Compton Focal Planes for Gamma-Ray Lenses

Why a Ge Compton Detector?

Configurations Studied

Compton Analysis Basics

(preliminary) Results

In collaboration with

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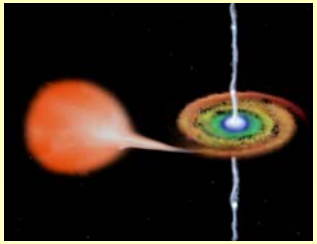
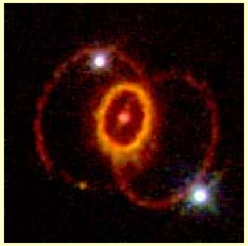
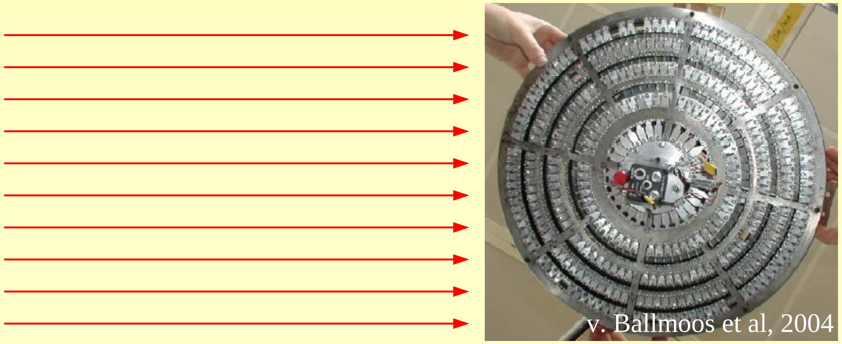
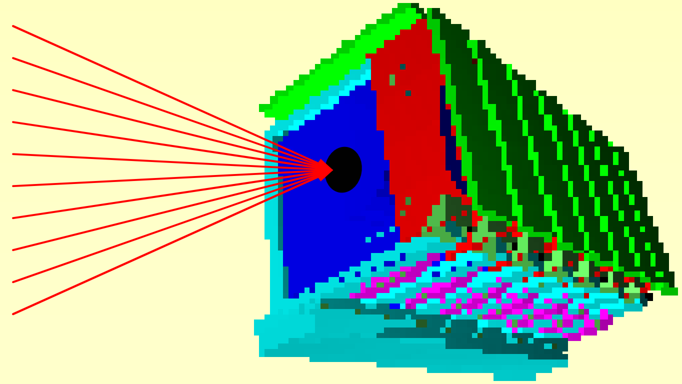




