RHESSI AND FUTURE MEASUREMENTS OF GRB POLARIZATION

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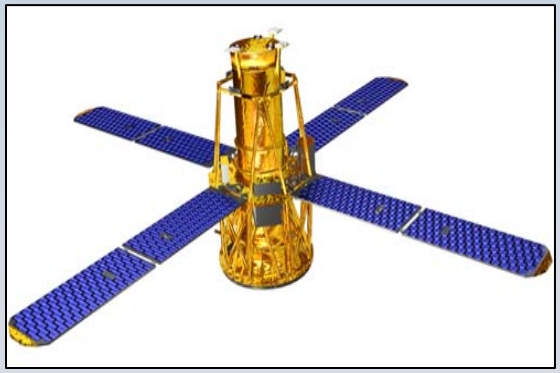
on behalf of PSI RHESSI team and POLAR collaboration
PSI, Villigen, Switzerland

RHESSI SATELLITE

- **The Rouven Ramaty High Energy Solar Spectroscopic Imager**
- **Goal:** Spectroscopy and Images of Solar Flares SF in X- and γ-rays
- **Launch:** 5th February 2002 as NASA SMEX mission, 2 years, extended +5
- **Orientation:** points toward the sun and rotates - period of 4 s
- **Orbit and Inclination:** Low Earth 588 km, 38 deg
- **Instruments:** Imager/Telescope, Ge-Spectrometer
- **Data acquisition:** event by event; photon energy, time, detector No.



See R.Lin et al., Sol. Phys., 2002

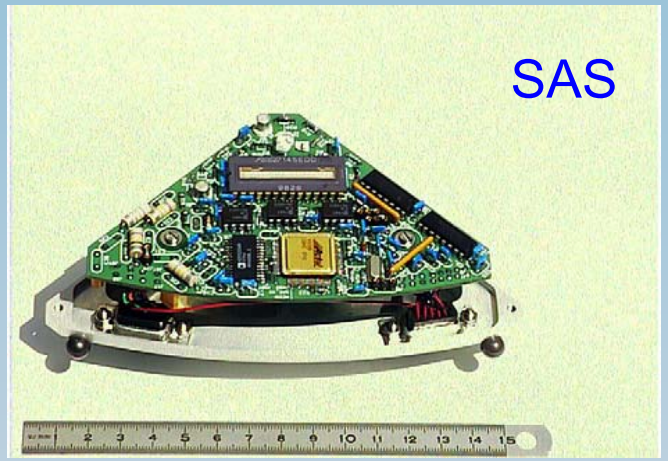
GSFC
UCB
PSI
SPECTRUM-ASTRO

PSI, RHESSI SUBSYSTEMS and DBASE

- PSI HW contribution
  - Solar and Roll Aspect Systems SAS, RAS
  - Telescope trays and tube
  - Twist Monitoring System TMS

- PIF Qualification - COTS mission oriented
  - 10 krad total dose TID- no damage
  - SEU cross section small
  - SEL protection circuit

- Satellite Mass Model (except Ge-spectr.) and MC
  - off-axis response functions for NS science
  - atmospheric scattering
  - maintains RHESSI GRB web



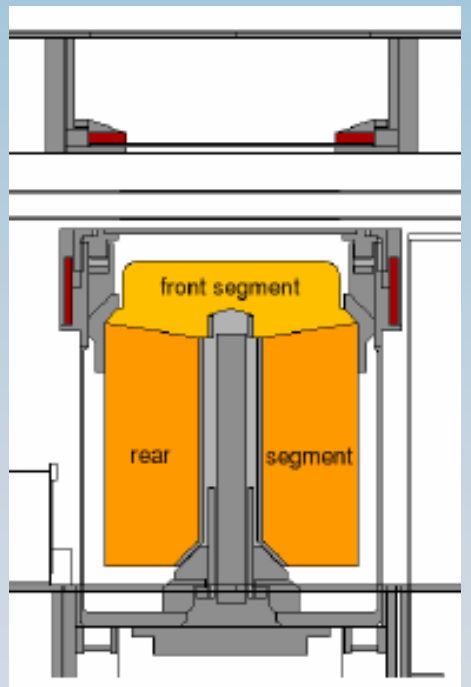
GERMANIUM SPECTROMETER

- 9 hyper-pure, cylinder-like Ge-detectors
- Size: ϕ = 7.1 cm, h = 8.5 cm, operation at 75 K
- Segments: front (1.5 cm) and rear (7.0 cm)
- Only thin side shield of Ta-Sn-Fe stack (2 mm)
- Transmission grids from front (50%)
- Effective area up to 200 cm^2 at 200 keV.
- Energy range 3 keV – 20 MeV
- $\Delta E \approx 3$ keV ; $\Delta t = 1$ μsec

