Monte Carlo Study of Detector Concepts for MAX

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Motivation

- Basic question:

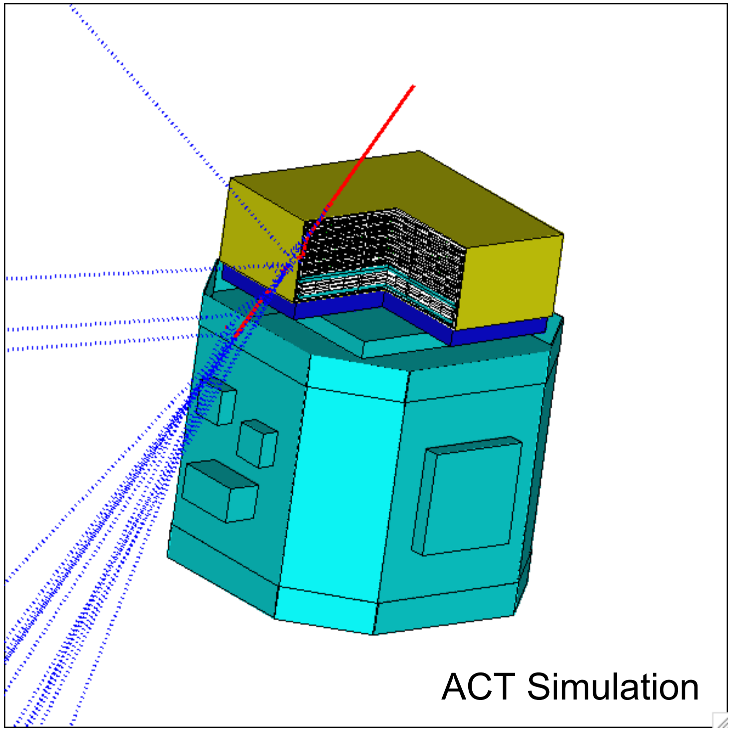
What is the best focal spot gamma-ray detector?
(hardware and analysis software)

- Requirements:
  - Sensitivity
  - Sensitivity
  - Sensitivity
  - Spectral Resolution
  - Polarimetry

- Trade Off Between:
  - Efficiency
  - Background
  - Spectral & Spatial Resolution

Approach

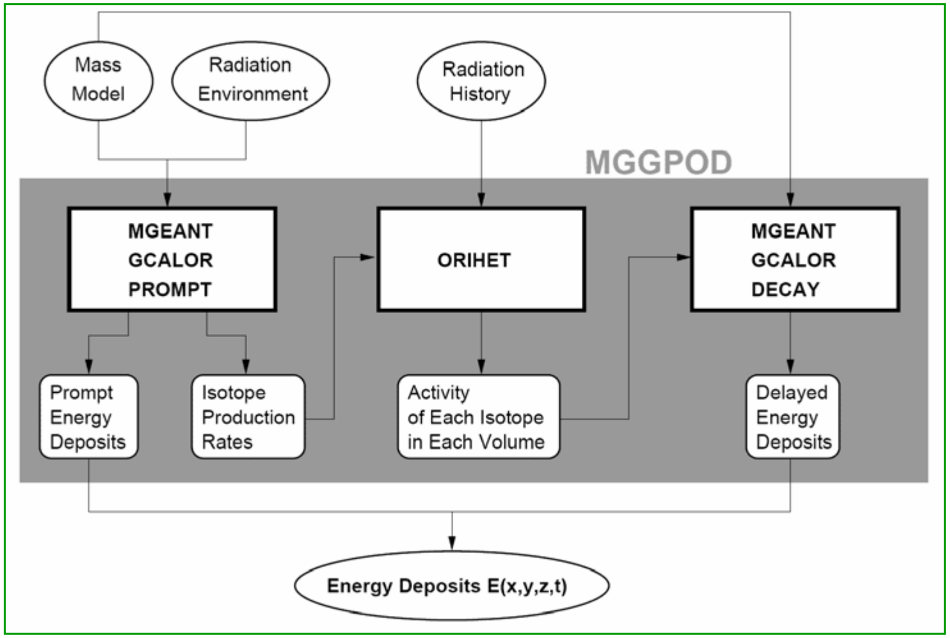
- *ab initio*
  Monte Carlo Simulation
- MGGPOD + MEGAlib
  (also used for e.g. ACT study)



