-by-step approach from balloon exp. to a space mission**

History: Crab polarization measurements with OSO-8 (1/3)

Conducted in 1976 by a Columbia group (M. Weisskopf et al.)

Bragg Diffraction Polarimater (Carbon):

Mod factor for 100% pol = 94%
Count rate = 3.8kHz (2.6keV)
= 0.7-0.9kHz (5.2keV)
S/N = ~10 (2.6keV), ~2 (5.2keV)
Pol x S/N = 1-2 (2.6keV), 0.2-0.6 (5.2keV)
Total obs. Time = 71.2 hrs

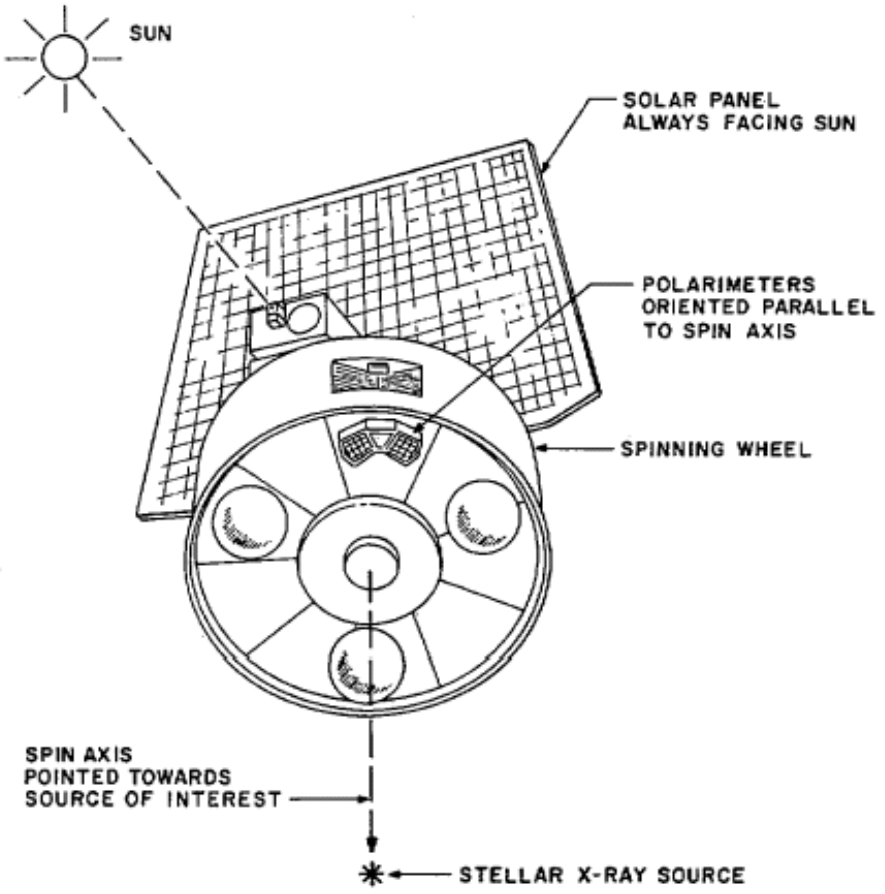


History: Crab polarization measurements with OSO-8 (2/3)

Conducted in 1976 by a Columbia group (M. Weisskopf et al.)

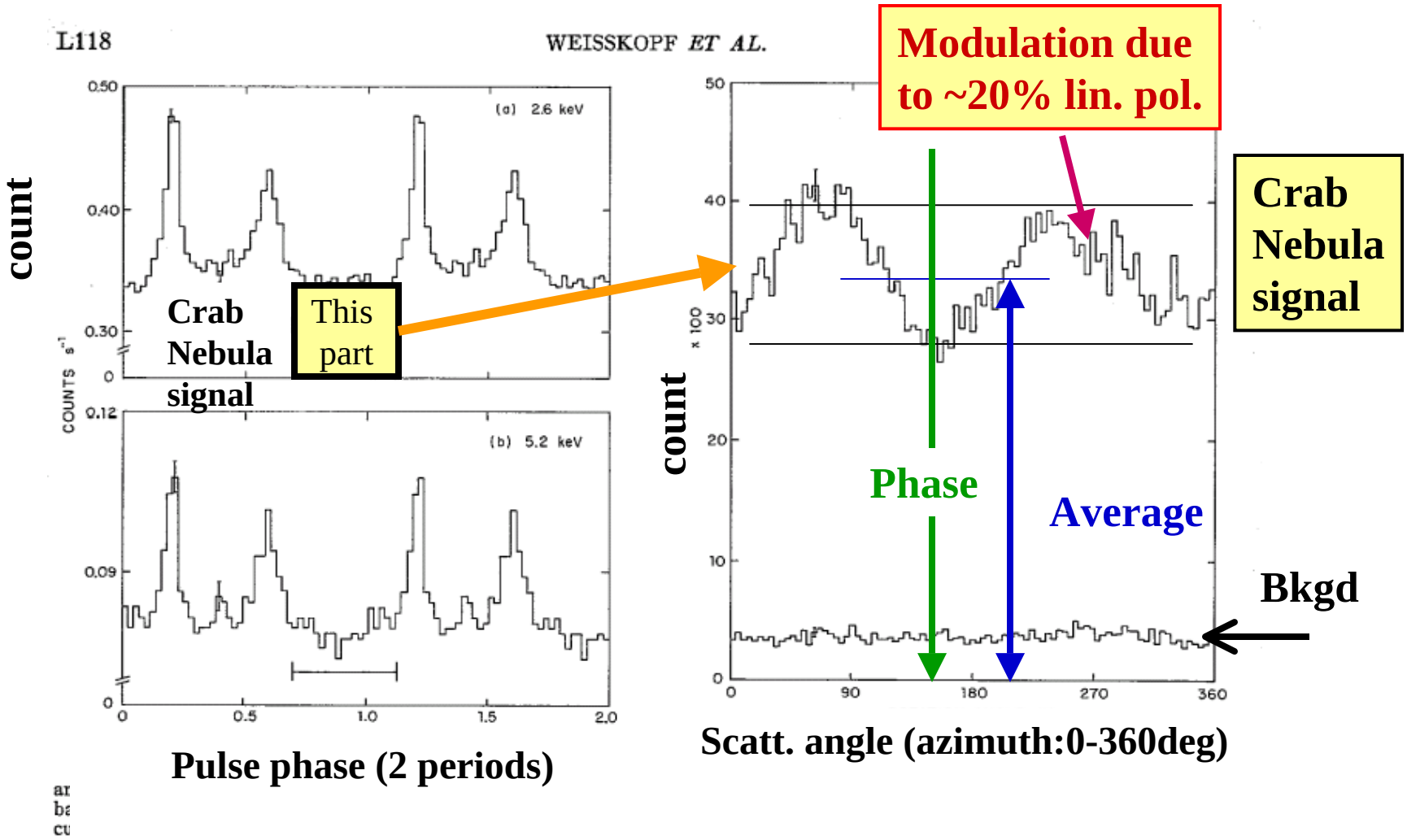
Rotating wheel:

Minimize possible systematic bias



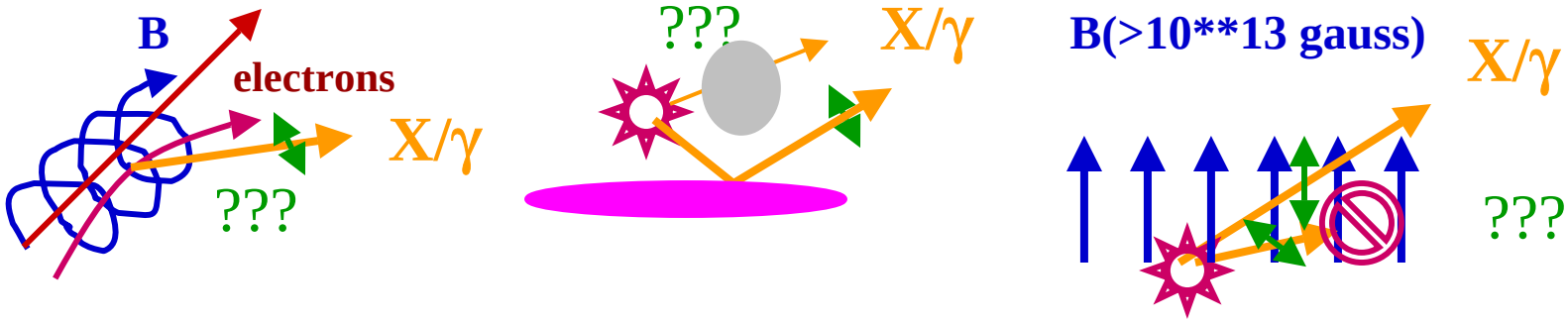
History: Crab polarization measurements with OSO-8 (3/3)

Conducted in 1976 by a Columbia group (M. Weisskopf et al.)



New science: processes known to polarize X/γ-rays

- **Synchrotron process**: Electrical vector is perpendicular to the magnetic field and hence polarization measurement determines **the direction of magnetic field in high energy jets.**
- **Re-scattered via Compton scattering:** Electric vector is perpendicular to the plane of scattering and hence polarization measurement determines **the geometrical relation between the photon source and the scatterer.**
- **Propagation of photons in strong magnetic field:** Magnitude of polarization depends on the energy of photons. When the magnetic field is very high (>10**13 gauss), photons with electric vector perpendicular to the magnetic field are highly absorbed. Polarization measurements will directly observe **high-B QED effects on the neutron star surface.**



New science: astronomical X/γ sources of interest

- **Super-massive black holes:** matter accretion powers relativistic jets, accelerates particles, and emits photons via **synchrotron** and **inverse-Compton**. **(Geometry around SMBH)**

- **Galactic black hole binaries:** matter accretes onto a black hole and emits hard X-rays. **Inverse-Compton** reflection off the accretion disk polarizes hard X-rays. **Micro-quasars** belong here. **(Geometry around BH) (Space-time distortion around BH)**

- **Active galaxies:** isotropic emission is scattered toward the Earth by **inverse-Compton** scattering. **(Geometry around the nucleus of Seyfert galaxies)**

- **Neutron stars with high B-field:** strong **cyclotron line features** will induce **polaization and energy dependent photon-absorption cross-section**. **(High B-field, non-lin. QED)**