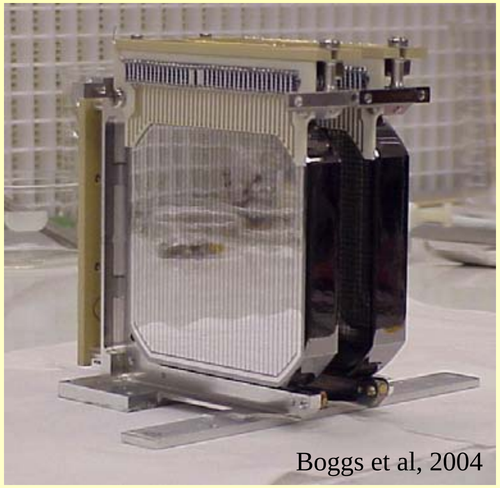


v. Ballmoos et al, 2004



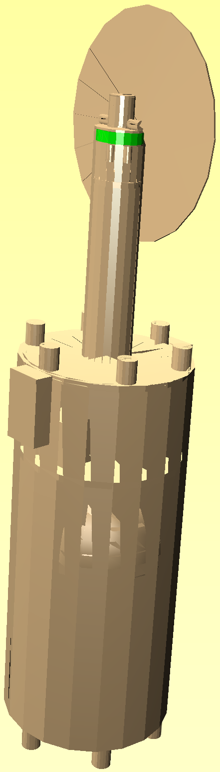
Focal Plane Instrumentation

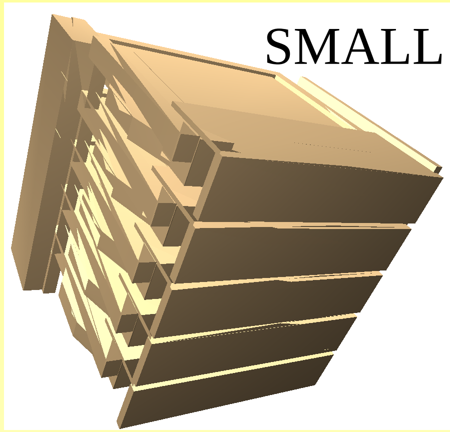
- Ge detectors offer best energy resolution available at ~ 2-3 keV FWHM, ⇒ detectors of choice for an MeV spectroscopy mission
- Compton detector focal plane has three advantages over monolithic detector(s)
  - Better capability for background rejection
  - Inherently finely pixellated detector naturally allows selection of events according to focal spot size and position
  - Inherently sensitive to γ-ray polarization
- Ge-strip Compton detectors have been tested in the laboratory at UC Berkeley and flew on a balloon in Spring 2005

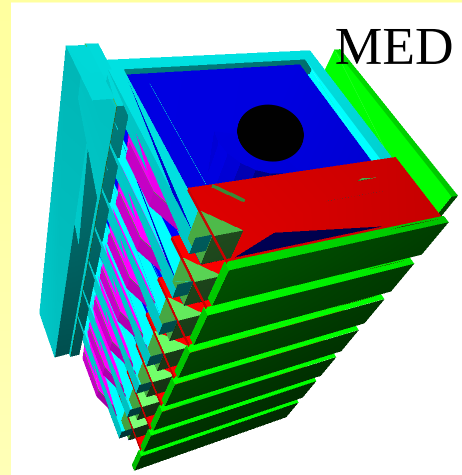


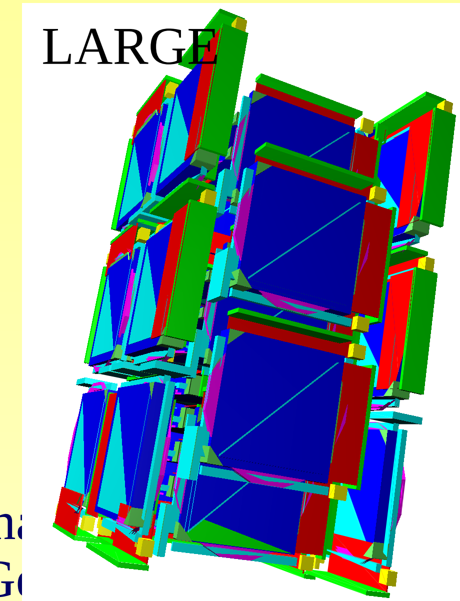
Boggs et al, 2004

Configurations Considered



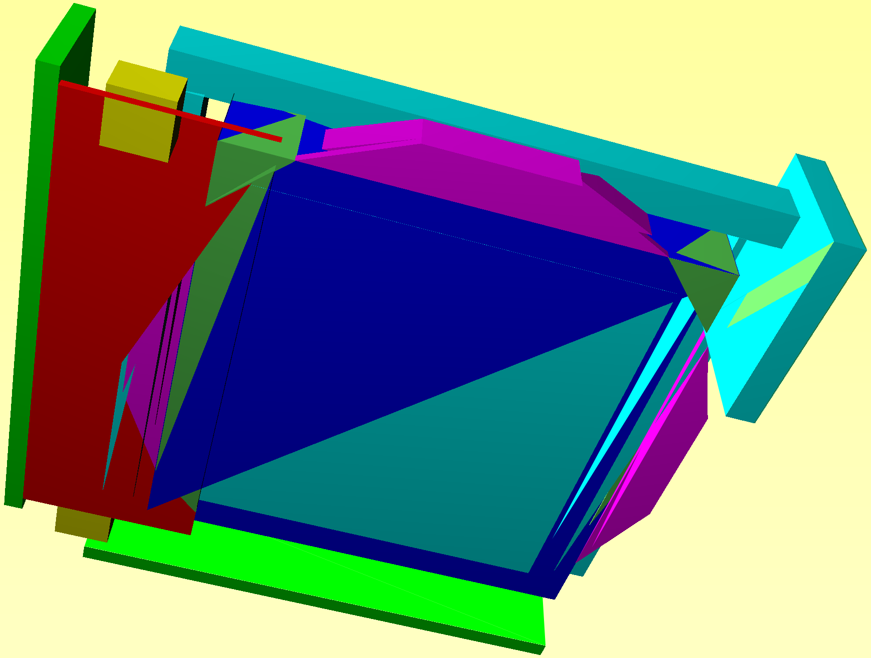






- Tower concept and BGO shield reduce SC-origina
background; geometry identical to that used by G
Weidenspointner
(based on CNES study of MAX mission)
- Mass models built starting from existing NCT (balloon !) detectors
- Strip pitch for MED and LARGE 1 mm (NCT and SMALL 2 mm), LARGE uses larger Ge ingots (9.2 × 9.2 cm detectors instead of 8 × 8 cm detectors) and 2 detector thicknesses (1.5 cm and 7.5 mm)