⇒ high fidelity Monte Carlo study

MGGPOD

- MGGPOD Monte Carlo package (Weidenspointner et al., 2005) based on CERN's GEANT3.21
- Available to the public: http : // sigma-2.cesr.fr/spi/MGGPOD
- Already applied to TGRS, SPI, RHESSI, ACT concept study, …



Some Capabilities:

- Gamma-ray sources (celestial and laboratory) and instrument response - including polarization
- Cosmic rays and their secondaries: prompt background and activation
- Diffuse X and gamma ray background
- Earth albedo
- Radioactive decays (including isomeric levels)

MEGAlib

- Originally developed for MEGA
  - an ACT prototype - data analysis
  (Zoglauer et al., 2005)
- Complete Compton telescope data analysis,
  including the crucial step of
  event reconstruction (background rejection)
- Available to public:
  http : // www.mpe.mpg.de/MEGA/megalib.html
- More detail: next talk by C. Wundererer

The Very First Step…
Scope

- Compare three different detectors:
  - single co-axial Ge detector
    (« MAX-TGRS »)
  - stack of segmented, planar Ge detectors
    (« MAX-NCTseg »)
  - stack of Ge strip detectors
    (« small Compton telescope »)

- Compare three different Compton telescope designs (→ C. Wunderer)

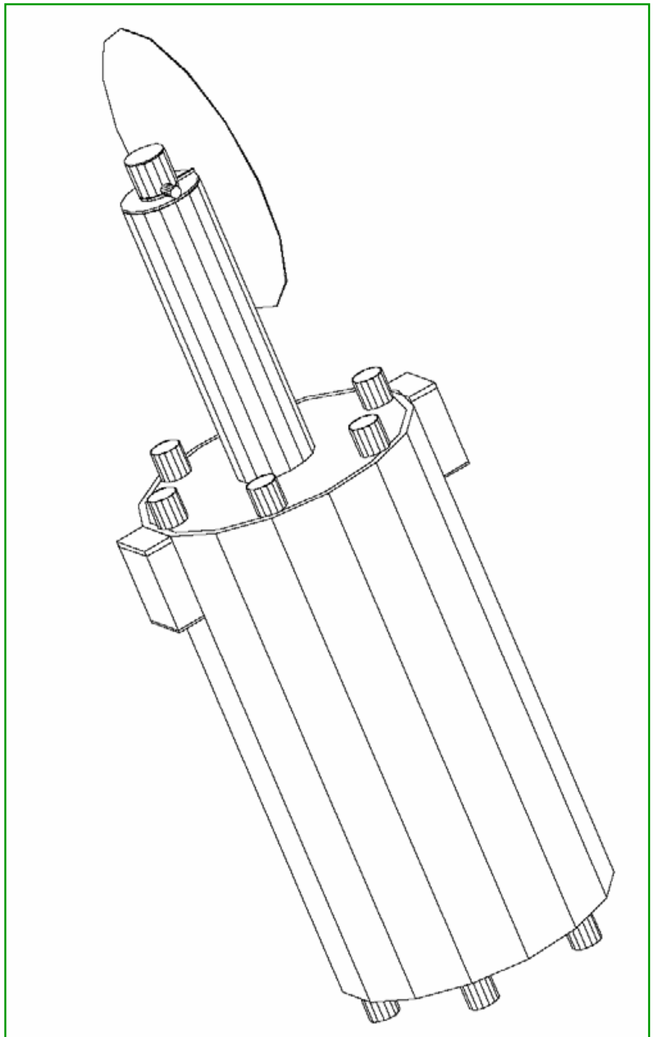
The Very First Step… in Perspective

- Detector designs: « intuition »
- Only existing detector technology
  $\Rightarrow$ concepts could be built today
- Different from designs considered in MAX proposal
- Spacecraft model: CNES phase 0 « design »

Therefore:
- Preliminary results
- Conservative sensitivities
- For now: relative results are more interesting than absolute results
- Much room for improvement/optimization

BUT: we now have the tools to do so!