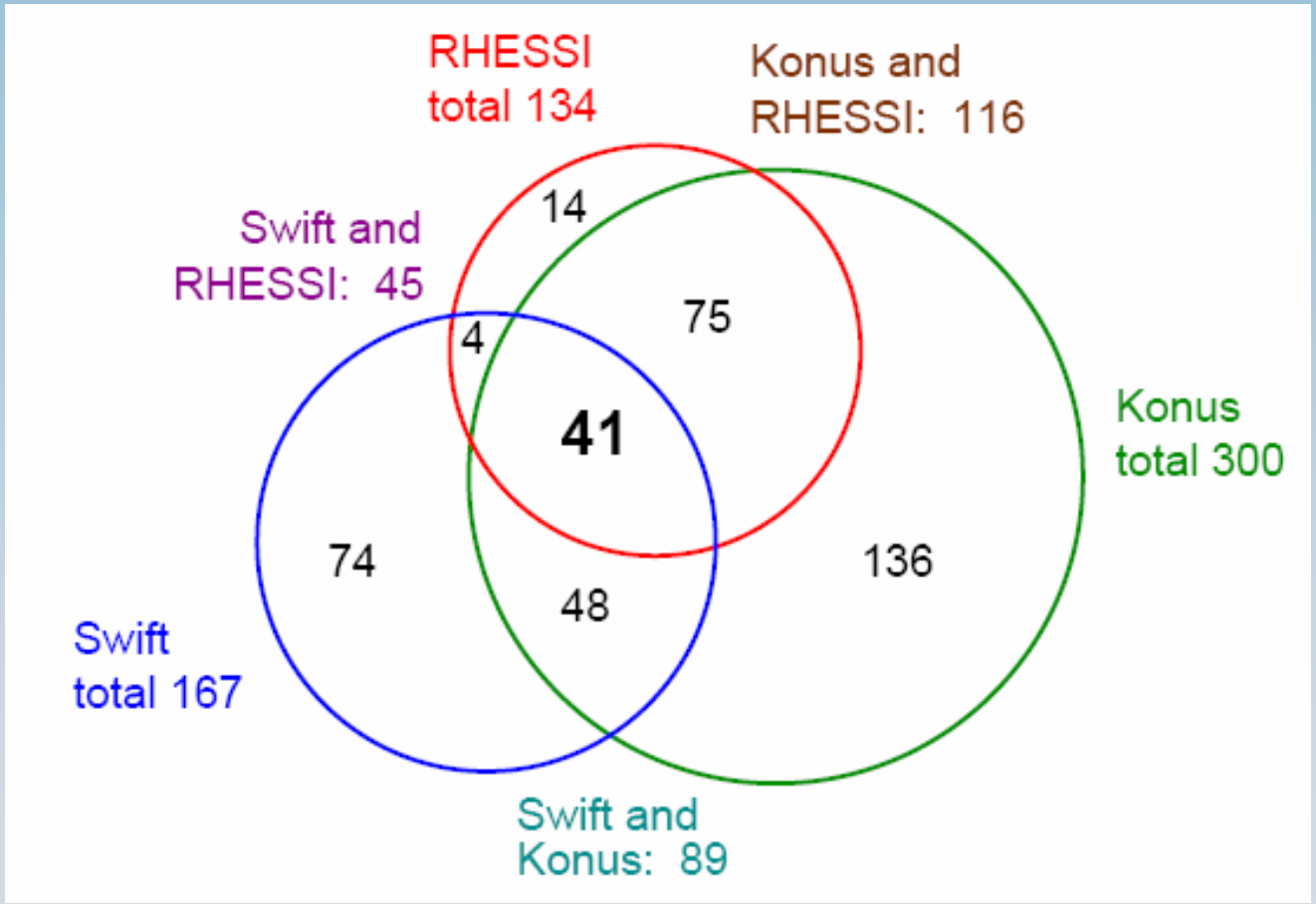
See D.Smith et al., Sol. Phys., 2002

RHESSI AS GRB DETECTOR

- Photons with E>25 keV can enter from the side
- Photons with E>100 keV enter from all directions
- Excellent for detection of Gamma Ray Bursts GRB
- Large field of view (≈ 2π), large volume (~SPI INTEGRAL)
- 376 GRB observed until March 2006
- Typical detection rate: 1-2 per week
- Active area depends on GRB direction (A_{eff}≈150 cm^2)
- See online catalogue http://grb.web.psi.ch



GRB DETECTIONS vs. MISSION



Statistics from December 2004 to March 2006 by K.Hurley,

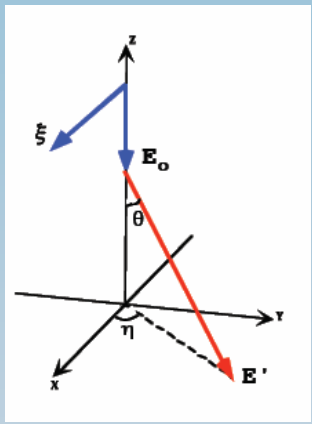
See Wigger et al, Venice 2006

γ-RAY POLARIZATION MEASUREMENTS

(based on numerous M. McConnell presentations)

Utilizes Compton scattering;
photons scatter at right angles to initial polarization vector;
θ - Compton Scatter Angle
η - Azimuthal Scatter Angle

$$d\sigma = \frac{r_o^2}{2} d\Omega \left(\frac{E'}{E_o}\right)^2 \left(\frac{E_o}{E'} + \frac{E'}{E_o} - 2\sin^2\theta\cos^2\eta\right)$$



Signature from distribution in azimuth scatter angle $C(\eta) = A\cos 2(\eta-\varphi) + B$

Modulation Factor for 100% polarization defines polarimeter: $\mu = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} = \frac{A}{B}$

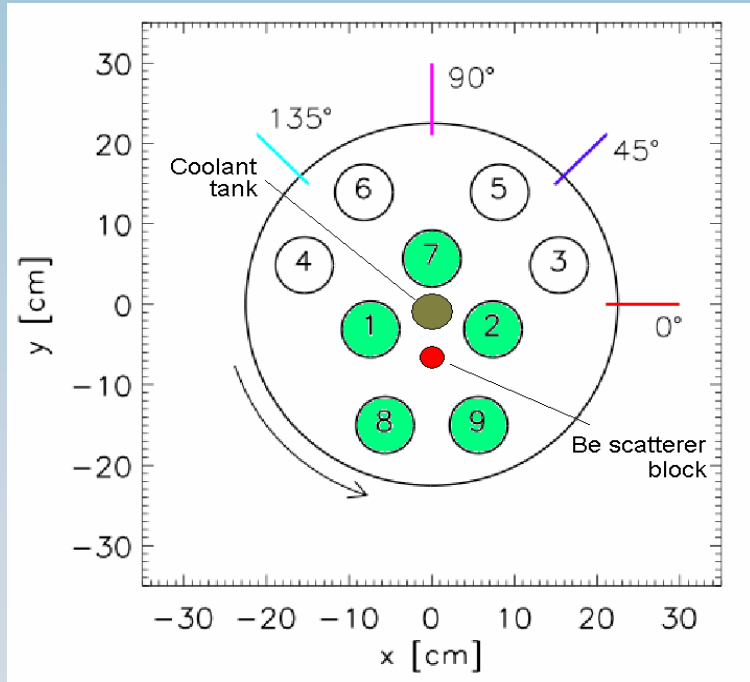
Instrument determines level of polarization as $P = \frac{\mu_P}{\mu_{100}} = \frac{1}{\mu_{100}}\left(\frac{C_{max}(P) - C_{min}(P)}{C_{max}(P) + C_{min}(P)}\right)$