Single Detector Unit



one spot where we were too optimistic … :
For detectors with central hole, the hole is not surrounded by a guard ring. A real detector would need ~ 1 mm guard ring there.

- Balloon detector geometry (“cheap & reliable” over optimization)
- Al parts holding detectors
- Details down to metal screws
- Large passive-Ge “handles” used for Ge mounting
- Thick circuit boards protruding between detector active areas
- Faithfully represented in our Detector mass model at correct composition and mass

➢ Mass models contain lots of passive material that can be reduced, avoided or repositioned

- For the LARGE design, shrunk Al bars and electronics boards within reasonable limits (all the pieces still there!)

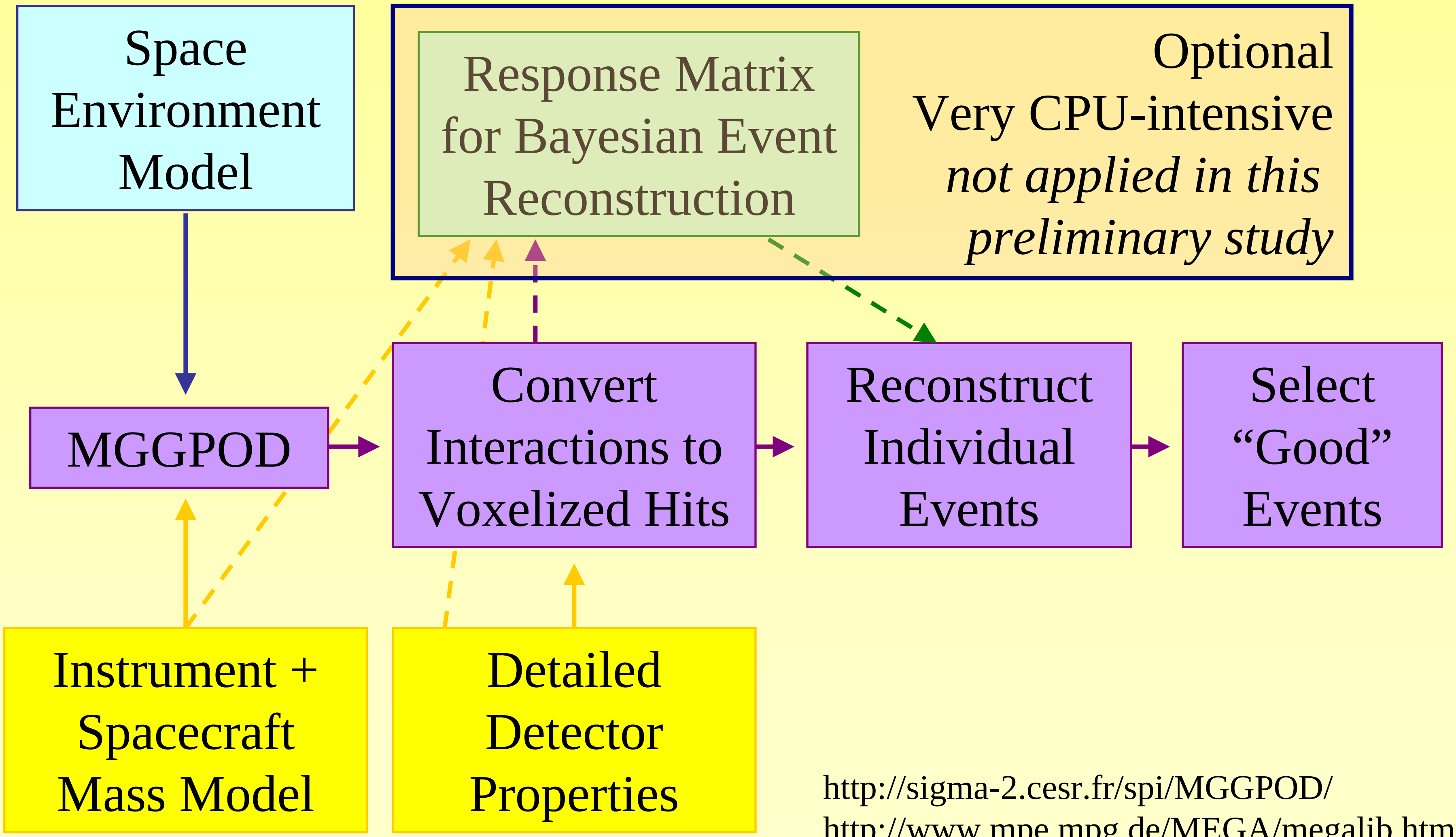