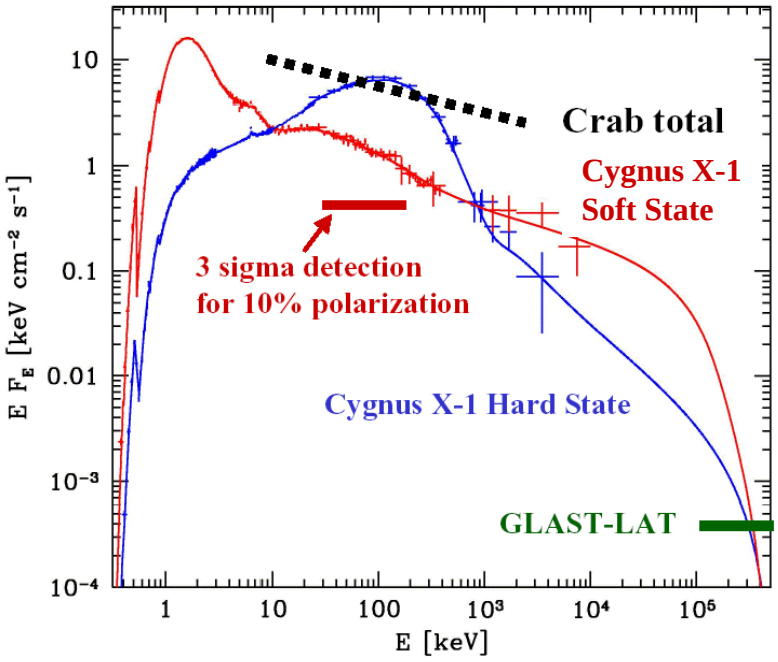
- **Isolated pulsars:** synchrotron emission occurs where **strong magnetic field has small curveture**. **(Geometry of B-field)**

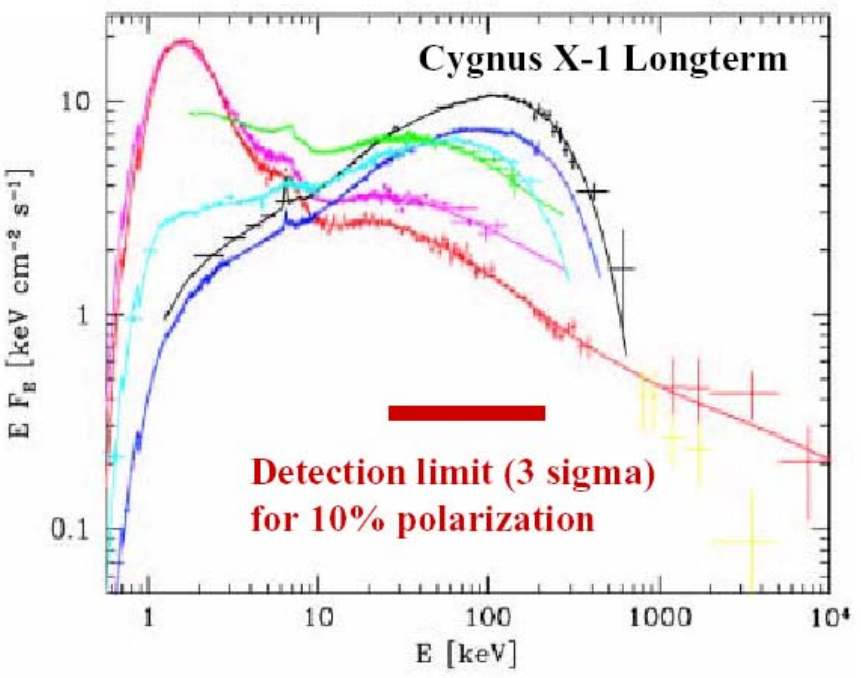
- **Ordinary galaxies (incl. our own):** diffuse high energy emission is dominated by extended **inverse Compton** halo. **(Geometry of inverse-Compton component)**

New science: possible targets for observation (1/2)

Cygnus X-1 (Geometry around the best-known Black Hole Binary)

Cygnus X-1 transitions between the hard and soft states in a few mon. to a few years

