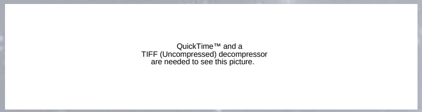
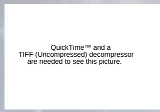
PoET: Polarimeters for Energetic Transients

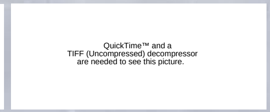
Mark McConnell (UNH)
Scott Barthelmy (GSFC)
Joe Hill (USRA)

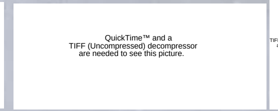
POET Science Team

Lorella Angelini	Taka Sakamoto
Matthew Baring	Bing Zhang
Peter Bloser	Kunihoto Ioka
Brian Dennis	Takashi Nakamura
Gordon Emslie	Yamazaki Ryo
Alice Harding	Kenji Toma
Dieter Hartmann	Zuefeng Wu
Phil Kaaret	Jochen Greiner
Robin Morris	Wojtek Hajdas
Jim Ryan	Gottfried Kanbach
Don Kniffen	Nicholas Produit
Anita Krishnamurthi	Toru Tamagawa





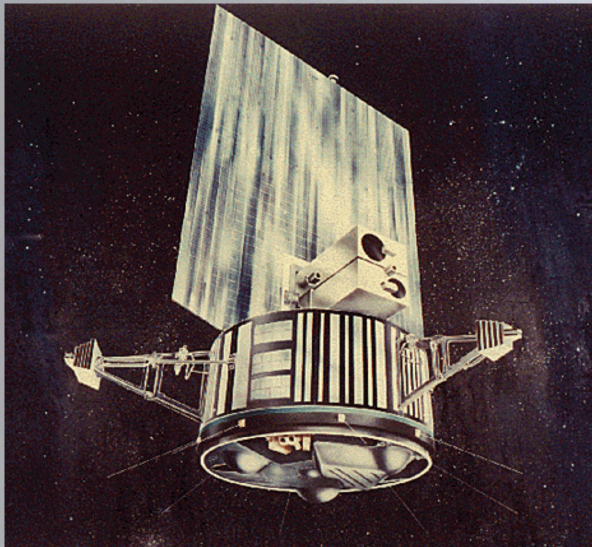




Overview

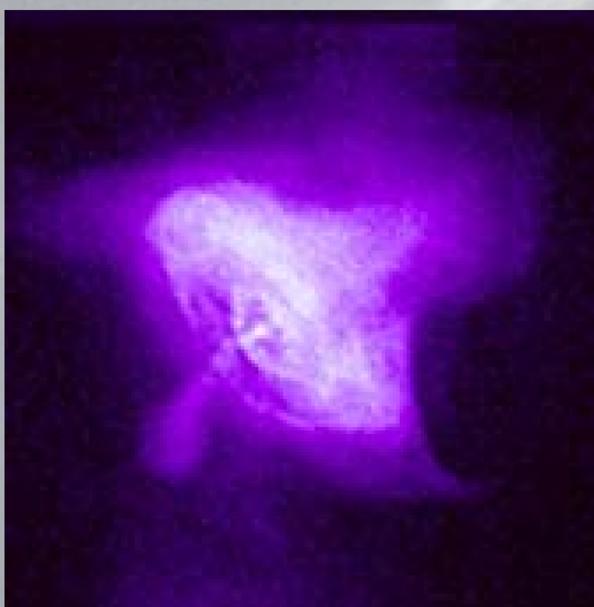
- GRB Polarimetry Science
- POET mission
  - GRAPE
  - LEP
- POET Performance
- What Now?

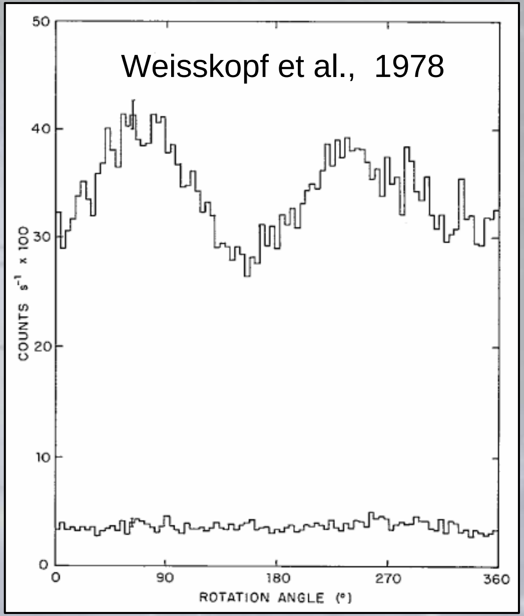
Quest for the holy grail



- X-ray polarimetry will be a valuable diagnostic of high magnetic field geometry and strong gravity…..

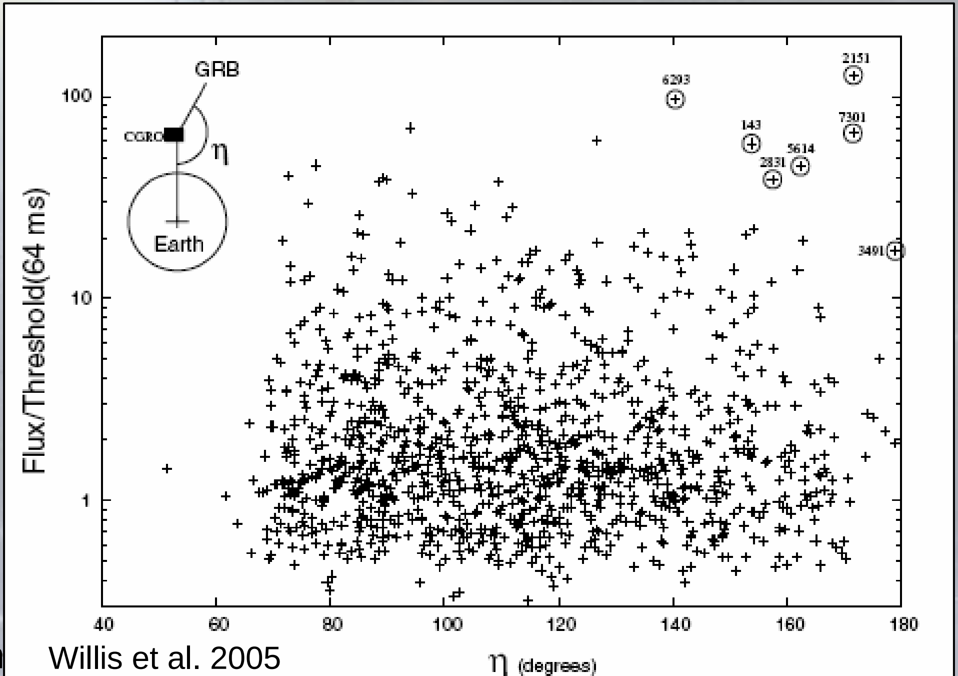
- One definitive astrophysical measurement (1978) at two energies
  - Weisskopf et al.
  - P=19.2% $\pm$1.0%
  - @ 156°





Other Measurements

- Intercosmos (Tindo)
  - Solar Flares
- Rhessi (Coburn & Boggs)
  - GRB 021206
- BATSE Albedo Polarimetry System (Willis)
  - GRB 930131 P>35%
  - GRB 960924 P>50%
- INTEGRAL (2 groups)
  - 2σ result
  - $98 \pm 33\%$



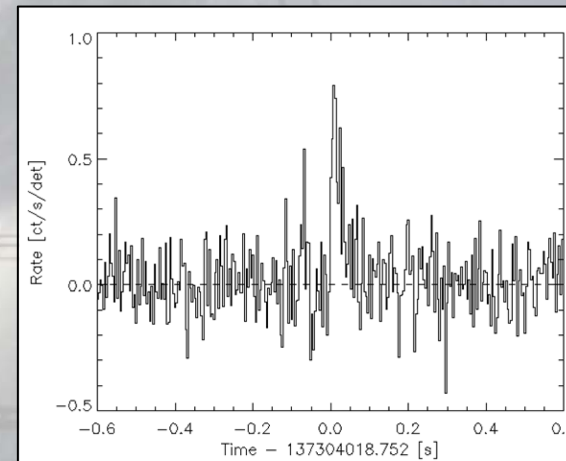
Willis et al. 2005

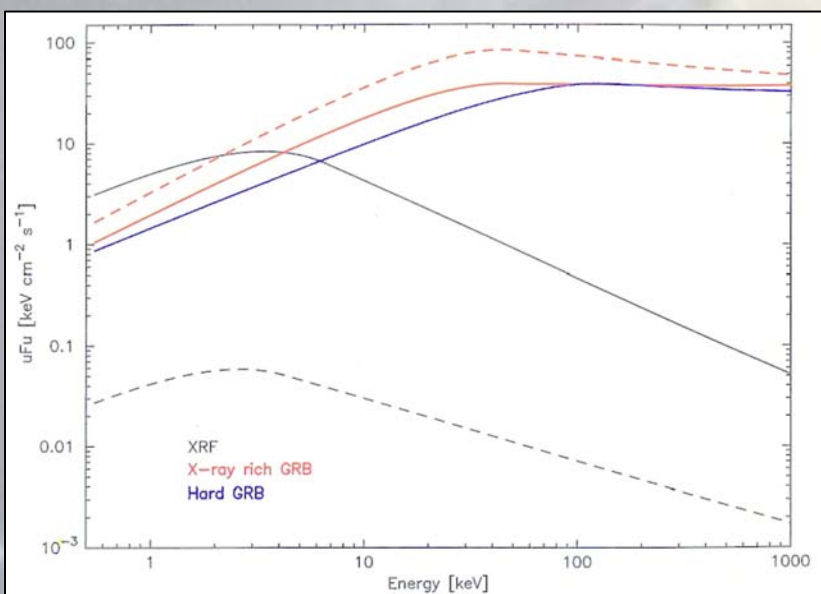
Current Status

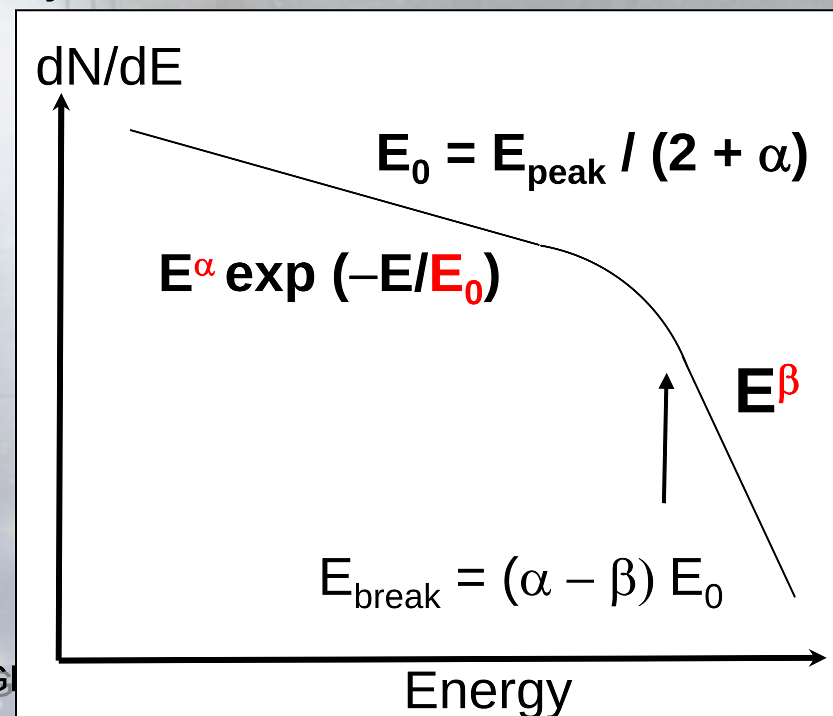
- Recent instruments have not been optimised for polarimetry…
  - …or never launched
- Gazillion papers describing the importance
- Need a way to break the cycle
  - new techniques have lowered the technical barriers