Performance Predictions

- Need to predict interactions in detectors
  - From source
  - From background
- Need to get from these raw events to the sensitivity achievable after Compton event analysis

The ACT concept study has assembled existing software packages into a toolset covering all aspects of Compton telescope performance prediction from space environments to Compton event reconstruction and event selection

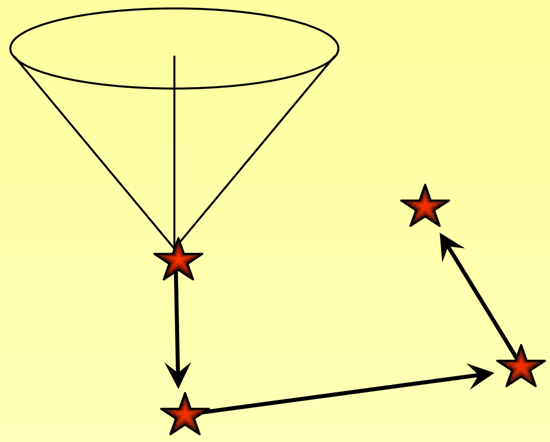
… we're leveraging off these toolsets

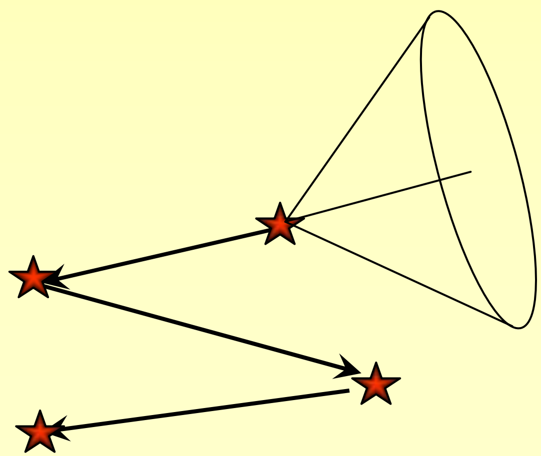
Data Analysis Overview



http://sigma-2.cesr.fr/spi/MGGPOD/
http://www.mpe.mpg.de/MEGA/megalib.html

Event Reconstruction Intro I

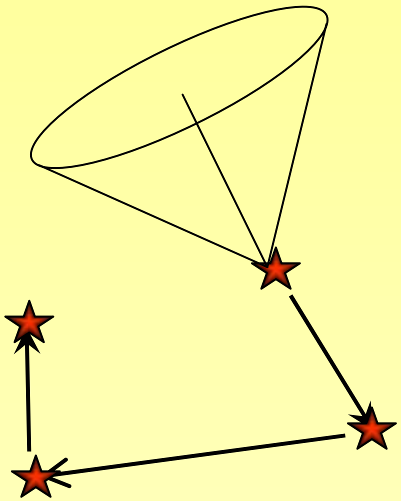


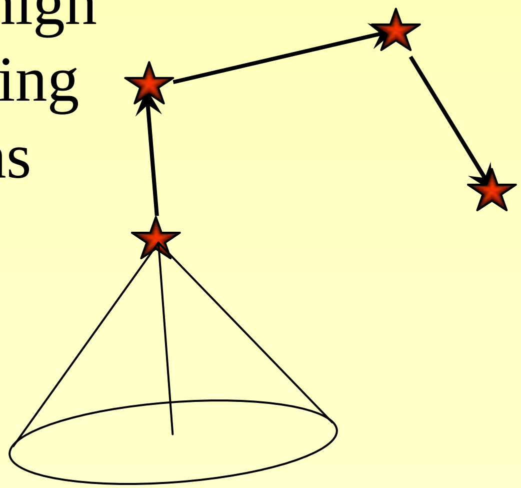


What happened?