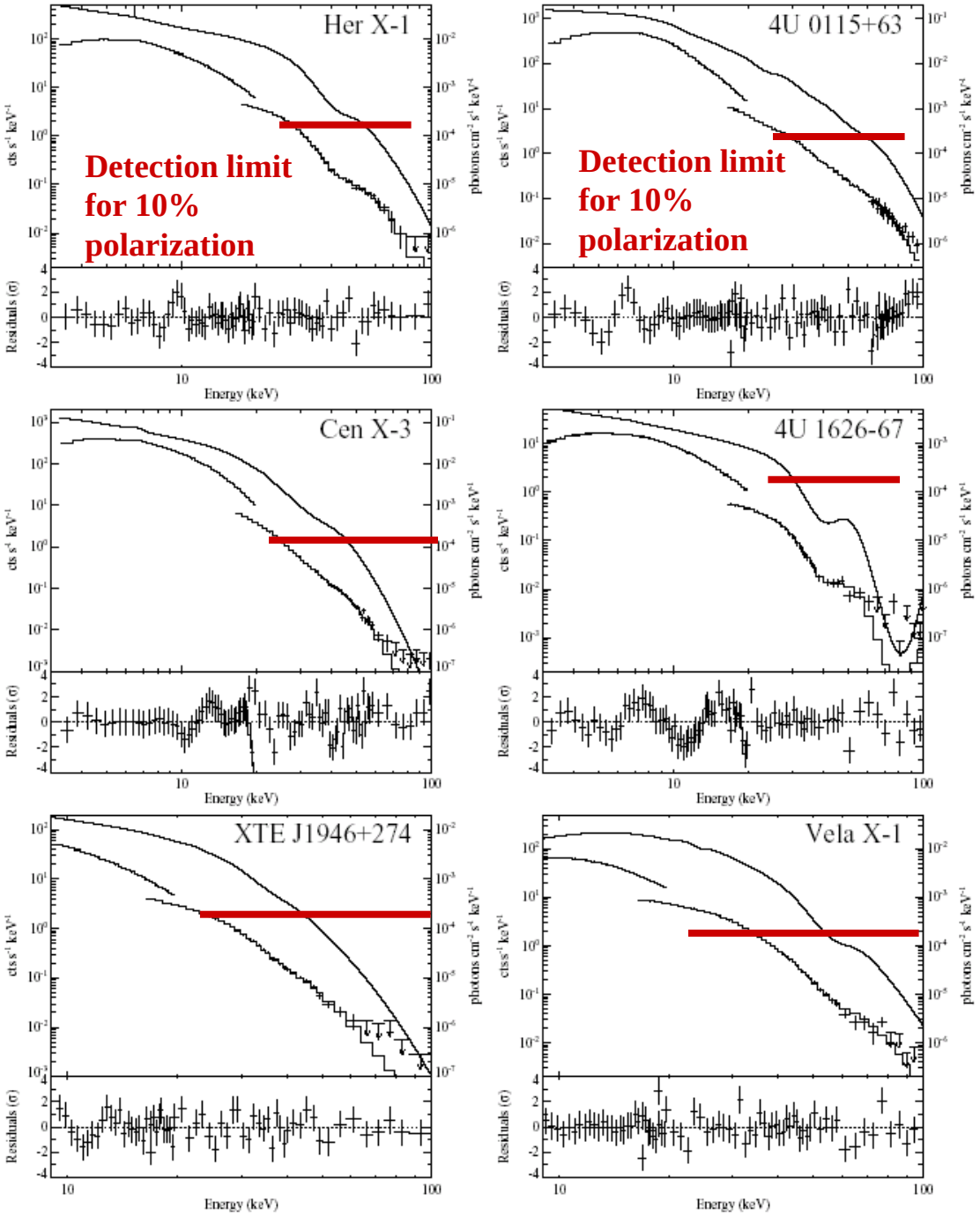




New scinece:
possible targets for observation (2/2)

Neutron Stars with cyclotron resonance and scattering by super-critical B-field (>4x1013 gauss).**

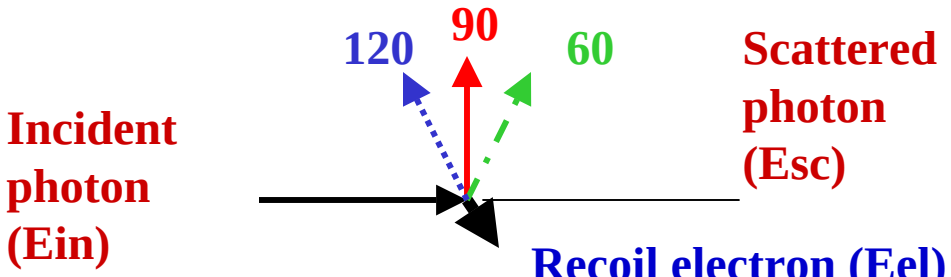
(High B-field and non-linear QED)

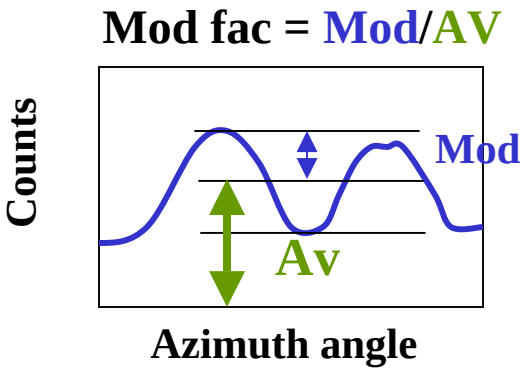


R/D done: Photo-absorption vs. Compton scattering

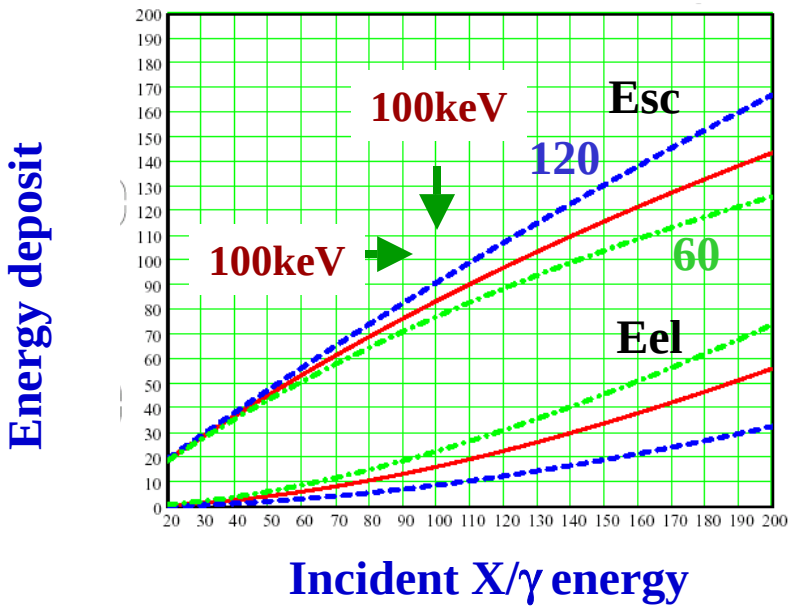
	Photoelectron absorption	Compton scattering
Energy range	3.5 - 10keV	25 - 200 keV
Good S/N by	•X-ray mirror •Fine tracking	•Active shield •Coarse segmentation
Main bkg	•Thermal emission from the source	•Source confusion in FOV •Cosmic ray background
Mod factor	~30-40%	~30-40%
Platform	Satellite	Balloon (penetrate thru thin air) Satellite
Merit	•Fine imaging	•Optimal to pol. processes •Simple and robust (no gas) •Cost-effective
Demerit	•Consumable gas •Heavy on data processing	•No image