Observed **Prompt** GRB Properties

- High variability: ~ms
- Prompt Spectrum:
  - Band Function: $\alpha \approx -1 \pm 1 \quad \beta \approx 2^{+1}_{-2}$
- Huge release of energy: ~10^{51} erg
- Relativistic process to avoid pair-production opacity paradigm
- Achromatic steepening implies GRB jet

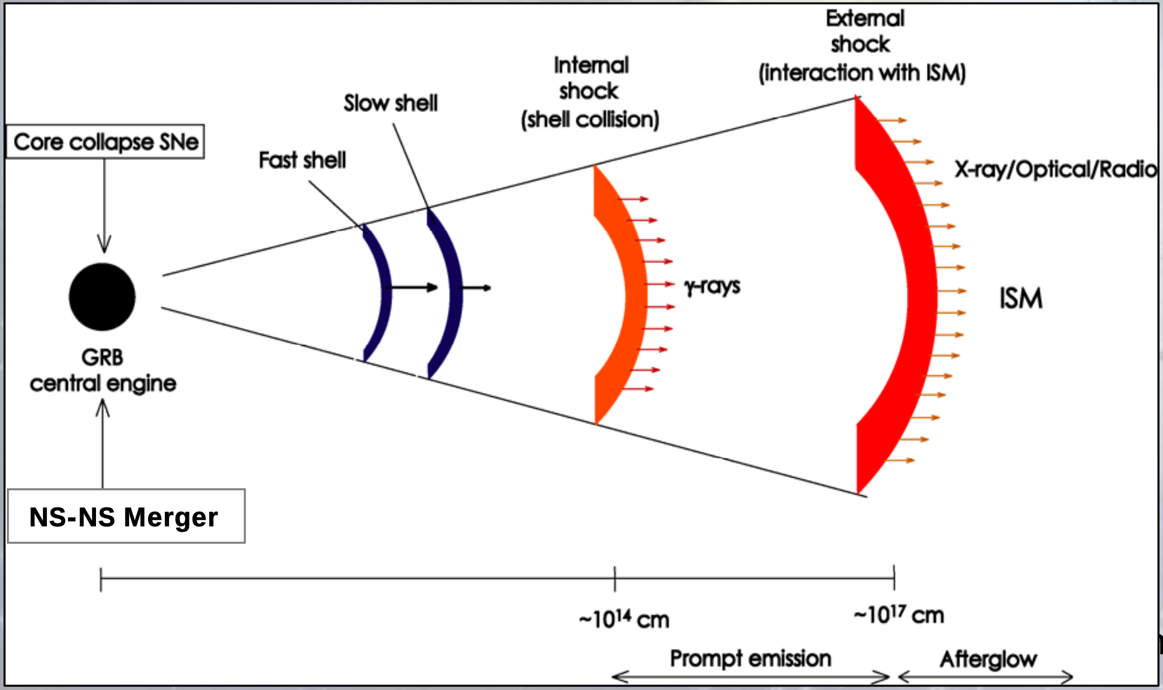




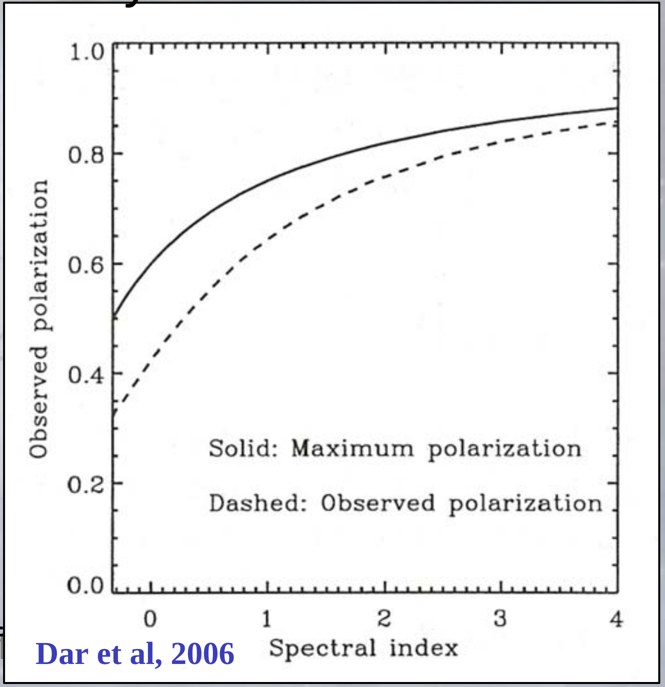


Standard Fireball Model

- Explains the late afterglow observations well
- Debates for prompt emission on-going
  - Internal shock model solves the rapid variability problem
  - Energy has to be extracted from KE of shells
    - Low efficiency
    - Requires additional mechanisms

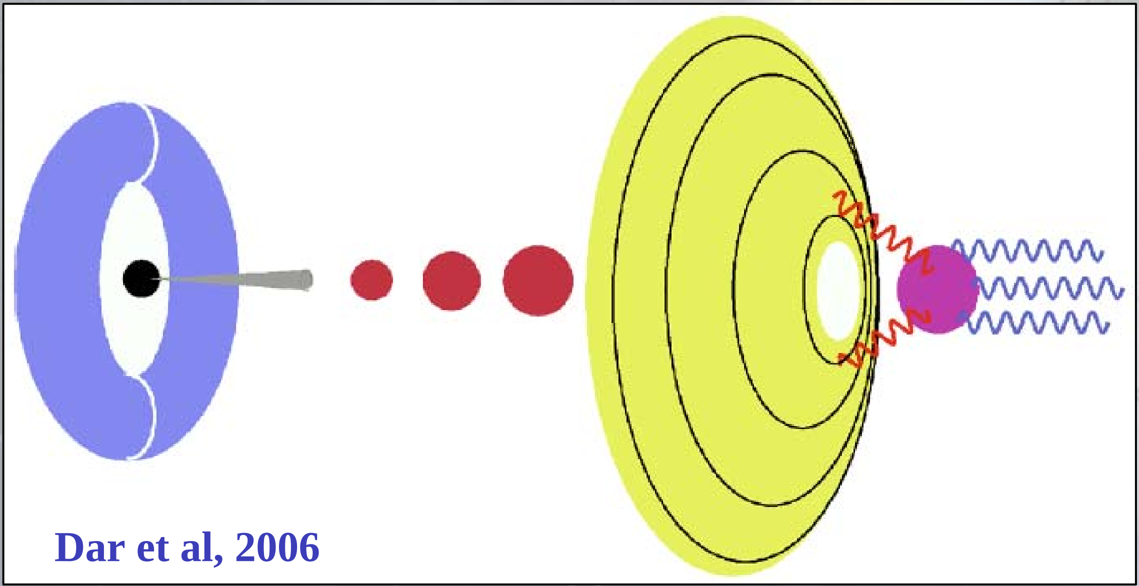


Synchrotron Emission

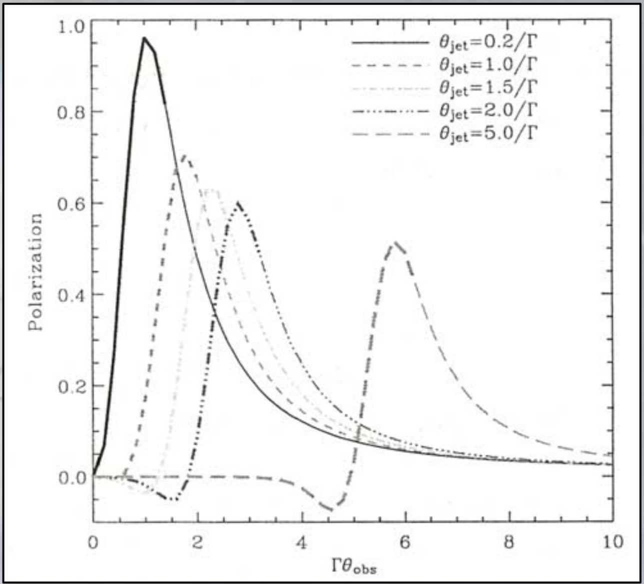


Cannon-ball model

Cannon balls ejected from central engine
Inverse Compton scattering of ambient photons
Unclear how the cannon balls would survive acc^n
over large dynamic range and Lorentz factors



Dar et al, 2006

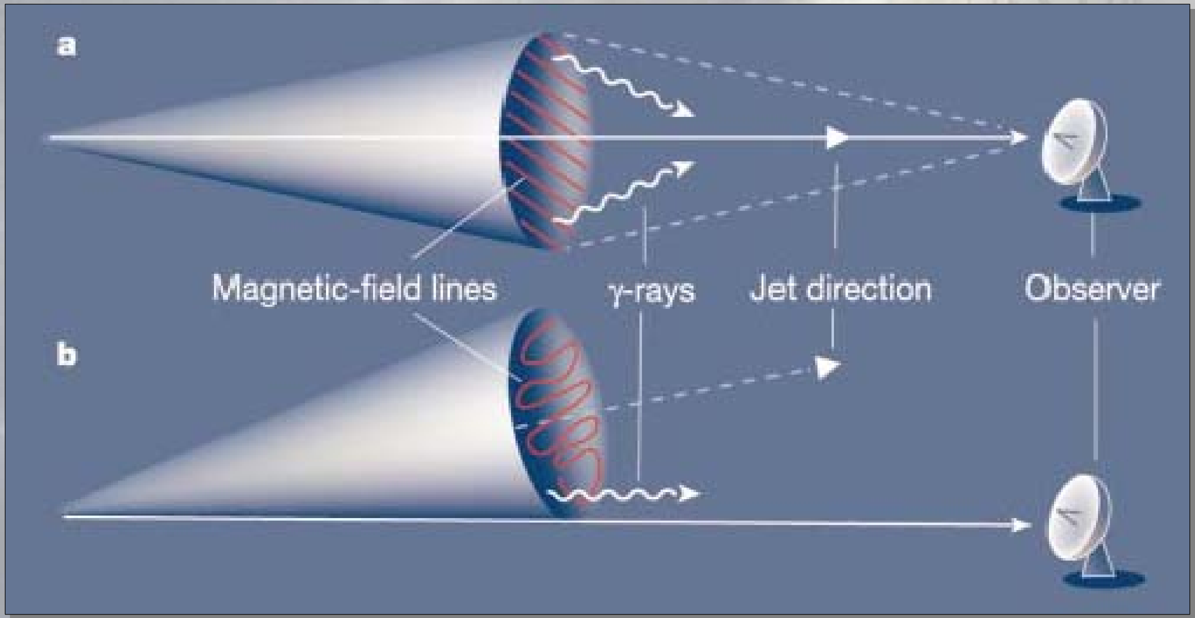


GRB Unknowns

- Unknown Fire Ball content
  - Kinetic energy or magnetically dominated
- Unknown location of ‘where’ the prompt emission is produced
  - Internal Shocks - favored
  - External Shocks
- Unknown dissipation mechanism
  - Shocks
  - Magnetic reconnection
- Unknown radiation mechanism
  - Synchrotron
  - Comptonization
  - Etc

Motivation for POET

- ☞ What is the magnetic structure of the jets?
- ☞ What is the geometric structure of GRB jets?
- ☞ What is the prompt radiation mechanism of GRBs?