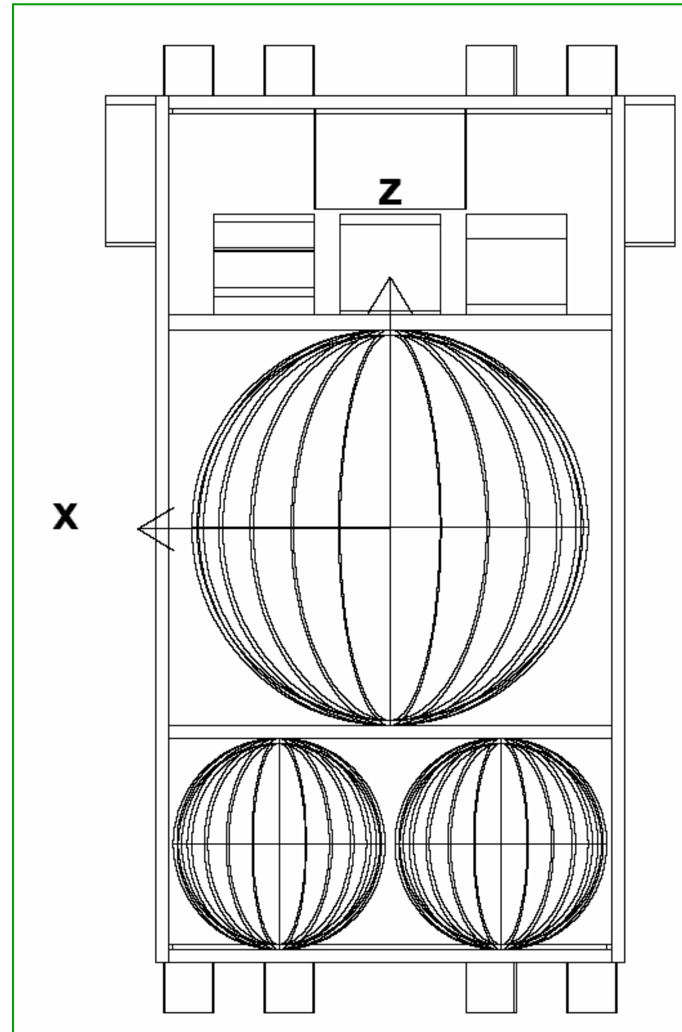
Simulation Details…
Mass Models - Spacecraft