Minimum Detectable Polarization for instrument is a function of:
S, B: source and background rate, T: observation time, μ_{100}: Modulation Factor

$$MDP = \frac{n_\sigma}{\mu_{100} S}\sqrt{\frac{S+B}{T}}$$

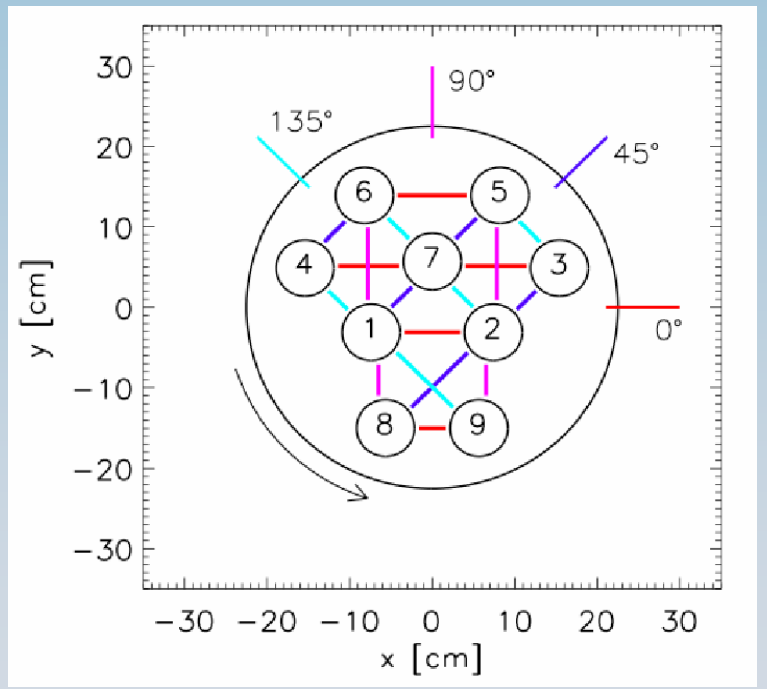
RHESSI AS PASSIVE POLARIMETER

- Scatterer - Be-block looking at the Sun
- Used for 20 keV < E < 80 keV
- Nearby detectors measure scattered radiation
- Only rear segments used
- Spacecraft rotation samples angular scattering distribution
- Large modulation factors and figure of merit
- Big and variable background from Earth scattered photons



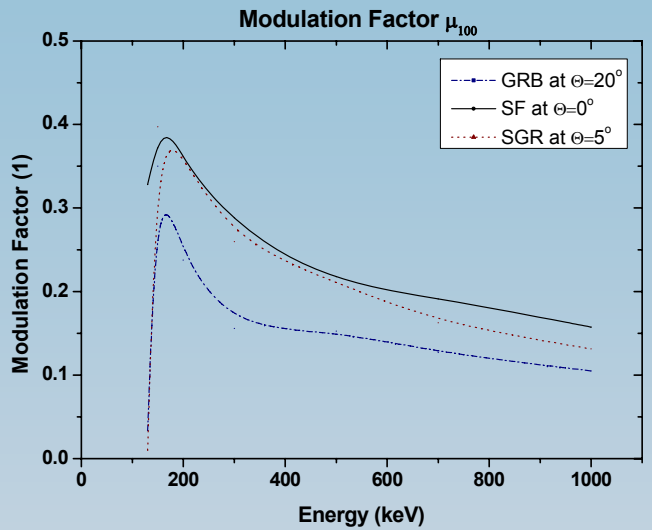
RHESSI AS COINCIDENCE POLARIMETER

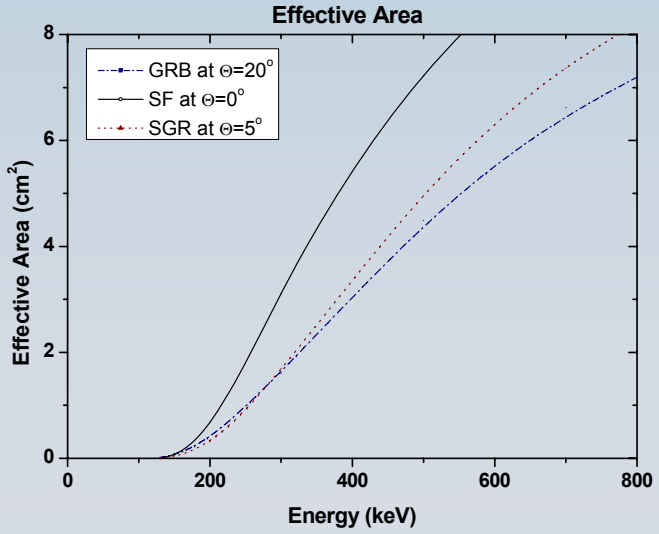
- For higher energies the scattering medium is one of the Ge detectors
- Another, close detector measures distribution of scattered radiation
- Rotation of the spacecraft provides sampling of the scatter distribution
- Large modulation factors feasible for near axis GRBs (front and rear)
- 18 detector pairs favorable for coincidence measurements (out of 36 combinations)



RHESSI POLARIMETRIC CAPABILITIES

Event type	GRB	SF
Energy (keV)	100-1000	100-350
Power index (1)	2	3
Polar angle (deg)	20	0
Fluence (erg/cm^2)	$2.0 \cdot 10^{-4}$	$1.2 \cdot 10^{-3}$
Duration (s)	1	200
Area single (cm^2)	177	282
Area coinc. (cm^2)	2.19	0.698
Mod. Factor (%)	14.6	31.7
Signal events	**1308**	4165
Background	**64**	4420
Accidentals	**1180**	512
$MDP_{1\sigma}$ (%)	35.	10.