Physical Model

Geometric model

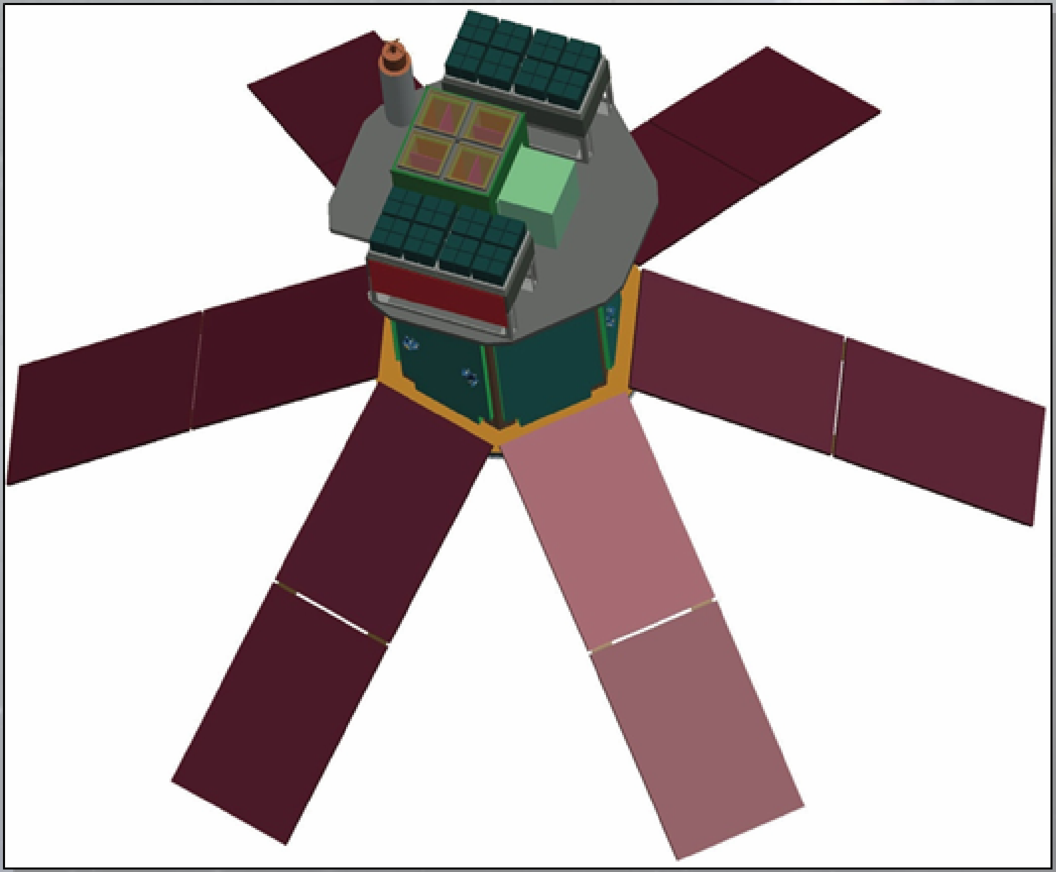
Waxman, Nature, 2003

Polarization Predictions

- ☞ The theories on the GRB production mechanism can be constrained by different degrees of linear polarization (P):
  - ☞ P>~80% Generally difficult to achieve within synchrotron emission models. Could be Compton scattering jet viewed from outside the edge of the jet
  - ☞ 20%<P<60% is predicted if synchrotron emission in an ordered B-field or as a result of viewing the burst from near the edge of the jet
  - ☞ Low degrees of polarization can be expected can be expected from hydrodynamical models in which the random magnetic fields are generated in the shocks with an on-beam viewing geometry

POET - Proposed SMEX Mission

POET - POlarimeters for Energetic Transients



Institutional Responsibilities
University of New Hampshire
PI : Mark McConnell GRAPE Instrument
Universities Space Research Association
Deputy PI : Joanne Hill LEP Instrument
Goddard Space Flight Center
Mission Scientist : Scott Barthelmy Mission Operations Center (MOC) POET Data Center (PDC) Data Archive (HEASARC)
Charles S. Draper Laboratory
Project Management Mission and Systems Engineering Safety and Mission Assurance
ATK Space, Inc
Spacecraft Bus Observatory Integration and Test

POET Science Goals

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POET GRB Science

POET will answer questions about GRBs that can only be answered by X-ray and Gamma-ray polarisation measurements

- What is the composition of GRBs?
- What is the prompt radiation mechanism?
- What is the small-scale geometry of the prompt emission region?

POET Characteristics

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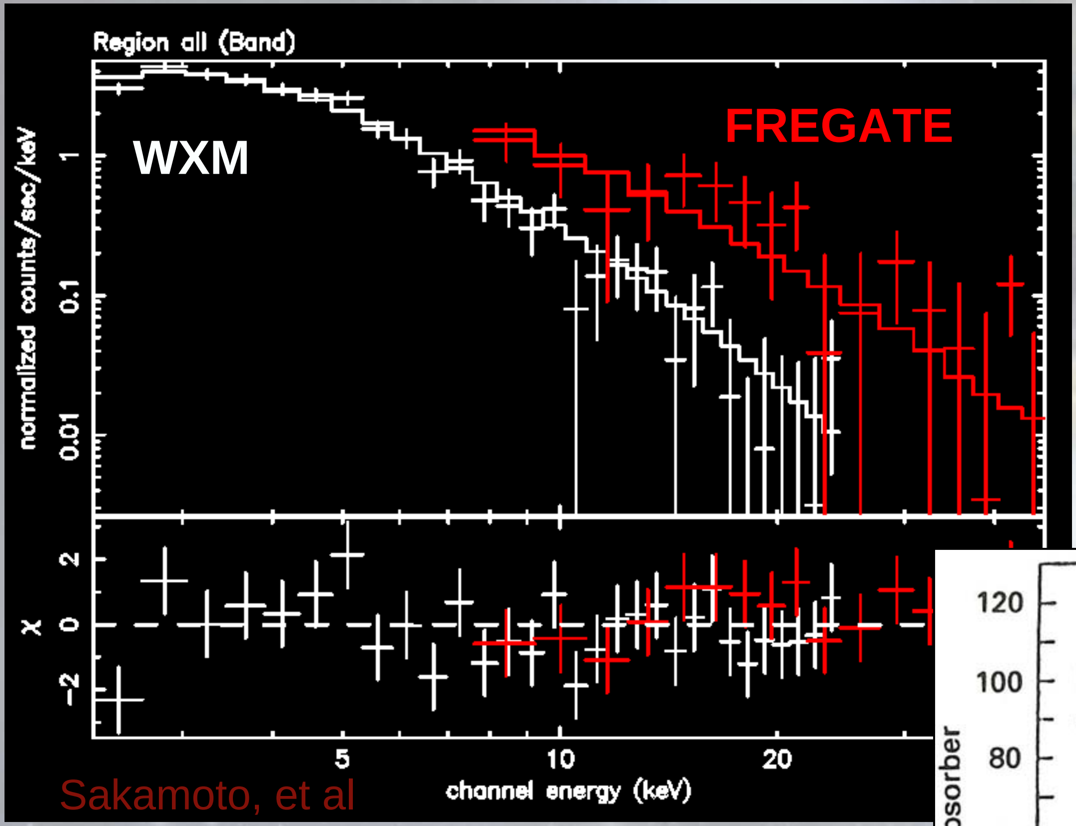
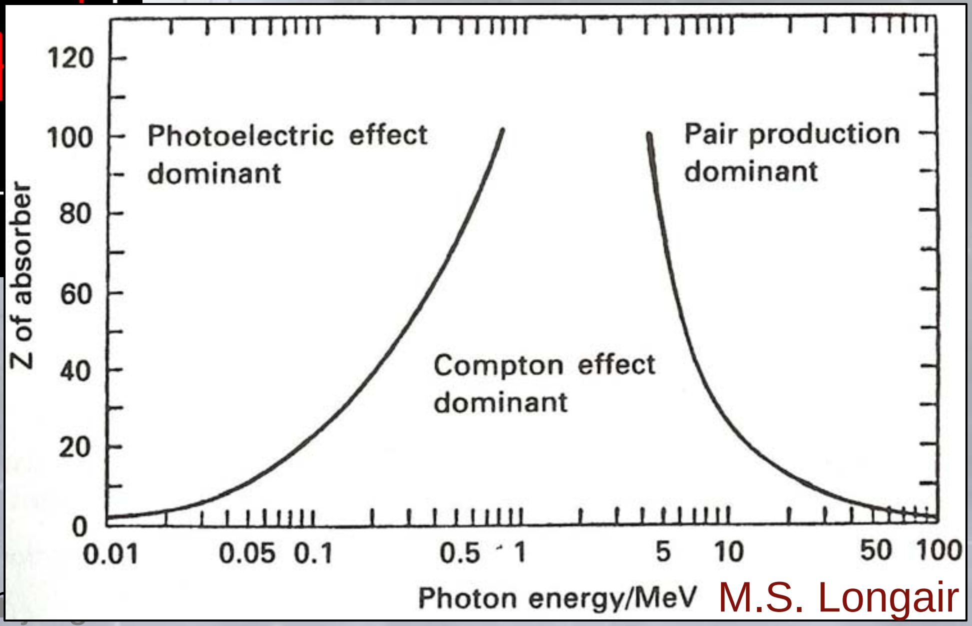
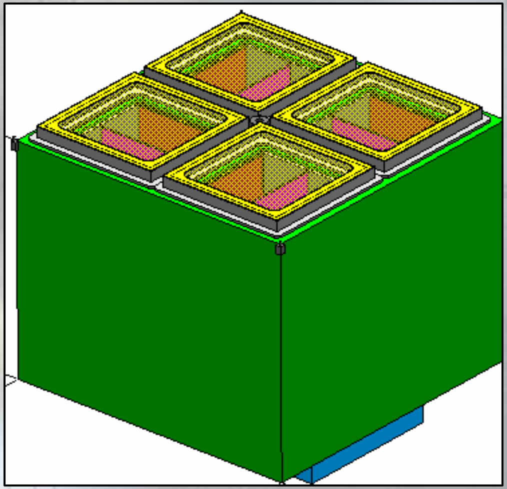
POET Characteristics



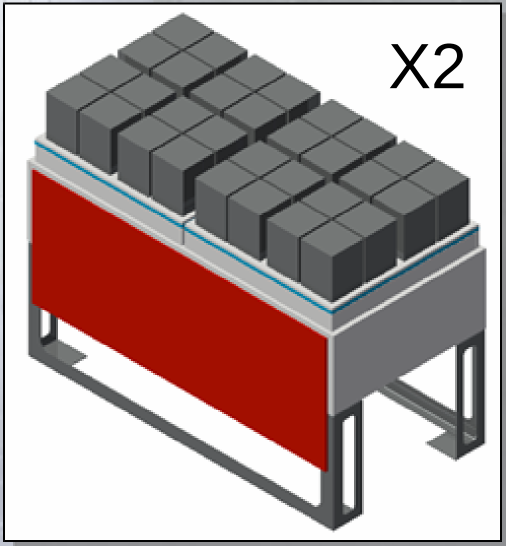


POET Instrument Suite

LEP Parameters	
Polarimetry	2-15 keV
Detectors	$Ne:CO_2:CH_3NO_2$ Gas (8)
Spectroscopy	2-15 keV
Field-of-View	±44° (non-imaging)