R/D done: Simple kinematics and large modulation of Compton scattering

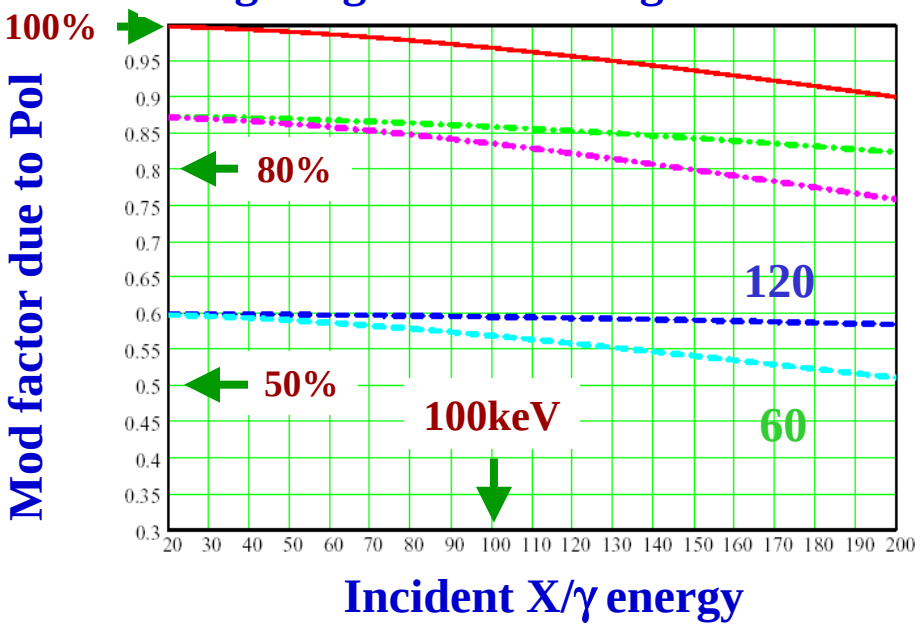




Crude E meas. resolve kinematics.