4 interactions ⇒
4! possibilities …

Goal: reject all events that don't have a high probability of having come from the lens





Event Reconstruction Intro II

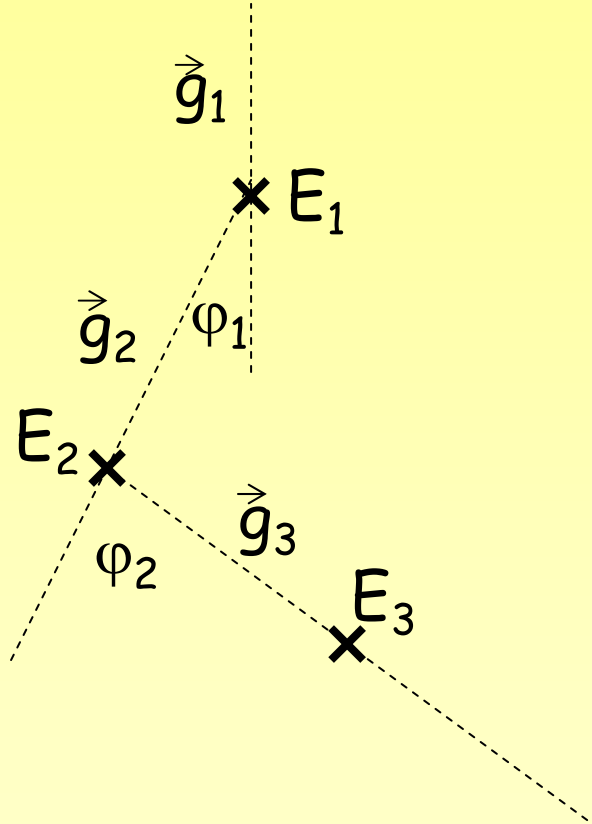
If an event has 3 or more interactions, then the second Compton scatter angle φ can be computed in two ways:

Via energies: $$\cos\varphi_i^E = 1 - \frac{E_{e0}}{E_i} + \frac{E_{e0}}{E_i^+}$$

Via angles: $$\cos\varphi_i^{geo} = \frac{\vec{g}_{i-1} \circ \vec{g}_i}{\left|\vec{g}_{i-1}\right| \cdot \left|\vec{g}_i\right|}$$

⇒ Redundant information

⇒ Can be used to determine Compton sequence



Compute for all possible sequences the following test statistics:

$$T_n = \left(\cos\varphi_i^E - \cos\varphi_i^{geo}\right)^2$$

The sequence with the lowest value is the correct one

(MEGAlib, A. Zoglauer 2005)

Event Selections

- Now we have to pick the "good ones"
- Selection criteria:
  - non-ambiguity of sequence (2 interactions only)
  - Test statistic value (for 3+ interactions)
  - Compton scatter angle
  - Number of interactions
  - (Minimum) angular distance from source (ARM)

  as well as
  - Total deposited energy

- We reject ~ 75% of source counts ☹

  … but also >> 99% of the background ☺!

Preliminary Findings I

- Our preliminary, conservative estimates indicate that sensitivities of 10^{-6} ph/cm^{2}s
  - For a 511 keV narrow line
  - For a 847 keV 3% FWHM broadened line

  are achievable with a Laue lens of 1200 cm^2 and 660 cm^2 effective area at 511 keV and 847 keV, respectively, with a Compton focal plane

- Keep in mind that
  - These estimates are based on *first* guesses at good detector configurations
  - For the Compton telescopes, we use ACT analysis methods as they stand, without in-depth optimization for the different beam as well as detector geometries in a Lens focal plane
  - Detector geometries are conservative (reflecting existing balloon or S/C hardware rather than "what could reasonably be done")
  - Both the 511 keV line and a broad-line region are "hard" cases since background levels are higher than for many narrow lines