GRAPE Parameters	
Polarimetry	60-500 keV
Detectors	BGO/plastic scintillator (62)
Spectroscopy	15 keV - 1 MeV
Detectors	NaI(Tl) scintillator (2)
Field-of-View	±60° (non-imaging)



X-ray and Gamma-ray Polarimeters

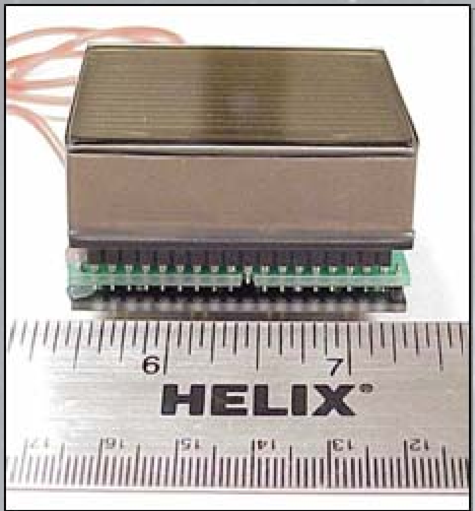
- Capitalize on: correlation between the incident photon electric field vector and the photoelectron emission direction or scattered photon direction

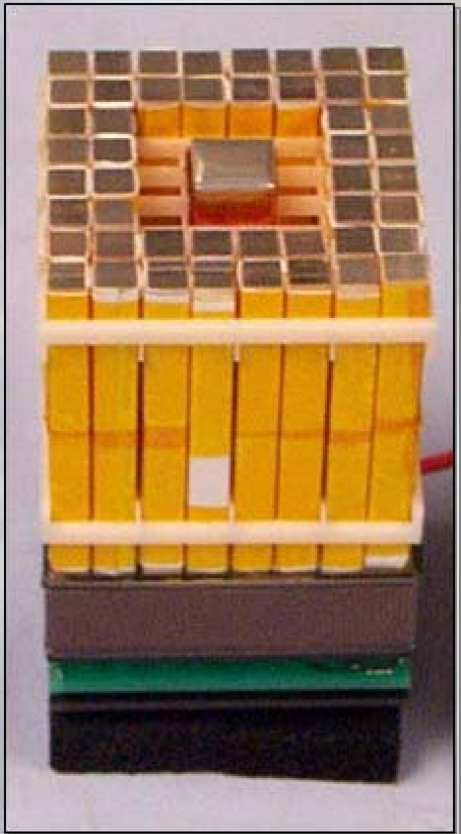
- Fit function to the angular distribution

- Modulation Factor, μ:

$$\mu = \frac{N_{\max} - N_{\min}}{N_{\max} + N_{\min}} = \frac{B}{2A + B}$$

GRAPE Prototype





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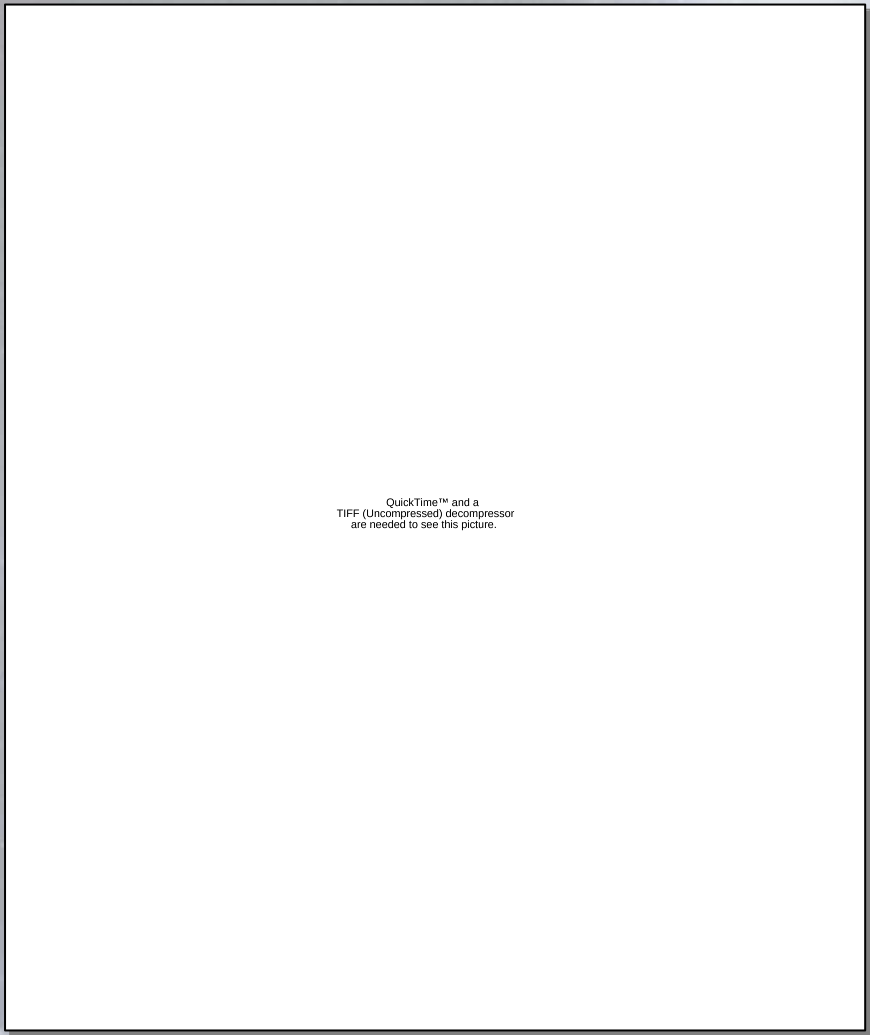
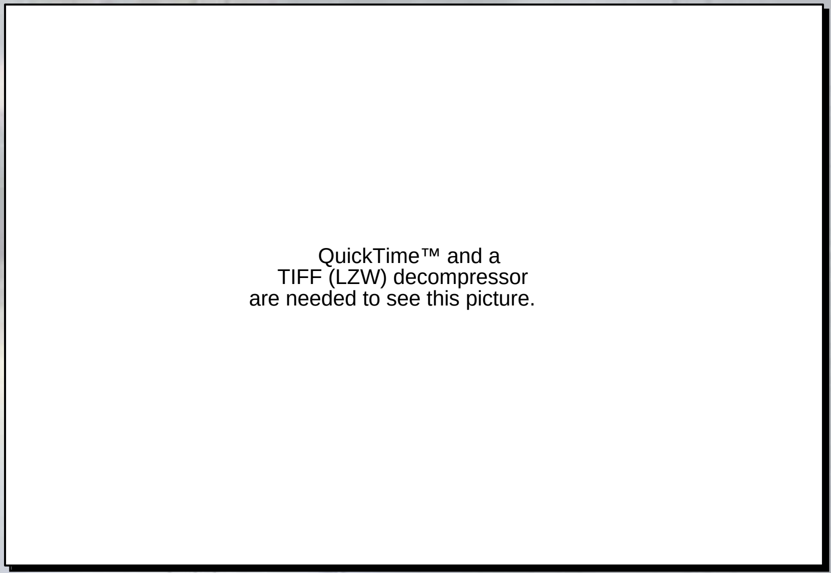
Based on use of flat panel PMT.

Grape Performance

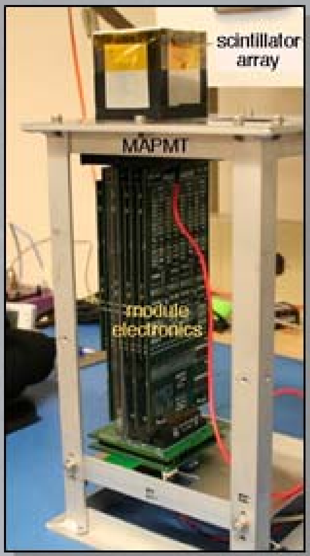
Legere et al., Proc. SPIE, 5898, 413 (2005)

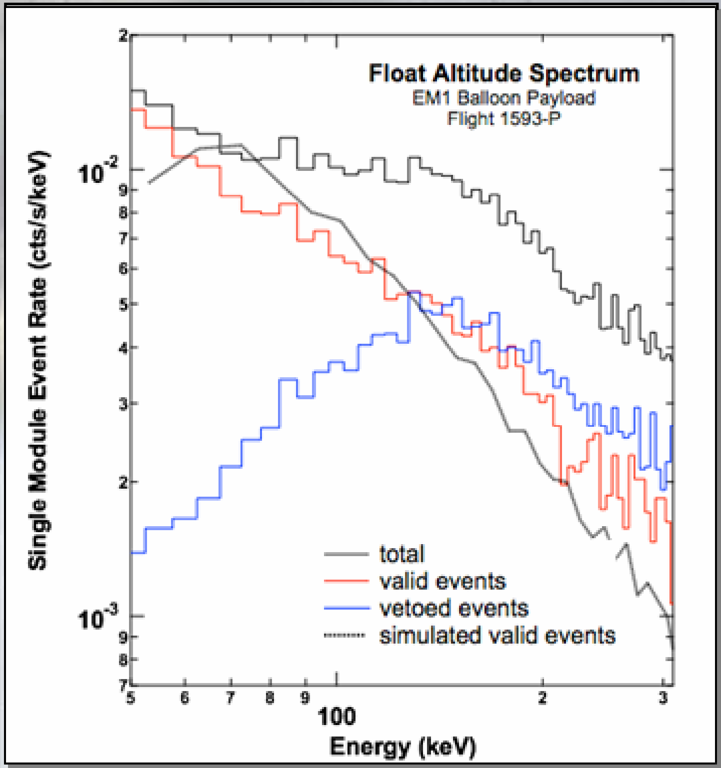




- μ=33%@69keV
- μ=44% @129keV
- Wide FoV and off-axis uniformity

GRAPE Engineering Balloon Flight





Balloon flight of an engineering prototype on June 21, 2007.

Measured background with (preliminary) simulated background.