Number of events for 1σ MDP=40% is ca 1000,
Since Feb 2002 RHESSI detected 3 such GRBs

CASE OF THE GRB021206 EVENT

letter to nature, Nature, 22 May 2003
W. Coburn & St. E.Boggs, SSL Berkeley

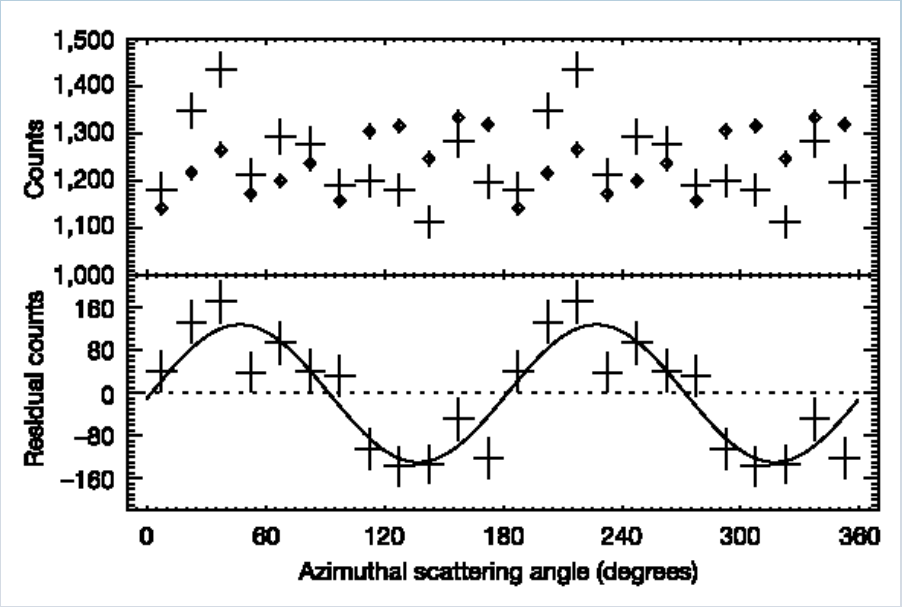
"Polarization of the prompt γ-ray emission from the γ-ray burst of 6 December 2002"

Analysis of RHESSI data

Linear polarization detected
with a C.L. of 5.7σ

polarization degree is
$P_{lin} = 80 \pm 20\%$

Huge impact on GRB theories but
other papers revealed errors in analysis



REANALYSIS OF THE GRB021206:

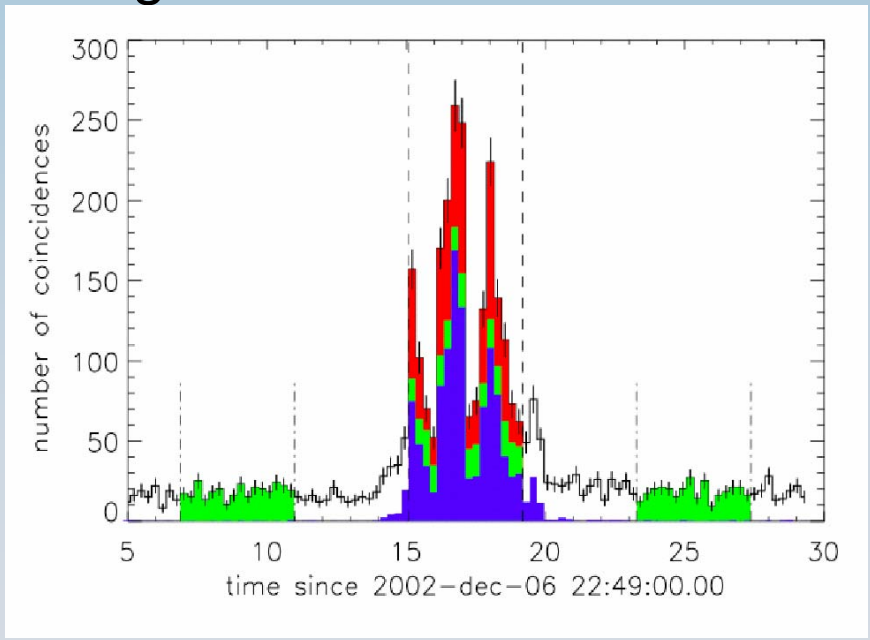
Wigger et al, ApJ2004

Cuts applied:

- Energy
- Close-pairs
- Coincidence time
- Kinematical
- No-multiples

$\Delta t = 4.10$ s, N_tot = 2141

light curve of coincidences



accidental coincidences:
N_acc = 1081

background coincidences:
N_BG = 290

Compton scattering candidates:
N_C = N_tot − N_acc − N_BG
N_C = 770

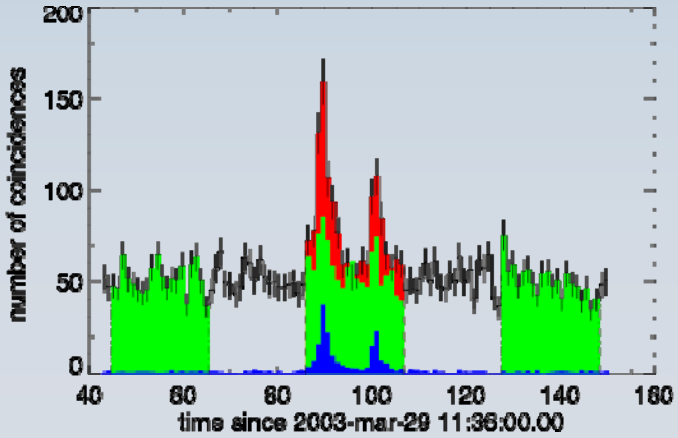
$\mathbf{P_{lin} \approx 41\ \%}$ $^{+\ 57\ \%}_{-\ 44\ \%}$