CNES phase 0
Spacecraft:
~ 260 kg

Instrument on top
of 1m tower

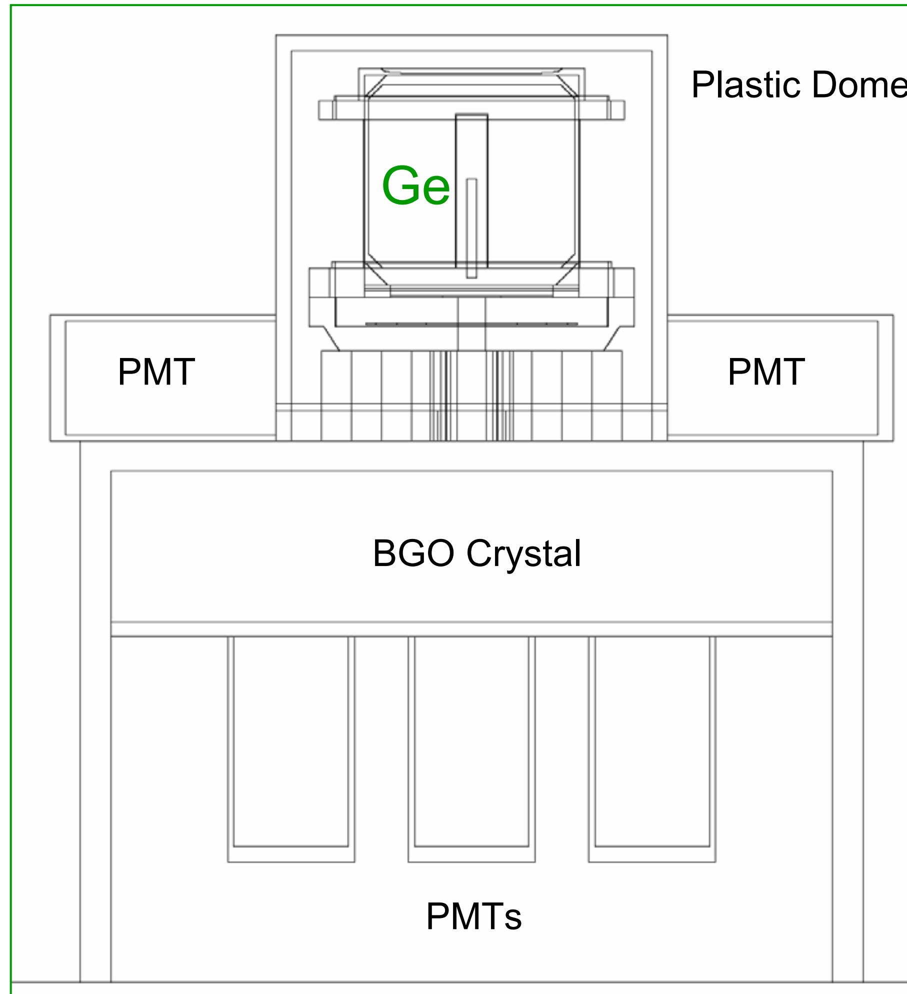
Passive cooling,
Be radiator



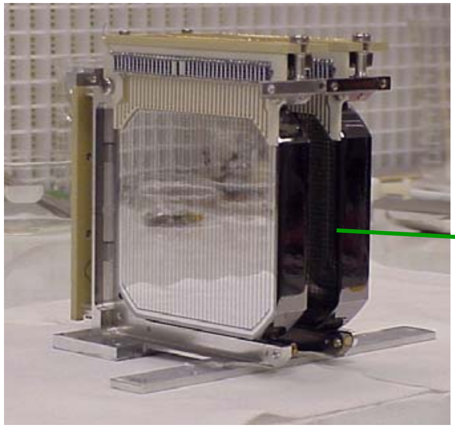
Simulation Details…
Mass Models – single Crystal

Single co-axial Ge detector:

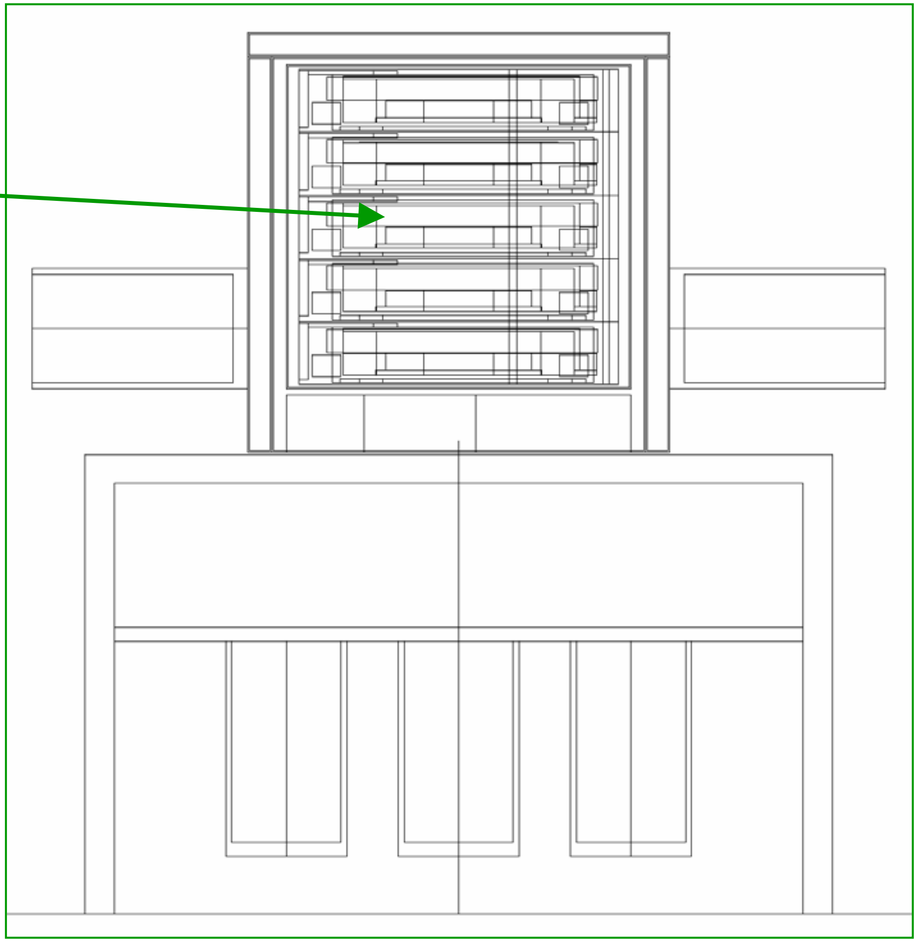
- TGRS-like detector
  (also Mars Odyssey)
- Size:
  - Radius ~ 3.4 cm
  - Height ~ 6.1 cm
  - Volume ~ 216 cm^3
- Veto shield:
  - BGO block below
  - plastic dome cover