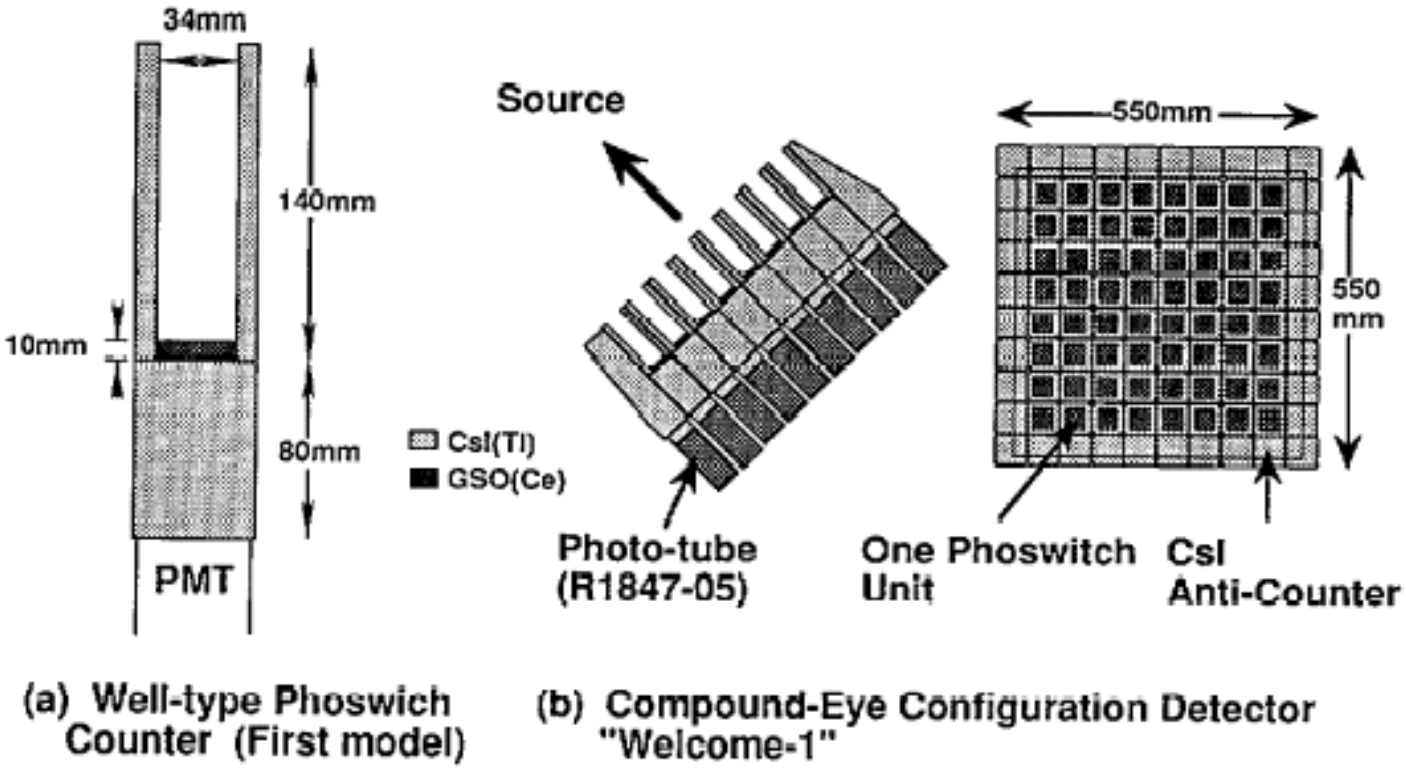


Large ang. mod. factor guaranteed.



R/D done: Heritage from Welcome-1 and Astro-E HXD (1/2)

Heritage from the balloon instrument Welcome-1 flown 4 times in Brazil



(a) Well-type Phoswich Counter (First model)

(b) Compound-Eye Configuration Detector "Welcome-1"

T. Kamae, T. Takahashi et al, 1988-1997

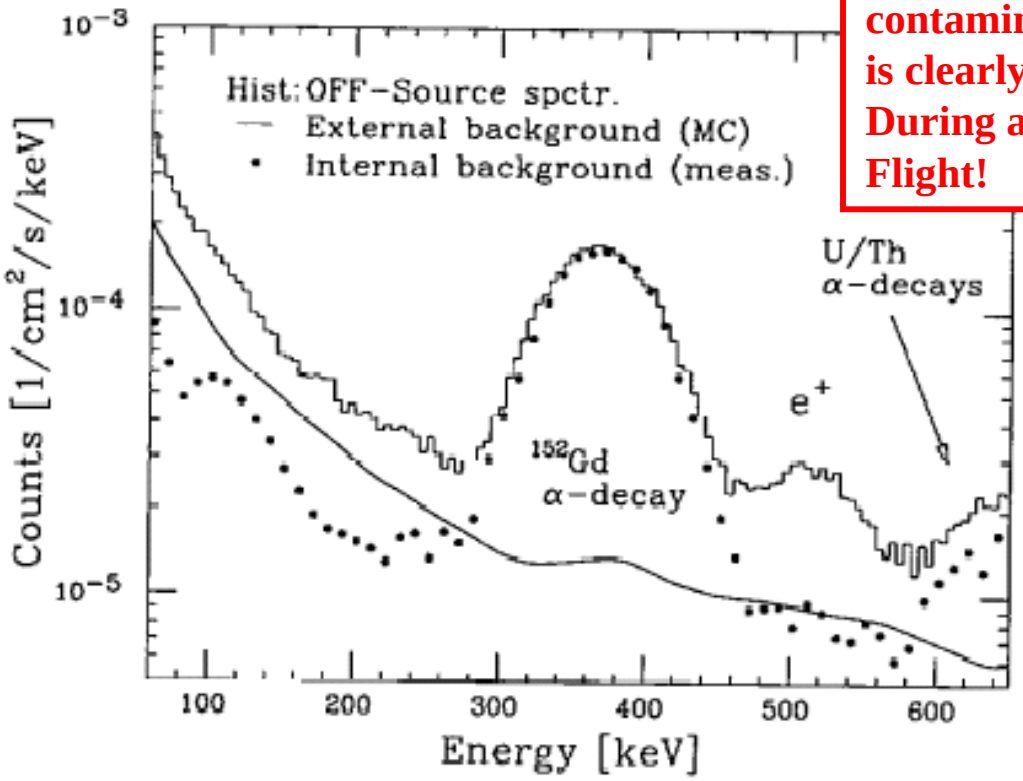
R/D done: Heritage from Welcome-1 and Astro-E HXD

Lowest background ever achieved in the hard X-ray band

Very low radioactive contamination is clearly visible During a balloon Flight!

Welcome-1:
A series of balloon experiments in Brazil

- **Upper limit to Co57 from SN1997A (ApJ-Letter)**
- **First detection in hard X-ray of PSR 1509 (ApJ)**
- **Detection of H.E. cutoff of CenA (PASJ)**
- **First detection of inv. Compton component in high latitude Galactic diffuse emission (ApJ)**



Many scientific papers (1992-1997)