OTHER GRB POLARIZATION CANDIDATES

GRB 030329 (SN)

N_tot = 1587
N_acc = 166
N_BG = 984
N_C = 437 ± 46

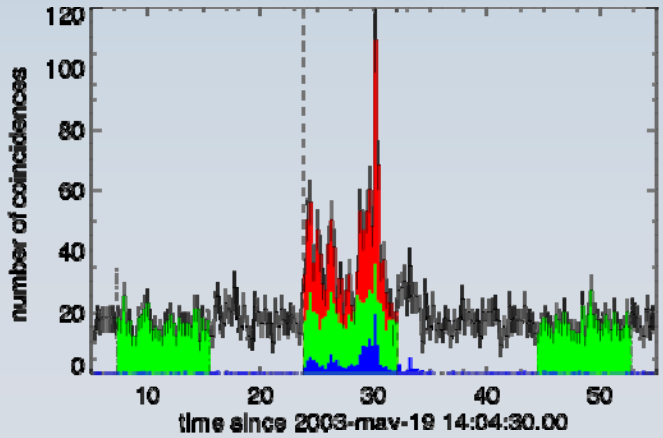
$P_{lin} \approx 65\ \%\ ^{+\ 75\ \%}_{-\ 60\ \%}$



GRB 030519B

N_tot = 1249
N_acc = 136
N_BG = 524
N_C = 589 ± 39

$P_{lin} \approx 28\ \%\ ^{+\ 51\ \%}_{-\ 39\ \%}$

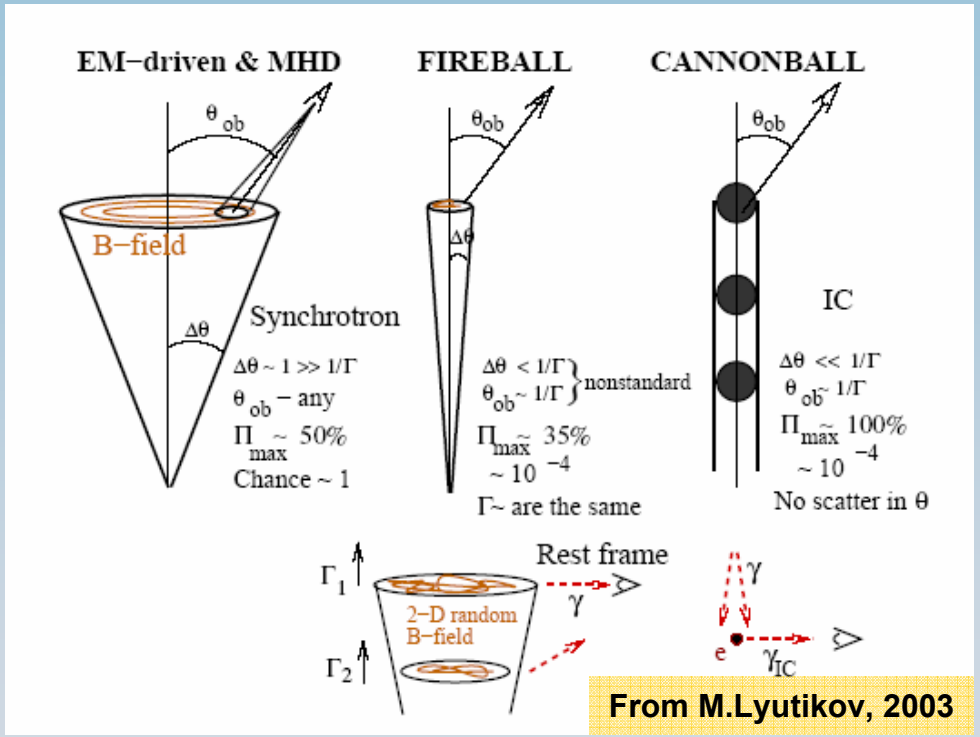


POLARIZATION MEASUREMENT STATUS

- Polarization observations in γ-rays were mostly neglected
- Many missions had difficulties with unambiguous measurements
- Recent reports of high polarization in GRB (RHESSI) alerted the community
- Also INTEGRAL SPI results reached $\Pi \approx 100\%$ for GRB041219a; see E.Kalemci et al. or S.McBreen et al., Moscow and Venice Workshops 2006
- BATSE analysis of Earth scattered photons found $\Pi > 35\%$ for GRB930131 and $\Pi > 50\%$ for GRB960924; see D.R. Willis et al.
- CORONAS-F reported single case of $\Pi > 70\%$ (60 keV < E < 100keV) in Solar Flares from 29 Oct 2003; see Zhitnik et al.
- Large set of observations, with energy and time dependence, is needed
- Several new polarimeters are being studied and constructed

GRB POLARIZATION LEVELS IN THEORY

- Fireball Model
  high values excluded
  Π_{lin} ~ 10-20 %
- Cannonball Model
  full range possible
  Π_{lin} = 0 - 100%
- Electromagnetic Model
  well defined, moderate
  Π_{lin} ~ 50 %
- To pin down the model large sample of bursts needed



From M.Lyutikov, 2003

See papers discussing various models: T.Piran, A.Dar, M.Lyutikov, D.Eichler, G.Ghisellini, D.Lazzatti, M.Medvedev, E.Rossi etc.