POET-GRAPE

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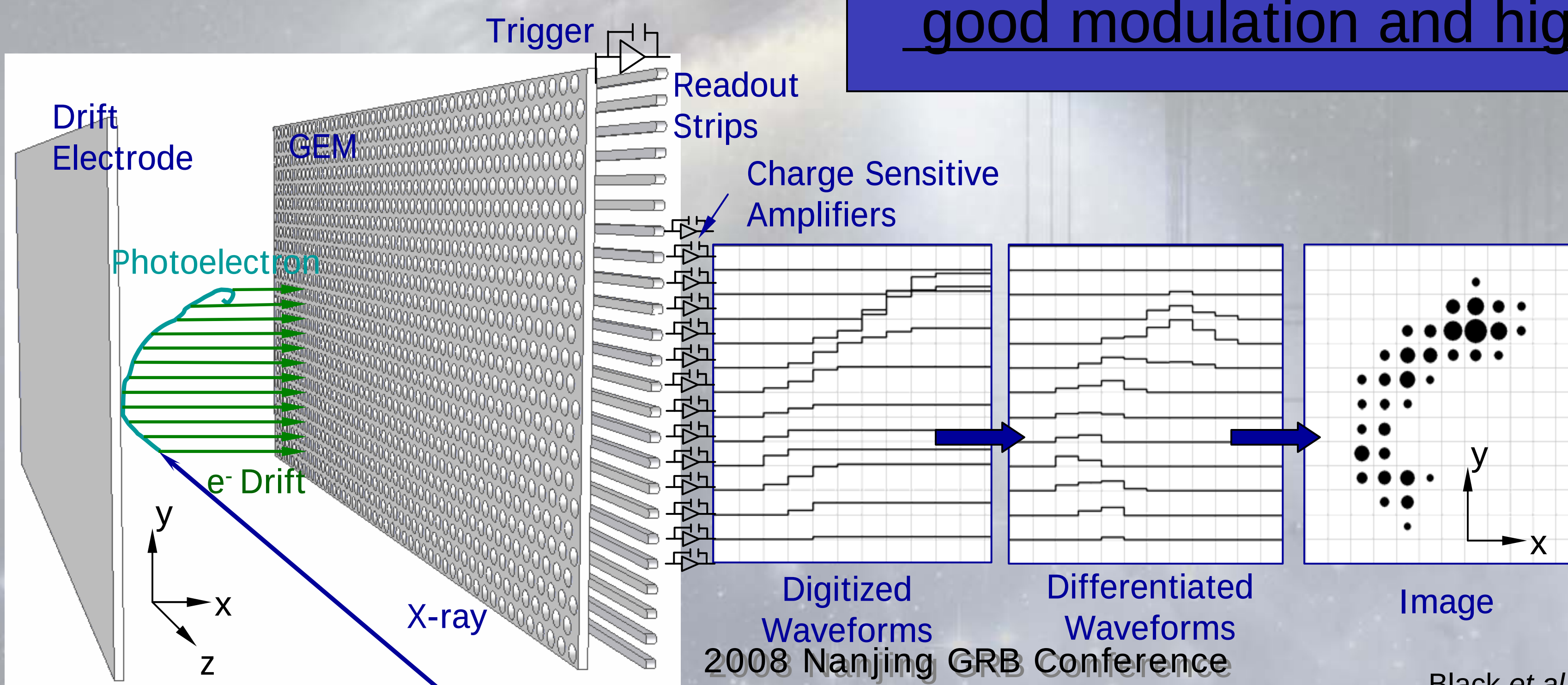
The TPC Polarimeter

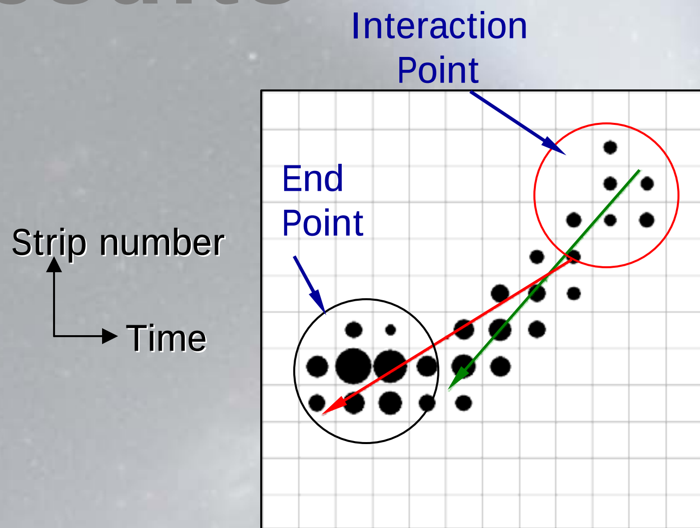
- GEM with strip readout
  - Track images formed by time-projection by binning arrival times
- Resolution is (largely) independent of the active depth
  - Max depth determined only by degree of X-ray beam collimation

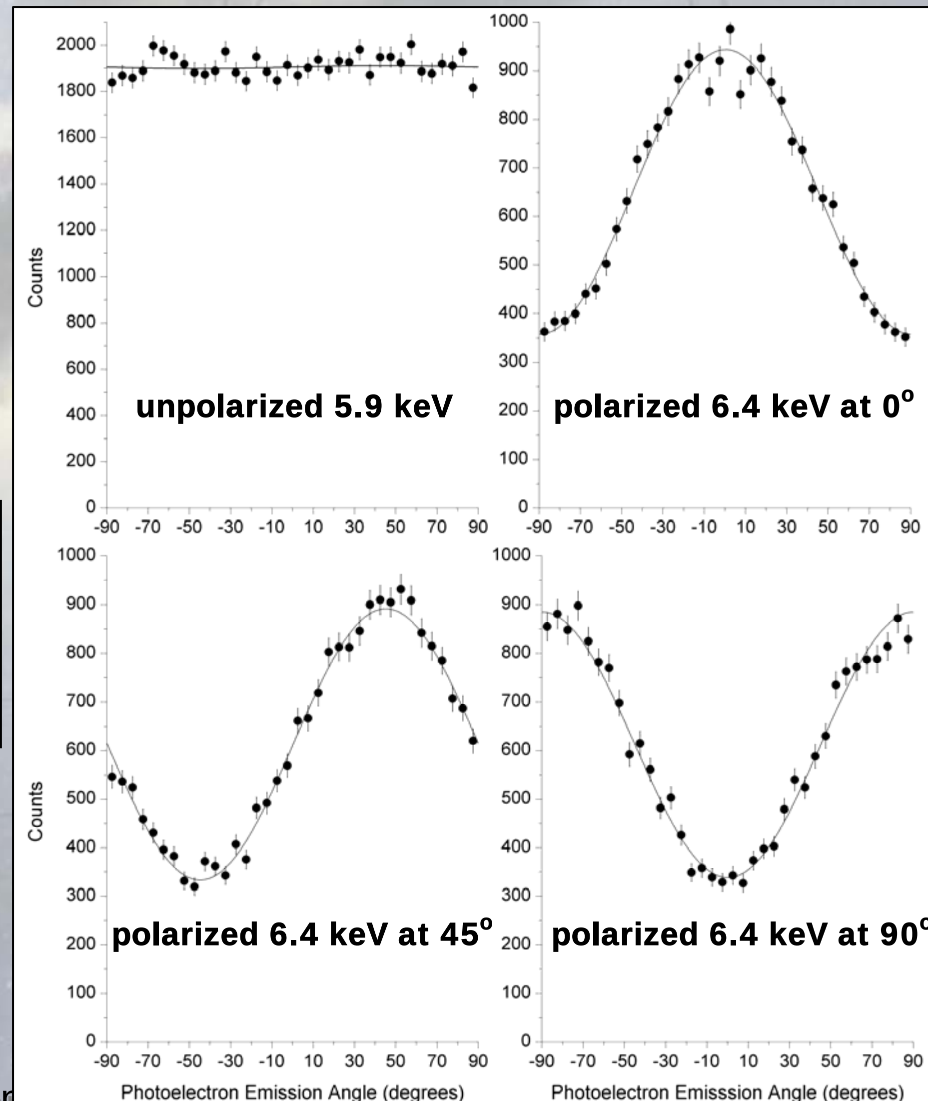
<u>good modulation and high QE</u>



Black *et al, NIM A, 2007*

Prototype TPC Polarimeter Results



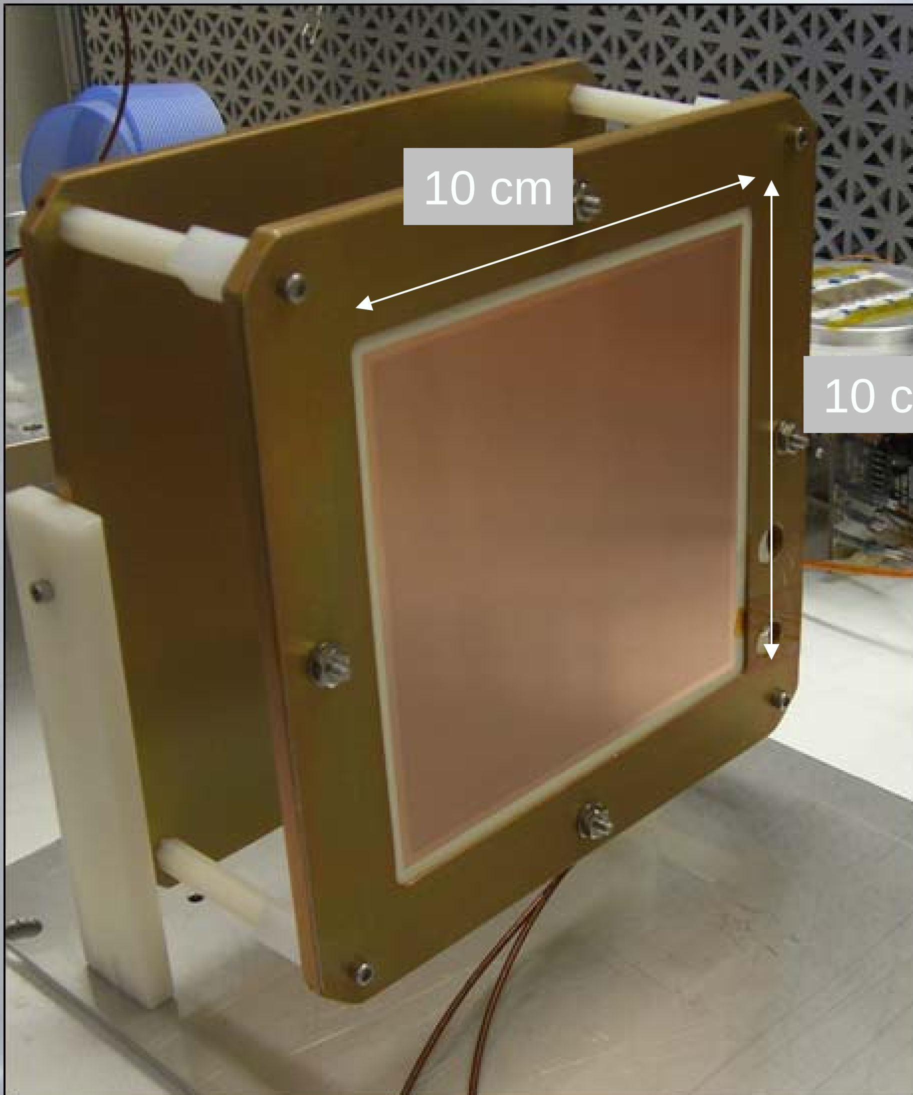


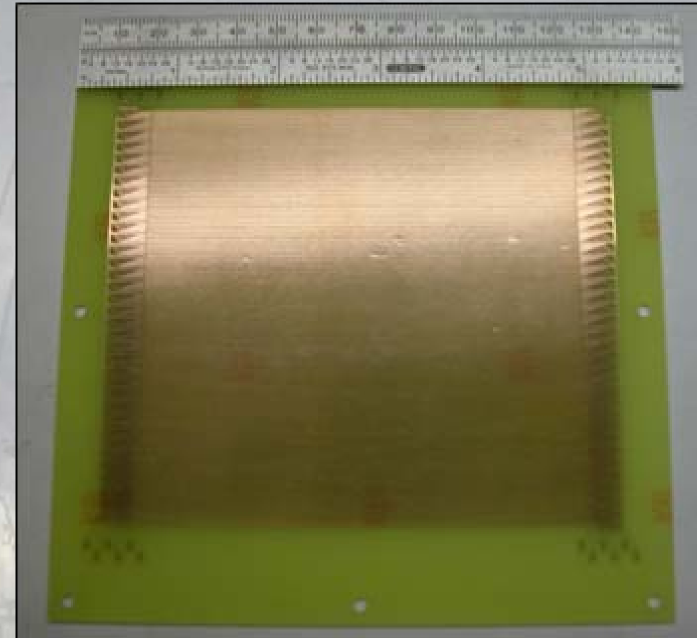
Polarization Phase	Measured Parameters		
	Modulation (%)	Phase (degrees)	χ_ν^2
unpolarized	0.49 ± 0.54	44.6 ± 28.7	1.2
0°	45.0 ± 1.1	0.3 ± 0.6	1.1
45°	45.3 ± 1.1	45.2 ± 0.6	1.0
90°	44.7 ± 1.1	-89.9 ± 0.6	1.4