Goal of this R/D: figure of merit for Compton polarimeter

Figure of merit = S/N for the source X Modulation factor

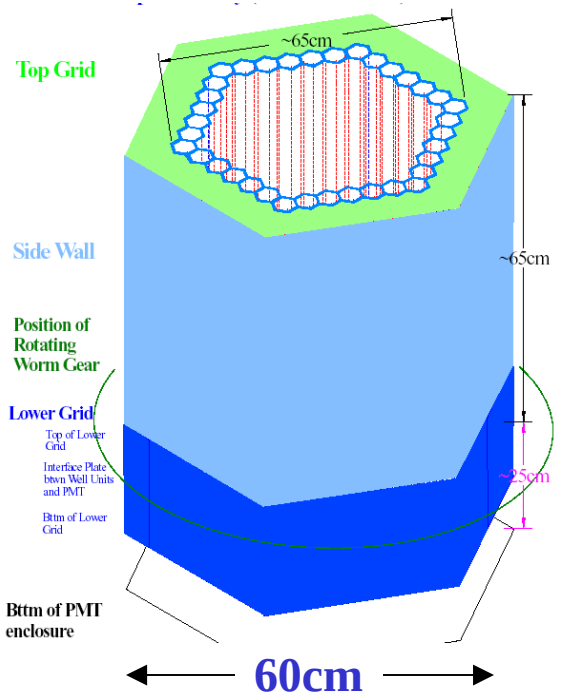
Fig. of merit must be >>1 in the energy band of interest.

This implies:

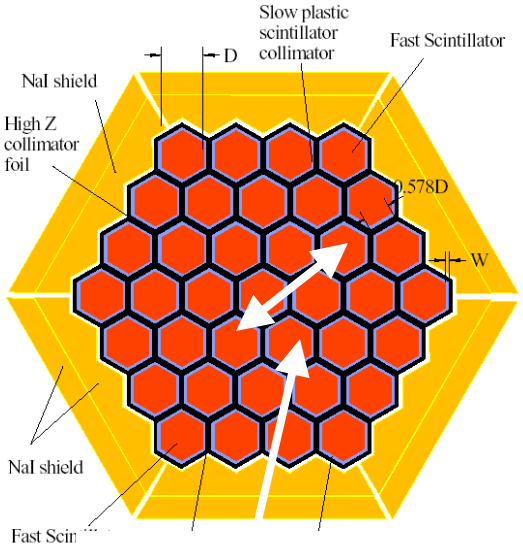
- **Maximize S/N ratio → Well-type Phoswich Counter**
- **Interesting energy band (20-100keV) → Plastic scintillator**
- **High modulation factor → Compton scatt. (60-120deg.)**

Goal of this R/D: an instrument for balloon experiments (1/3)

Sensor Part: conceptual design

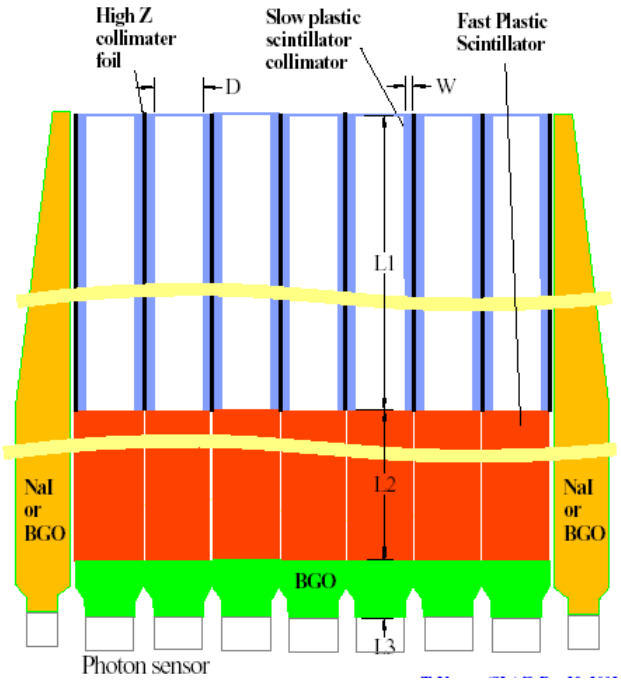


(a)



Coicidence along E-field of incident Gamma-rays

(b)