DETECTOR REQUIREMENTS

- Simple measurement of polarization with compact instrument
- Large area, large modulation factor and large field of view
- Optimized specially for GRB observations
- Relies on given burst position and spectrum (GCN / IPN, extra det.)
- Utilizes large angle Compton scattering and tolerates the small one
- Signal to background ratio carefully studied and optimized
- Measurements of CRAB etc. if S/C pointing stabilized

POLARIMETERS UNDER DEVELOPMENT

GRAPE Gamma Ray Polarization Experiment:
Low Z - high Z hybrid, 50-300 keV; last ver. AC;
M.McConnell et al., balloon flight next summer

PoGO Polarized Gamma-ray Observer:
phoswich of slow-fast units with AC, 30-100 keV;
T.Mizuno et al., designed for balloon flight

SGD Soft Gamma-ray Detector: Compton telescope
of Si-strips and CdTe pixels and AC, E<300 keV;
H.Tajima et al., planned for NeXT mission

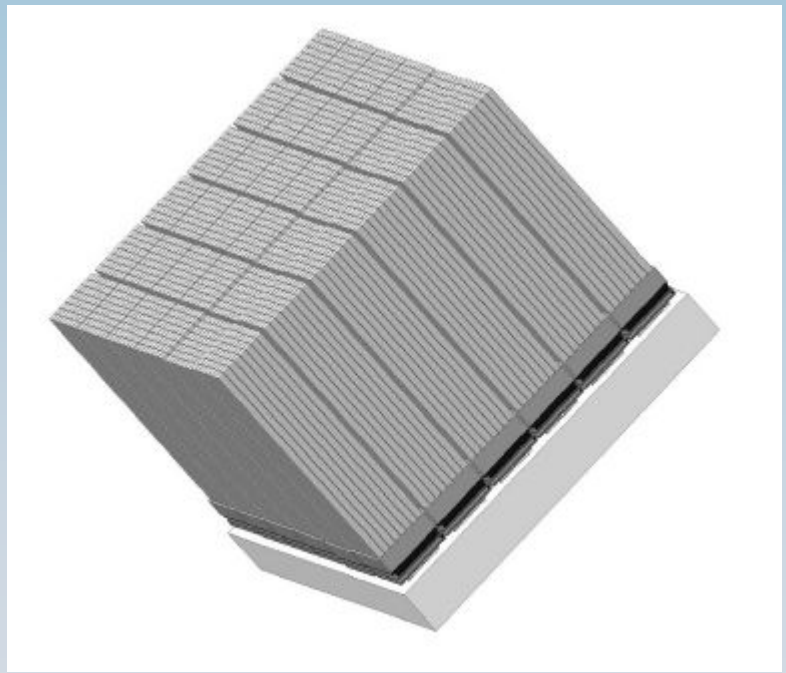
CIPHER Coded Imager and Polarimeter for High Energy Radiation:
CdTe array, E<1 MeV; R.Curado da Silva, follower of CACTμS,
planned for LobsterEye, SRG-II (?)

See other polarimeter projects e.g. SPIE, Orland'06 or COSPAR, Beijing'06!

POLAR DETECTOR

- 48x48 uniform scintillator array (scalable)
- Light, fast and low-Z plastic e.g. BC400
- Bar dimension 6x6x200 mm^3;
  fits new MAPM H8500
- Optical insulation and thin (≈ 1 mm) carbon fiber outside cover
- No active shielding; though outer layers can be used if needed

See Produit et al., NIM 2005, Hajdas et al., SPIE 2006



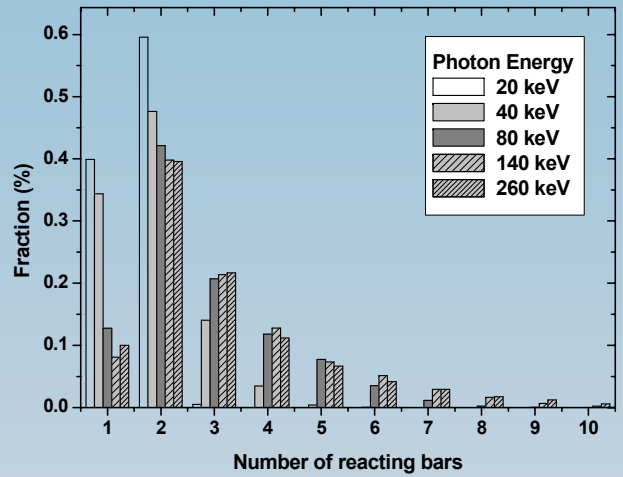
RESPONSE and TRIGGER CONCEPT

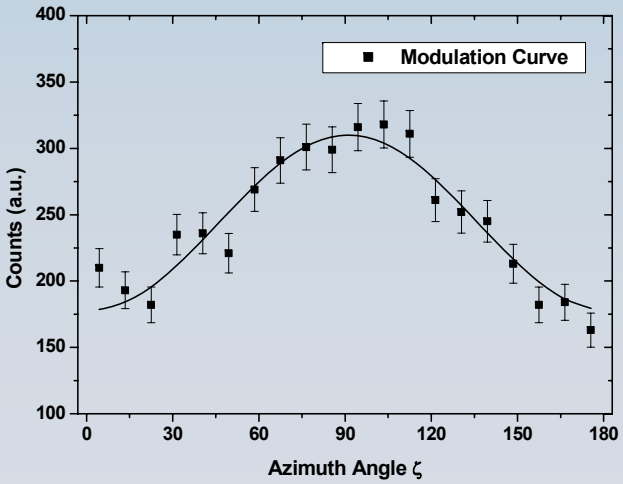
- Intensive GEANT4 MC modeling
- Threshold set at E_{min}= 5 keV
- Trigger activation: at least 2 channels