- Uniform response
- Modulation consistent with gas pixel detectors
- Unit QE possible

Black *et al, 2007, NIM A, 581, 755*

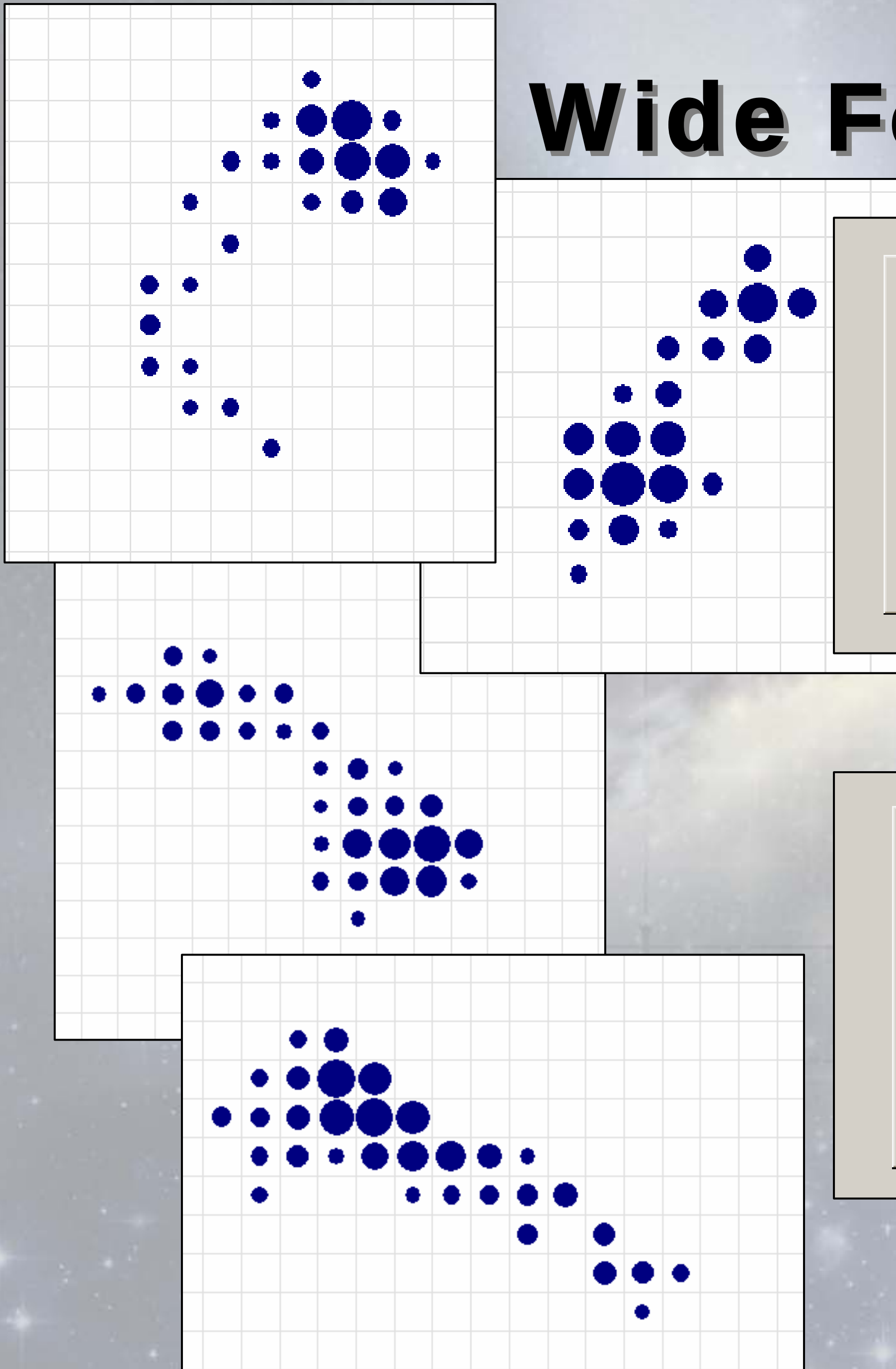
Wide FoV Prototype

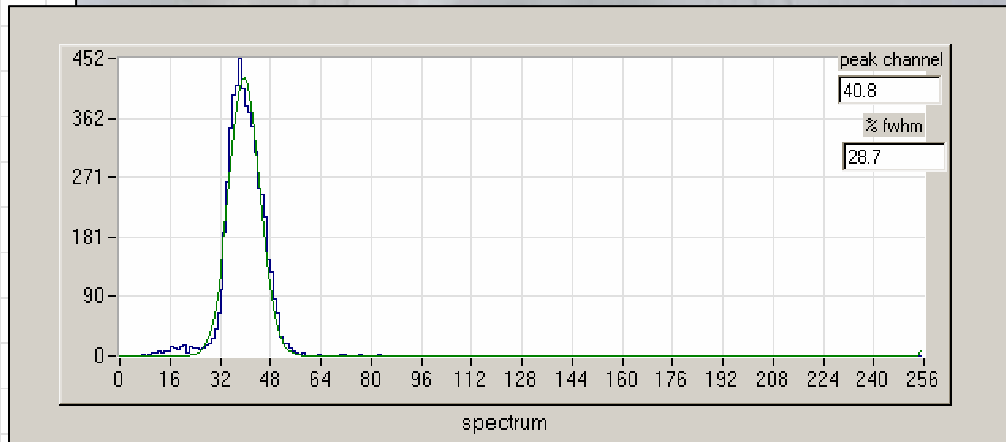




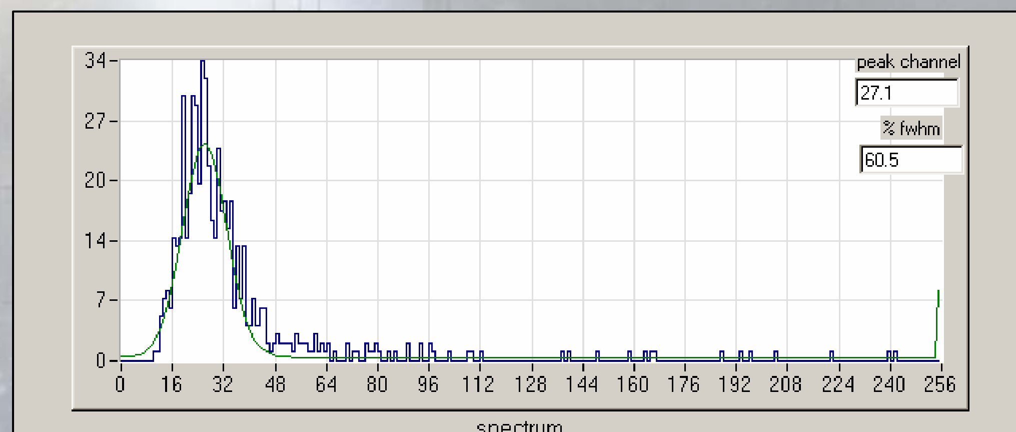
Parameter	Value
Active Element	$Ne:CO_2:CH_3NO_2$
Active Volume	24 x 24 x 24 cm^3
Pressure	780 Torr
Energy Range	2-15 keV
Energy Resolution	38% at 6keV
μ @ 6 keV	45%
Field of View	$\pm 44^\circ$
Mass	28.5 kg
Power (peak/ave)	33/31 W
Data Volume	248 MB/day
Temperature Range	25 $\pm$ 1 $^\circ$C / -10 to 50 $^\circ$C
Peak Sensitivity	~3.5 keV

Wide FoV Prototype





Spectra: Ne:CO_2



Spectra: Ne:$CO_{2:}CH_3NO_2$

Mission Concept

Mission Parameters	
Launch Date	May, 2012
Launch Vehicle	Standard SMEX
Orbit	600 km, 28.5° incl.
Mission Lifetime	2+ years
Pointing Mode	Zenith-pointed
Spin Rate	15 rpm

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POET Spacecraft

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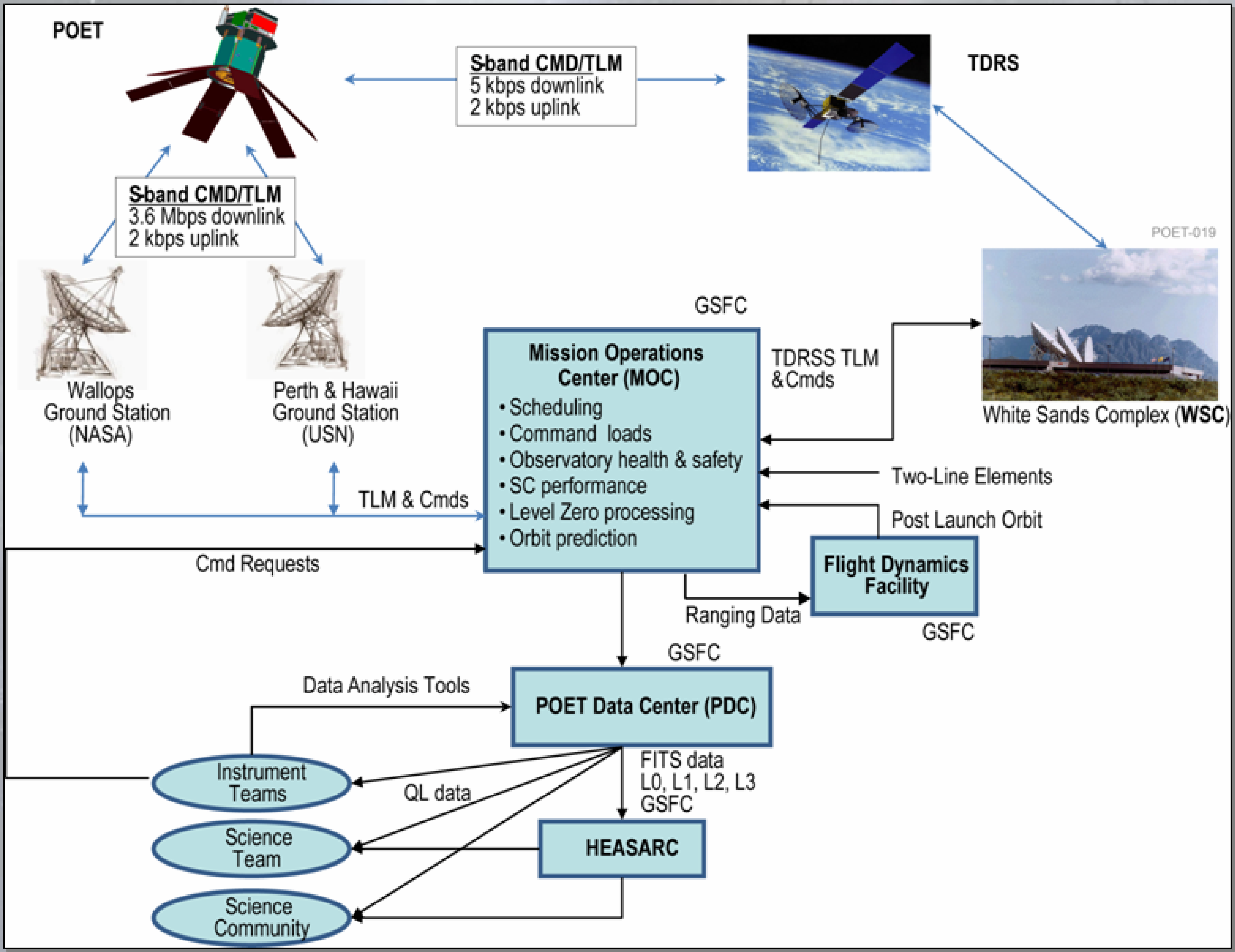
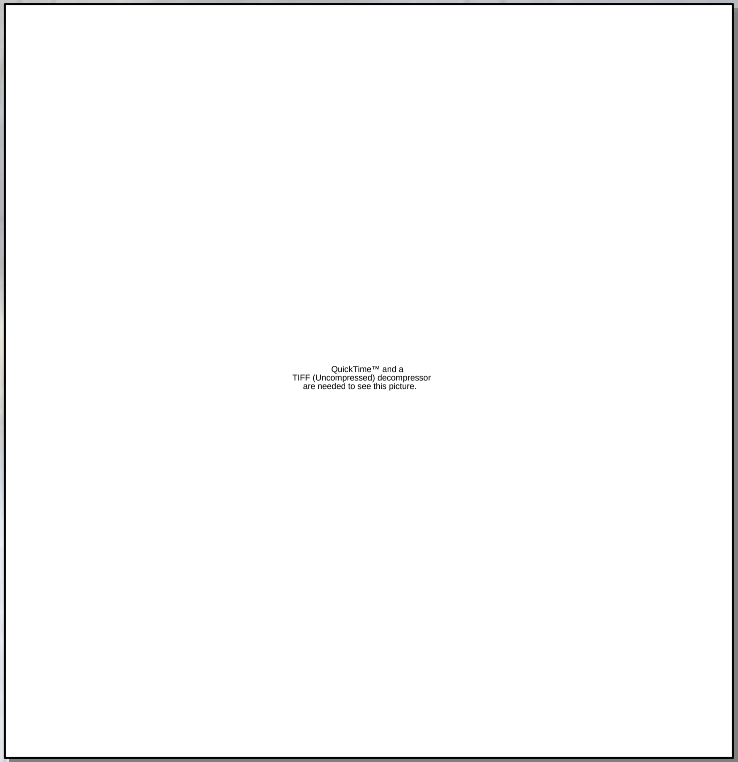
POET Mission Operations