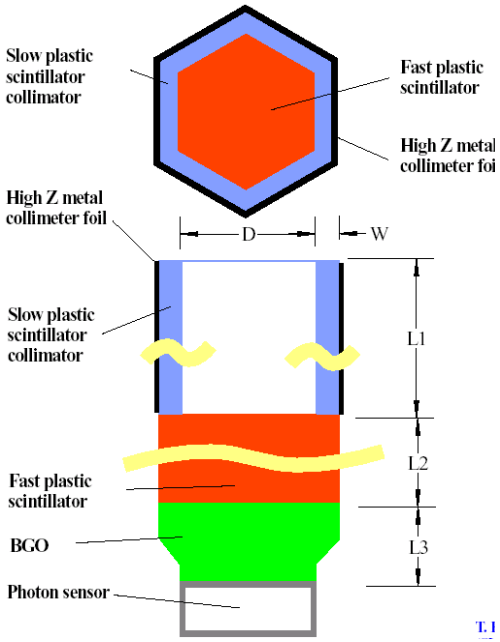


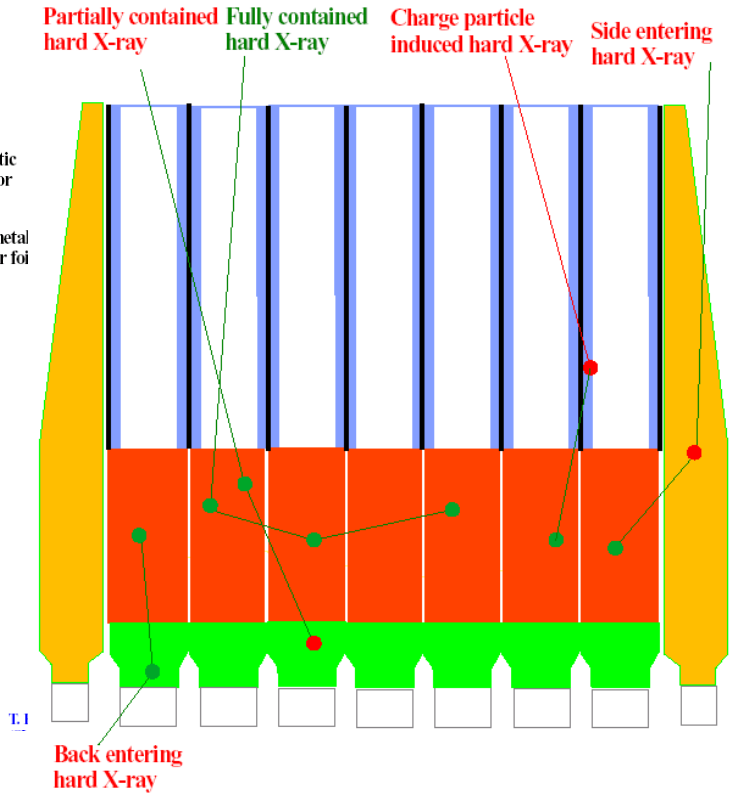
(c)

Conceptual design of the instrument (number of units will be greater than shown here): a) Isometric view; (b) View from the front of the instrument; (c) Vertical cross-section of the instrument. The proposed instrument will have ~400 units and L1 + L2 in (c) will be ~60cm.

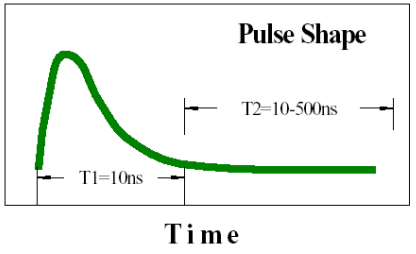
Goal of this R/D: an instrument for balloon experiments (2/3)

Electronics and DAQ: Simple L1 trigger and Pulse-Shape-Discrimination

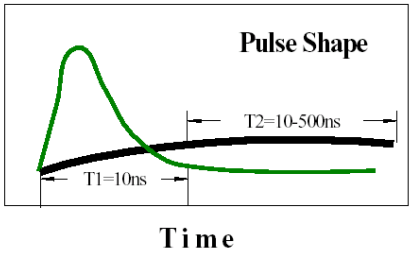




Very powerful way to reject Background by 1/1000



Fast Scintillator Only



Slow Scintillator and BGO

Goal of this R/D: an instrument for balloon experiments (3/3)

Schedule and cost:

- **April, 2003: NASA-SRT proposal (PI: John Mitchell of Goddard) for US FY04, 05, 06**
  - **Total a few MUSD over 3yrs in the "full costing" scheme**
  - **Non-US funds for M&S over 3yrs ~500kUSD**
- **August, 2003: Decision sometime in summer 2003**
- **October, 2003: NASA-SRT R/D program starts**

  FY2004
  - **Prepare 10 units (of ~400 units) and test in a synchrotron X-ray beam (All)**
  - **Design electronics and DAQ (Goddard+Princeton), sensors (SLAC, Sweden, Japan)**
  - **Develop MC: EGS4 with polarization (SLAC, DONE) and G4 with polarization**
- **Sepember, 2004: NASA-SRT review: go/nogo for the 2nd and 3rd year**

  FY2005
  - **Prepare ~100 units of sensors (SLAC, Goddard, Princeton, Sweden, Japan) and test in beams (All)**
  - **Design gondolla, pointing system, communication system**
- **September, 2006: Submit a proposal for balloon experiments**

  FY2006
  - **Prepare ~300 units of sensors (SLAC, Goddard, Princeton, Sweden, Japan) and test in beams (All)**
  - **Build gondolla, pointing system, communication system (Goddard, Princeton, All)**
- **June, 2007: Balloon flight (All)**

Path to Future: what may follow this R/D program

Step 1) Explore an Avalanche Photo-Diode option for a space mission

R/D on APD array in progress in Japan and Sweden

Energy coverage down to 20keV by detecting Eel ~ 0.5keV

Step 2a) Build an instrument for the long duration balloon flight program of NASA

Australia to Brazil flight will allow 2-3 weeks of observation at minimum cost for users.

Step2b) If scientific results justify and a collaboration build ups, we will propose a polarization mission to NASA, ESA, or ISAS.

Technology may be on this well-type phoswich polarimater or on silicon strip detector Compton polarimater.

Conclusion

- **The last unexplored and very interesting area (polarization in X/γ) will be opened with NASA Sustainable Research and Technology funds.**
- **Synergy with SLAC expertise: scinitillation counters, PMT, APD**
- **Minimum schedule conflict with GLAST-LAT (major work in FY2006 and balloon flight in FY2007)**
- **Strengthen GLAST-LAT science on jets, pulsars and diffuse γ from galaxies**
- **Basic ideas and early works come from us. We will be a leading institute in this exciting new field of X/γ polarization study.**
- **Give something very interesting for the future of young physicists at SLAC**