- Selection of two highest E deposits
- Reacting pixels define geometry
- Fit function:

$$N=A\cdot\cos(2(\xi-\xi_0)+\tfrac{1}{2}\pi)+B$$

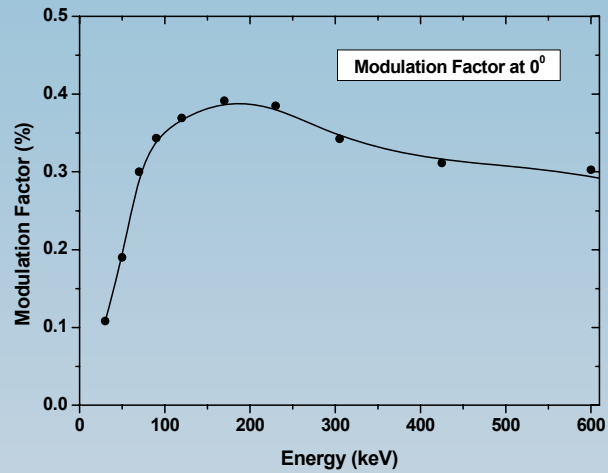
- Clear modulation signal

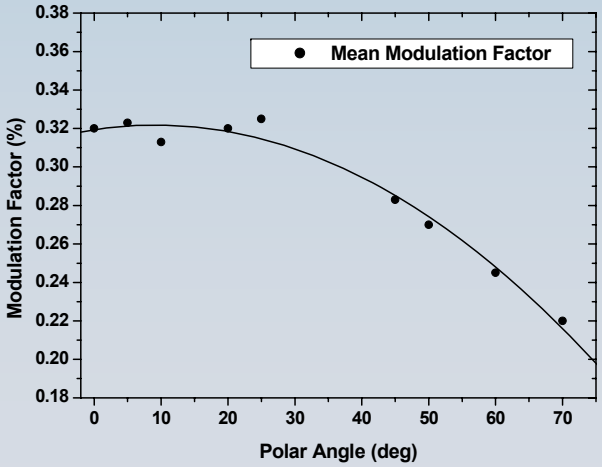




MODULATION FACTOR

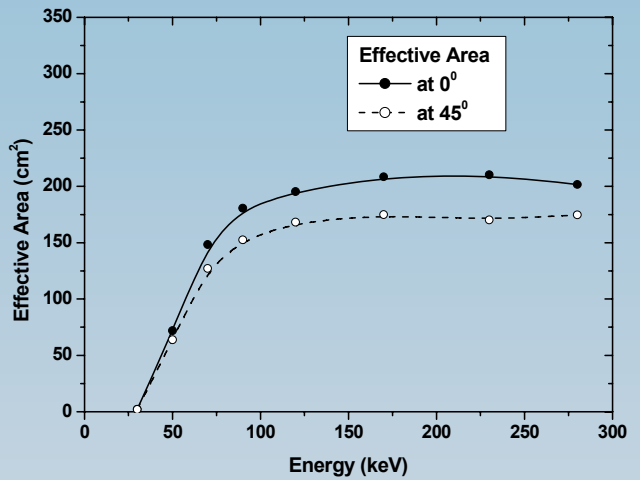
- Peak μ_{100} reaches about 40%
- High plateau between 100 and 250 keV;
- Lower energy threshold around 35 keV; no limits for higher one
- Constant values kept up to $\theta_\gamma = 30°$ for off-axis GRB
- 30% sky coverage possible
- μ_{100} values comparable with other polarimeters

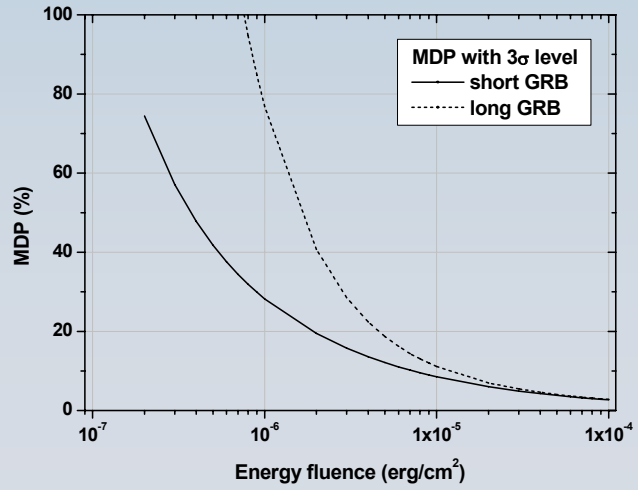




AFFECTIVE AREA and MDP

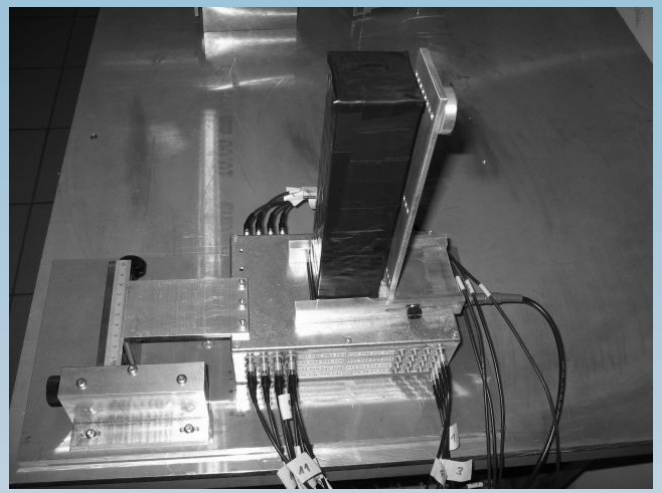
- Maximum effective area $\varepsilon \cdot A = A_{eff} \approx 160$ cm^2 for 6x6 mm^2 bars and Band-like spectrum (22% total area)
- MDP = $n_\sigma / \mu_{100} S \cdot \sqrt{(S+B)/T}$
- For E = 10^{-5} erg/cm^2 $\rightarrow$ $MDP_{3\sigma} \approx 10\%$
- Several such measurements per year !