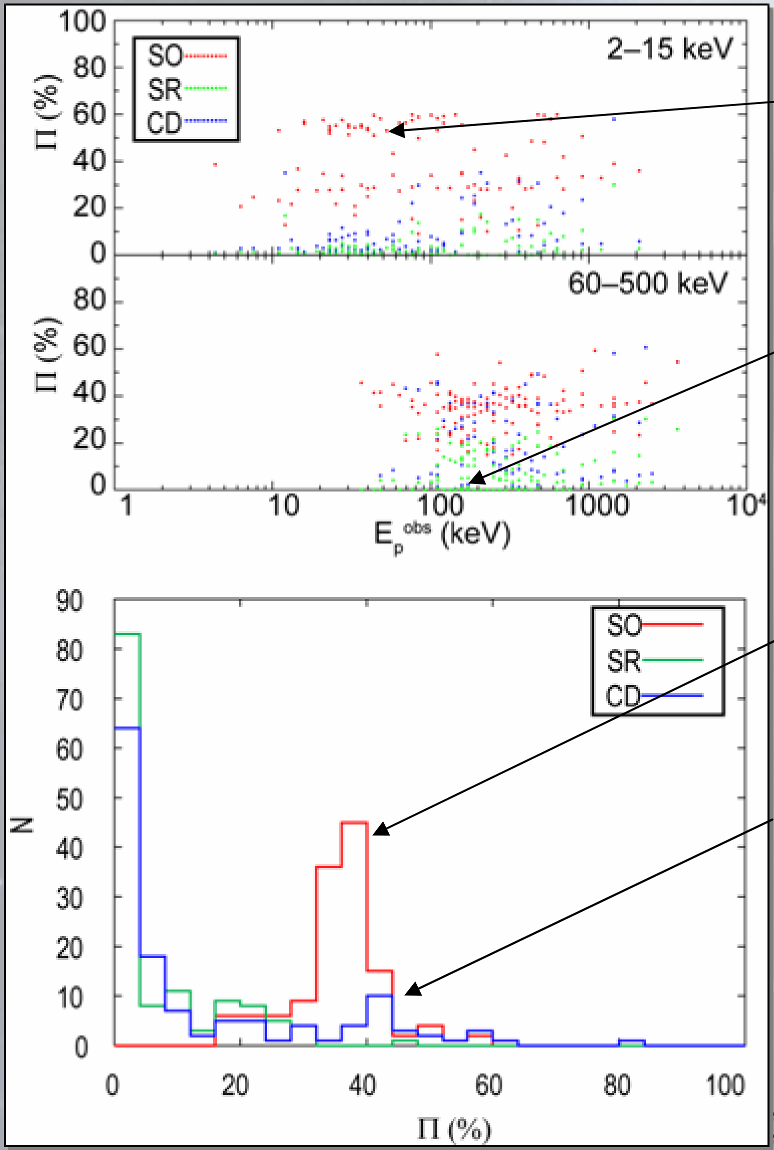


POET Performance



# GRBs S/N>5		# GRBs Ep	
LEP	99%	<10keV	20%
GRAPE	80%	<20 keV	50%
LEP+GRAPE	78%	0.2-1 MeV	~100%

Distinguish GRB Models



Physical Model

Ordered B-field

Geometric Model

Optimum viewing factor

Physical Model

Synchrotron Emission

Ordered B-field

Geometric Model

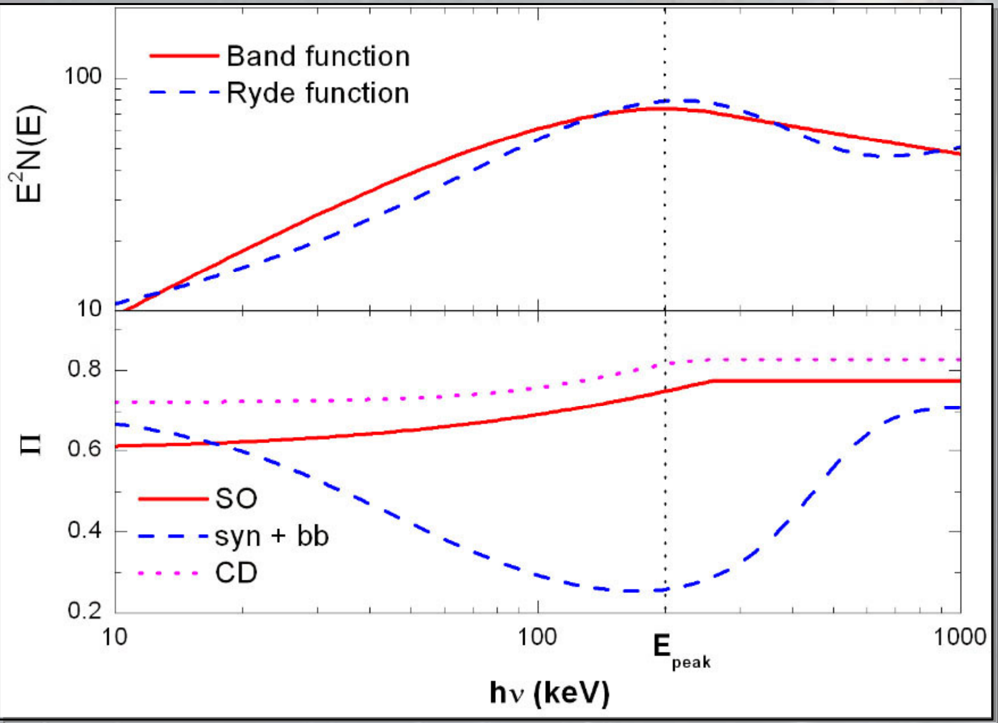
Synchrotron Emission

Random B-field

OR

Compton Drag

What is the GRB radiation mechanism?



GRAPE and LEP will independently measure Π above and below E_{peak}

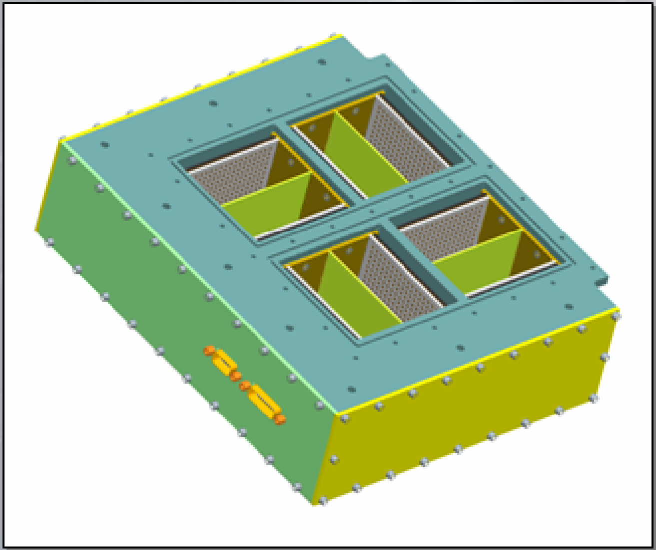
LEP		GRAPE	
GRBs	MDP	GRBs	MDP
8	10%	6	8%
40	25%	40	20%
*72	50%	62	51%

POET was not selected for Phase A so now what?.....