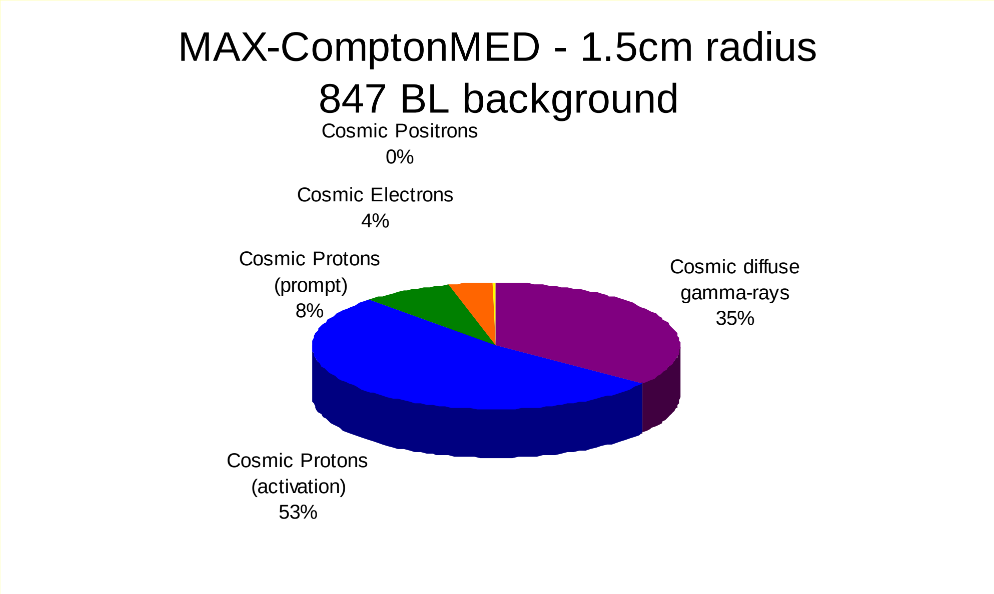
Preliminary Findings II

ComptonMED 1.5 cm, 847 BL

	Observation time [s]	counts in energy window	Limit	Rate [counts/sec]		
Cosmic diffuse gamma-rays	420,800.00	438		1.04E-03	+-	4.97E-05
Cosmic Protons (activation)	100,000.00	155		1.55E-03	+-	1.24E-04
Cosmic Protons (prompt)	4,220.45	1	yes	2.37E-04	+-	2.37E-04
Cosmic Electrons	9,174.40	1	yes	1.09E-04	+-	1.09E-04
Cosmic Positrons	91,744.00	1	yes	1.09E-05	+-	1.09E-05
847 keV broad line total:				**2.9E-03**	**+-**	**2.9E-04**

For narrow 511 keV line and event selections optimized for the LARGE concept, activation from CR protons accounts for up to 70% of the total background rate.

Prompt CR proton, CR electron, and CR positron contributions are small or negligible.



Preliminary Findings III

- Our *preliminary, conservative findings* indicate for a 2-band lens of 1200cm^2 and 660cm^2 effective areas at 511 keV and 847 keV respectively that *at least the following can be achieved*:

	Compton SMALL	Compton MED	Compton LARGE
511 keV sensitivity [ph/cm^{2}s]	$1.3\cdot10^{-6}$	$1.2\cdot10^{-6}$	$9.4\cdot10^{-7}$
847 keV broad-line (3% FWHM) sensitivity [ph/cm^{2}s]	$2.0\cdot10^{-6}$	$1.7\cdot10^{-6}$	$1.1\cdot10^{-6}$
Photopeak Efficiency (@511 keV / @ 847 keV)	6% / 6%	8% / 10%	13% / 7%
S/B ratio @ 511 keV	10%	6%	13%

… beyond the Lens

- A Compton-telescope focal plane not surrounded by a heavy scintillator shield will have secondary capabilities for survey science
- With a Compton-telescope focal plane, a Laue-Lens instrument might detect its own ToOs
- Sensitivities for this TBD

Summary and Outlook

- Our simulations show that sensitivities
  - for 511 keV narrow line
  - for 847 3% FWHM broadened line

  on the order of $1.0 \cdot 10^{-6}$ ph/(cm^{2}s) can easily be achieved with a 1200 cm^2 / 660 cm^2 effective area lens
- Sensitivity numbers for narrow lines other than 511 keV will be much better – we've asked the really tough questions here!
- A Compton detector focal plane will have secondary capabilities for survey science

Much remains to be done …

- SMALL and MEDIUM stacks are doing fairly well – optimize distances, as well as hole size for MEDIUM
- The LARGE concept must undergo significant redesign – it's much too leaky to justify the additional weight as it stands now …