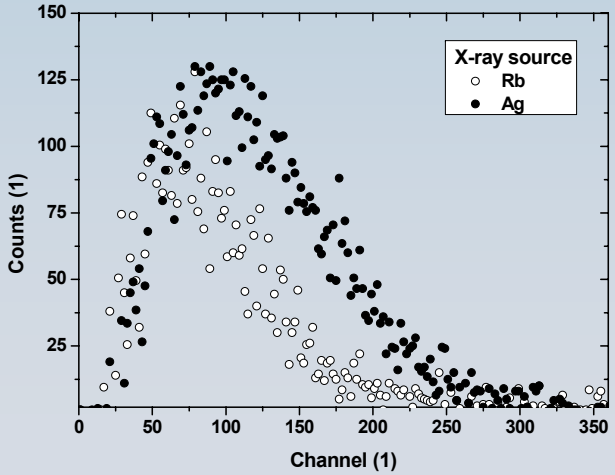




TESTS WITH 8x8 MAPMT

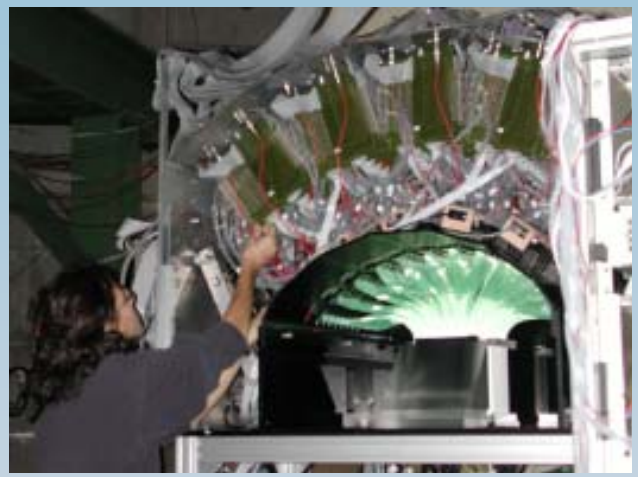
- Single modules assembly with 6x6x200 mm^3 BC400 plastics
- Teflon coating and Al foil isolation of each bar
- Coupling to H8500 8x8 MAPM (pitch 6 mm, anode size 5.8 mm)
- Mono-energetic fluorescence sources exposures (6-44 keV)
- Amplitude attenuation by 20% along bar length
- Threshold 5 keV feasible



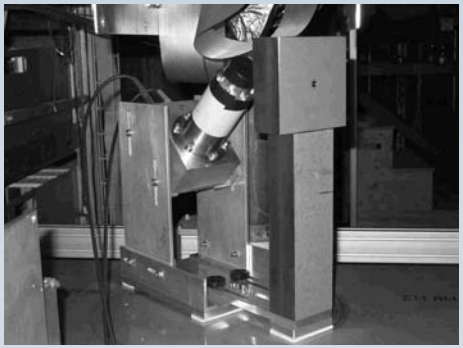


ONGOING: FAST, SLS and DM

- FAST equipment ideal for POLAR tests
- Detector equivalent to smaller POLAR:
  - 12.8 x 19.2 x 20 cm^3 scintillator array
  - 1536 BC400 bars (4 x 4 x 200 mm^3)
  - 96 H6568 MAPM
- DAQ: FD, TAC, event-by-event;
  polarized γ-rays, beam time Oct 06



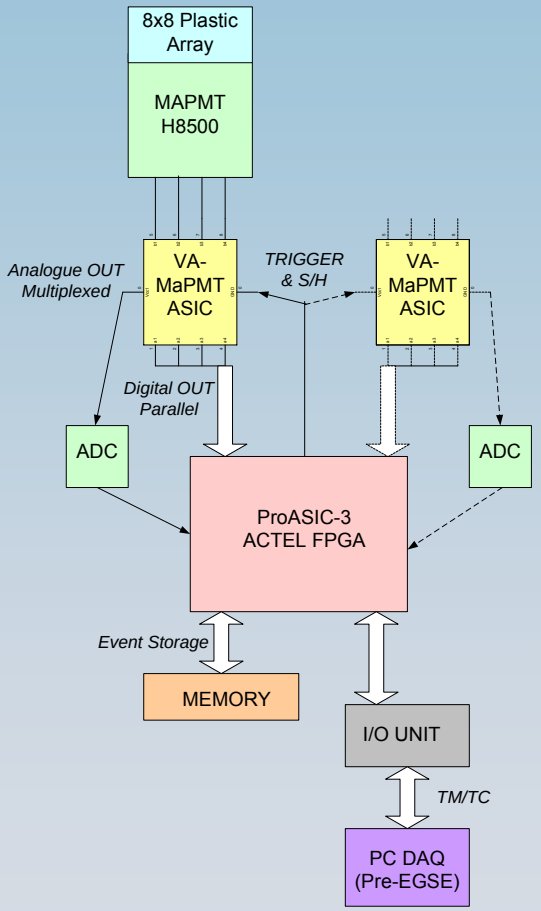
- PSI SLS synchrotron with polarized γ-rays
- Various energies up to many tens keV



- Prototype demonstration model DM with 8x8 pixels construction at PSI (DL December 06)
- Representative readout electronics and protoGSE

FLIGHT OPPORTUNITIES, FINANCING, PDR

- POLAR proposed to Indian Space Research Organisation (ISRO) for Small Astrophysical Payload; Decision November 2006
- Beijing Institute for High Energy Physics proposed POLAR for Chinese SpaceLab TianQong-2 with launch in 2010
- Preliminary Design Review and Acceptance by March 2007
- Proposal for SNF submitted for POLAR EM; budget for FM with SSO, ESA and partners



SUMMARY

- RHESSI is very efficient detector of GRBs with about 400 events to date
- Polarimetric capabilities of RHESSI are weak – no limits on Π_{GRB} yet
- Other instruments reported isolated GRB with high Π_{GRB} but large errors
- Several new polarimeters are either under development or construction
- POLAR is compact hard X-ray GRB polarimeter using Compton scattering
- Based on low Z scintillator array; has wide FOV, large A_{eff} and μ_{100}
- It will measure Π for hundreds of GRBs and for ca. ten/year $MDP_{3\sigma} \approx 10\%$
- Several lab tests completed, more ongoing, 8x8 array+GSE DM by Dec
- Financing for EM requested from SNF; FM from SSO and partners
- POLAR proposed for Indian Astro-Mission and China SpaceLab (2010)