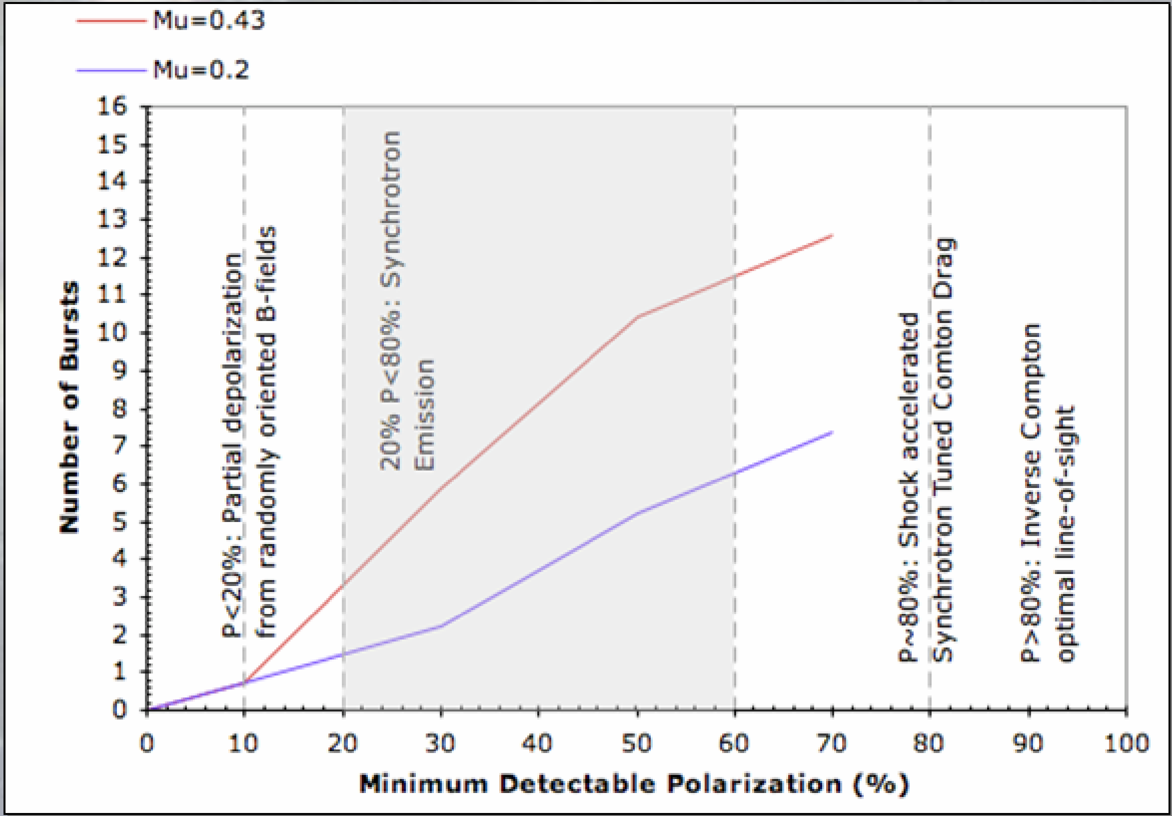
- Improve readiness of GRAPE
  - Balloon flight
- Improve readiness of LEP
  - MidSTAR-2 GRBP (~2011)
  - GEMS in Phase-A (Gravity and Extreme Magnetism SMEX)
- Look for new opportunities
  - e.g. Space Station

The GRBP: A payload for MidStar 2

Area: 144 cm^2
Depth: 5 cm
FoV: 1 steradian
Gas: $Ne:CO_2:CS_2$
Pressure: 1 atm



MDP averaged from 2 - 10 keV



MidSTAR-2

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USNA Project

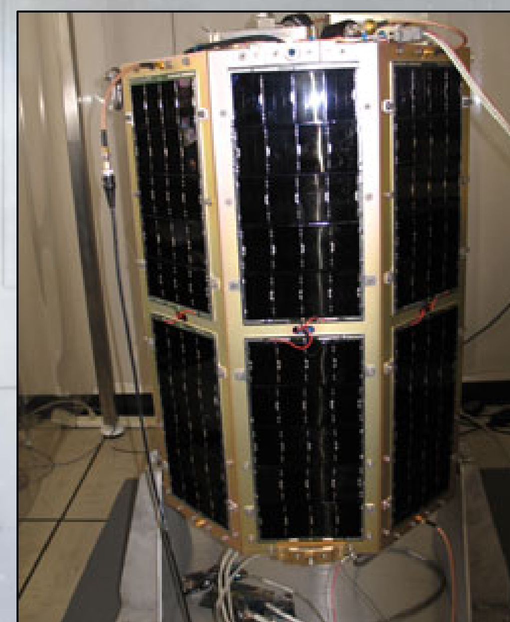
High risk Low-cost

Make a scientific measurement

- Several GRBs in 2 yr lifetime

Low cost proof-of-concept

Launch ~2011



GRBP Prototype

Prototype
Detector
Design

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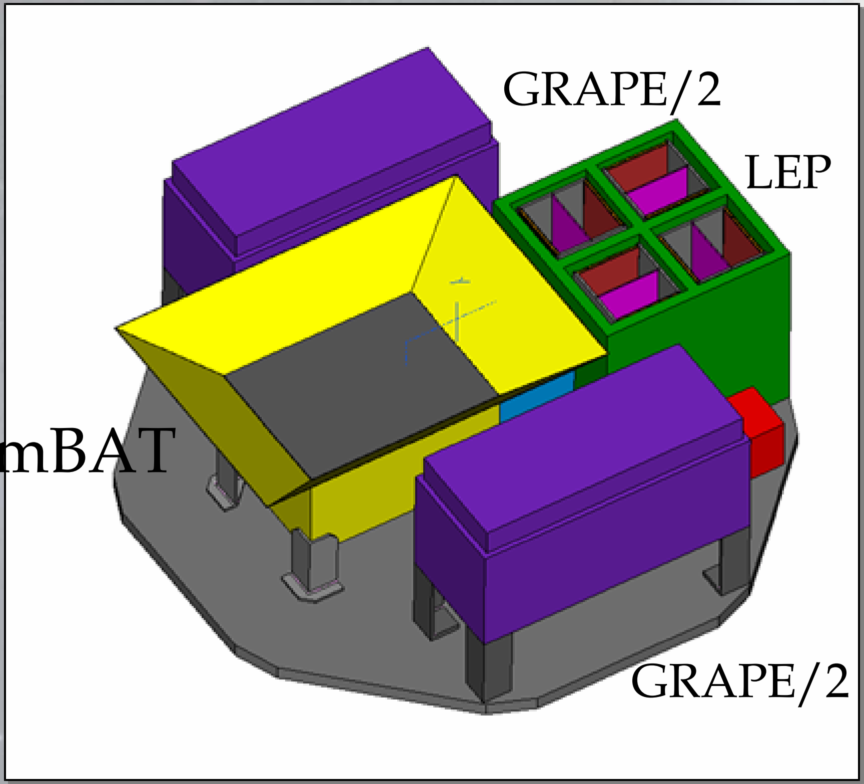
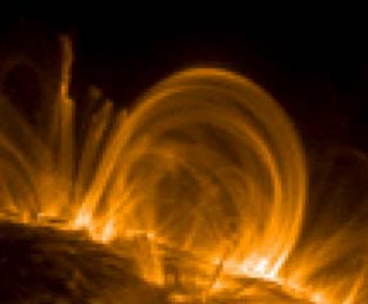
Prototype chamber

HV Power Supplies

(mBAT - Mini BAT 1/8 scale)

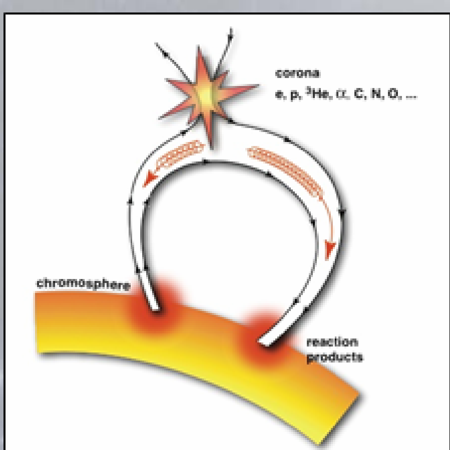


mBAT Parameters	
Energy Range	15-150 keV
FoV	~2 str partial coding
Spatial Resolution	~3 arcmin
Spectral Resolution	~7 keV
Position Notice	~4 arcmin in 20 sec



Solar Flare Science

- How does the Sun release such large quantities of energy in a Solar Flare?
- How does the Sun accelerate electrons and Ions with such high efficiency?
- POET will determine the angular beaming of electrons
- Polarimetry measures the electron beaming.
- Models predict 20-30% polarization.

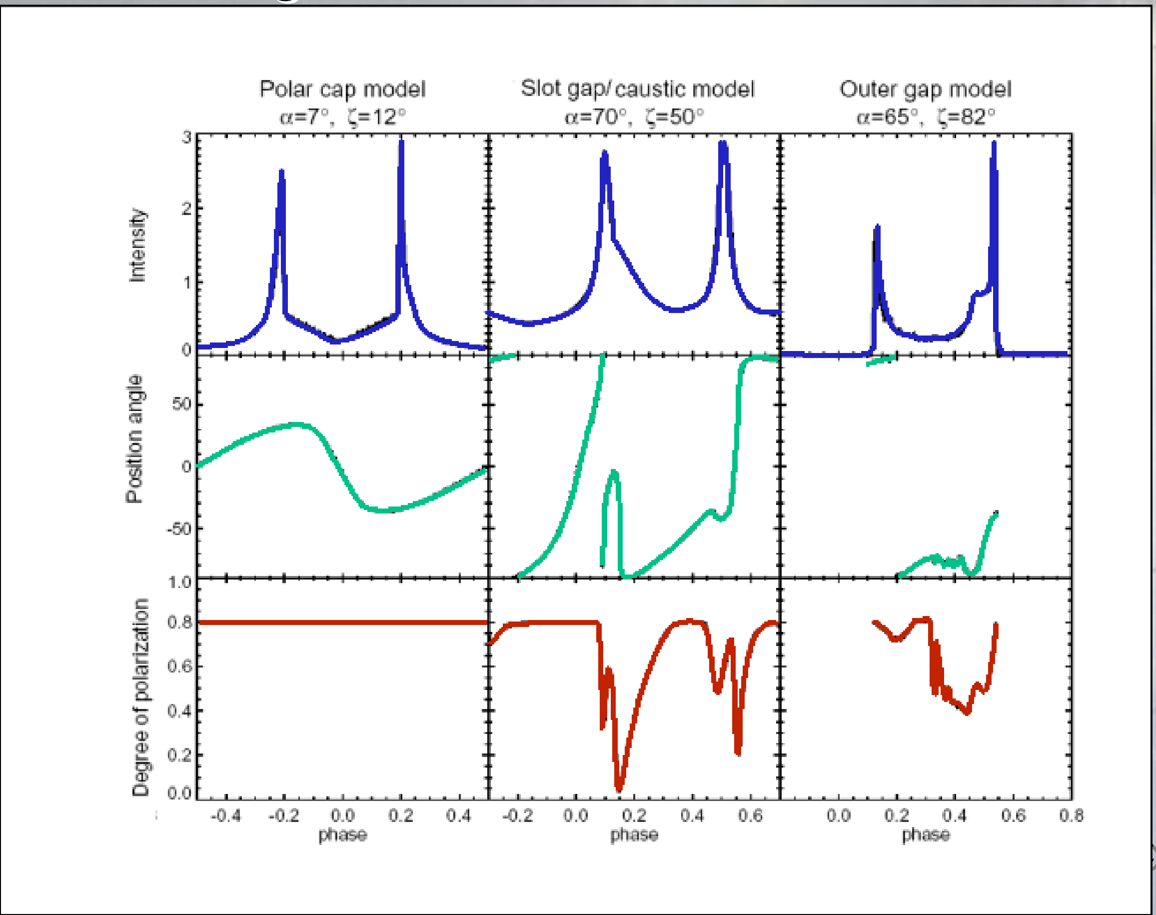


Energy Band (keV)	23 July 2002 (X4.8) Δt = 60 s	M5 flare Δt = 300 s
50-500	2.3%	27%
50-100	3.6%	43%
100-200	3.4%	40%
200-500	4.9%	62%

GRAPE will measure polarization direction and magnitude of Solar Flares to answer these questions

Pulsar Science

X-ray polarimetry is the ***only*** way to distinguish between the two leading models of accretion flow onto highly magnetized neutron stars.



Intensity (top), polarization position angle (middle) and degree of polarization (bottom) vs. phase predicted by different models for the Crab pulsar. All reproduce the intensity profile. Only polarization measurements can uniquely differentiate between models.

	LEP (2-10 keV)	
	MDP in 10 ksec	MDP in 1ksec
CRAB	4 %	8%
1/10 CRAB	8%	15%

conference