Simulation Details…
Mass Models – Detector Stacks



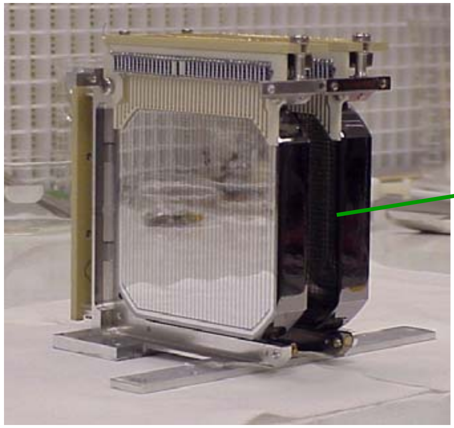
Boggs et al, 2004



Detector Stacks:
- 5 NCT Ge strip detectors
  (Ge ACT balloon prototype)
- Size: ~8×8×1.5cm^3~96cm^3
  total of 5: ~ 480 cm^3
- distance between layers: 0.7cm
- strip (Compton telescope)
  or segmented
- veto shield: as before

Simulation Details…
Mass Models – Detector Stacks

Detector Stacks:
- if segmented:
  one central pixel (∅ 1.9cm),
  one “outer” pixel



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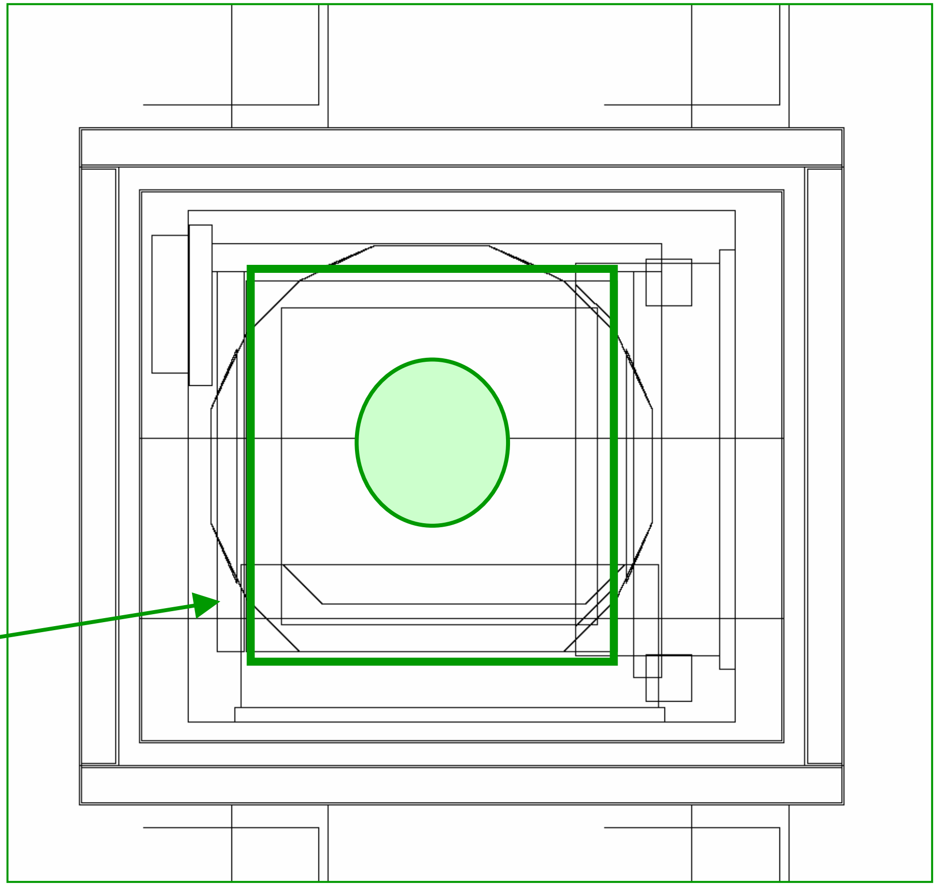


Simulation Details…
Lens Beam

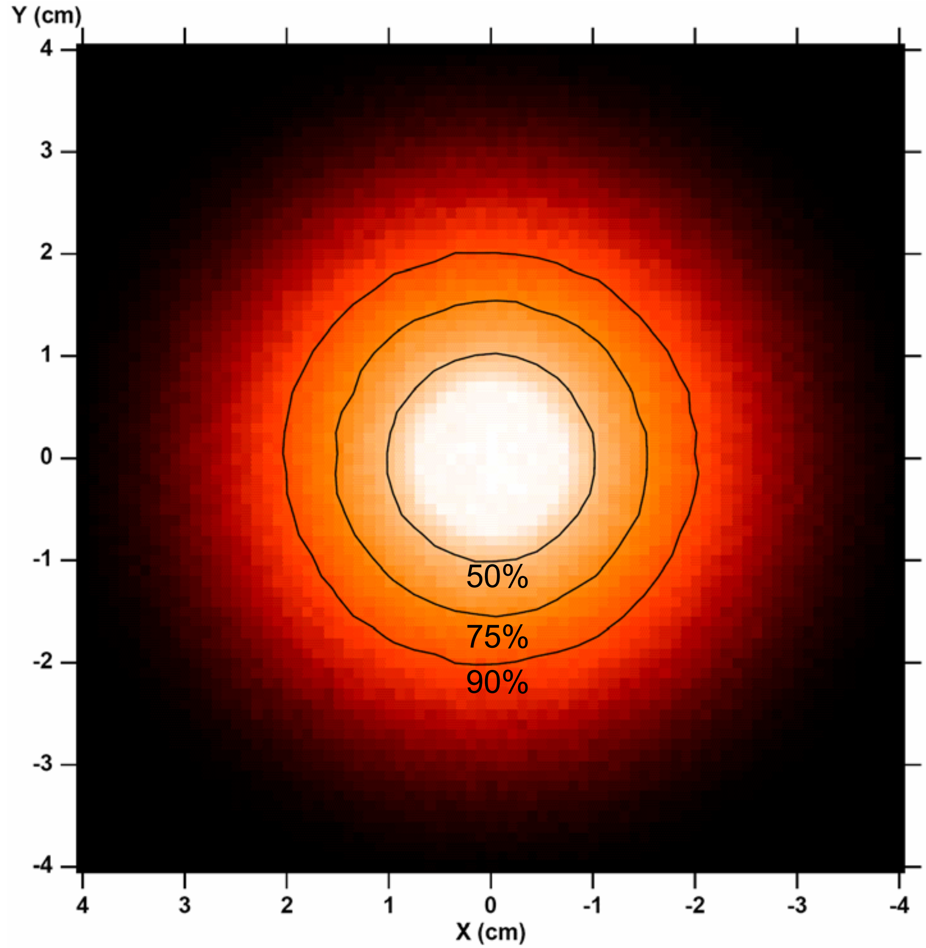
Lens parameters:

- focal length: 86m
- mosaicity: 30 arcsec
- crystal size: 15mm × 15mm

⇒ 50% of photons within 1 cm
75% -”- 1.5cm
90% -”- 2cm

Currently assumed:

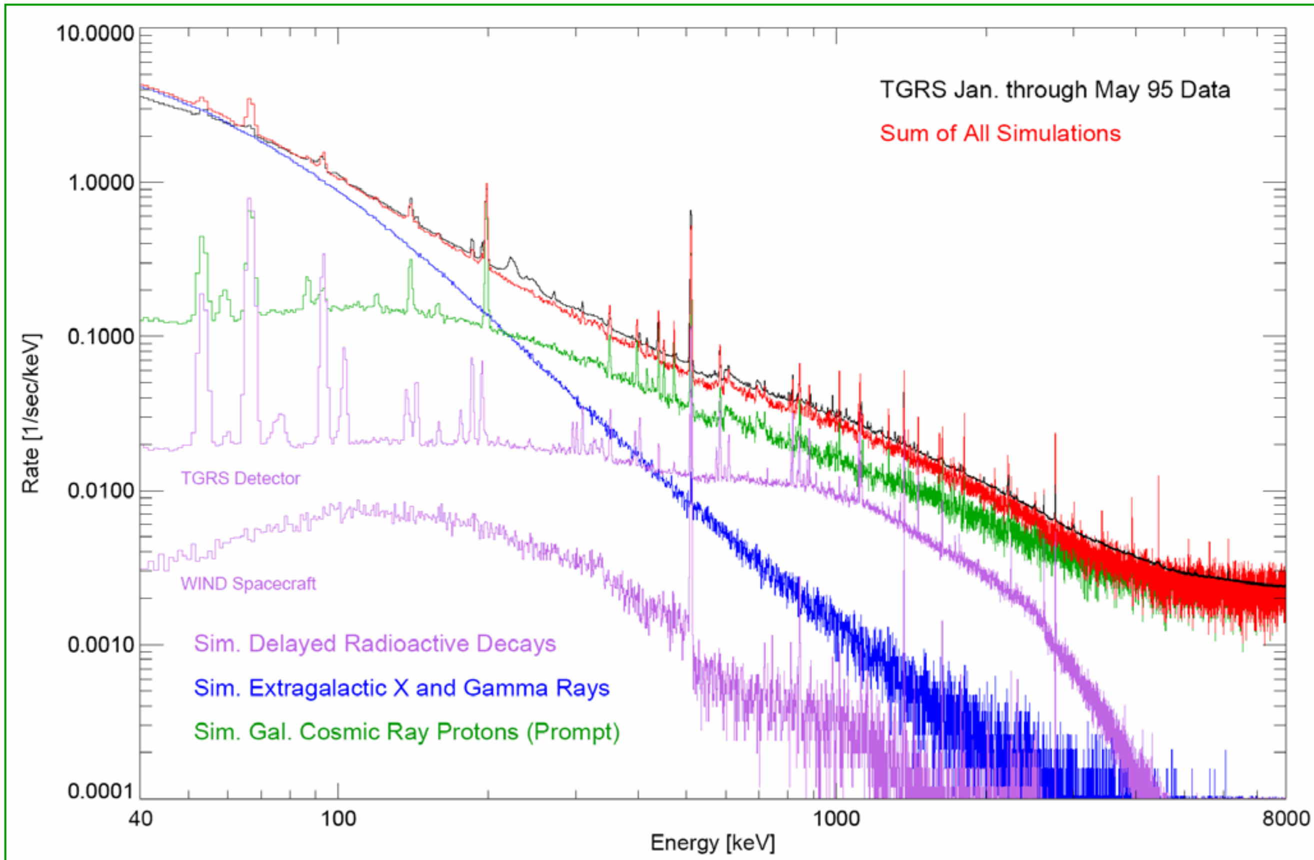
- Source on axis
- Photons are parallel
- Beam center at detector center



Beam footprint on detector

Some Simulation Results… TGRS Flight Data

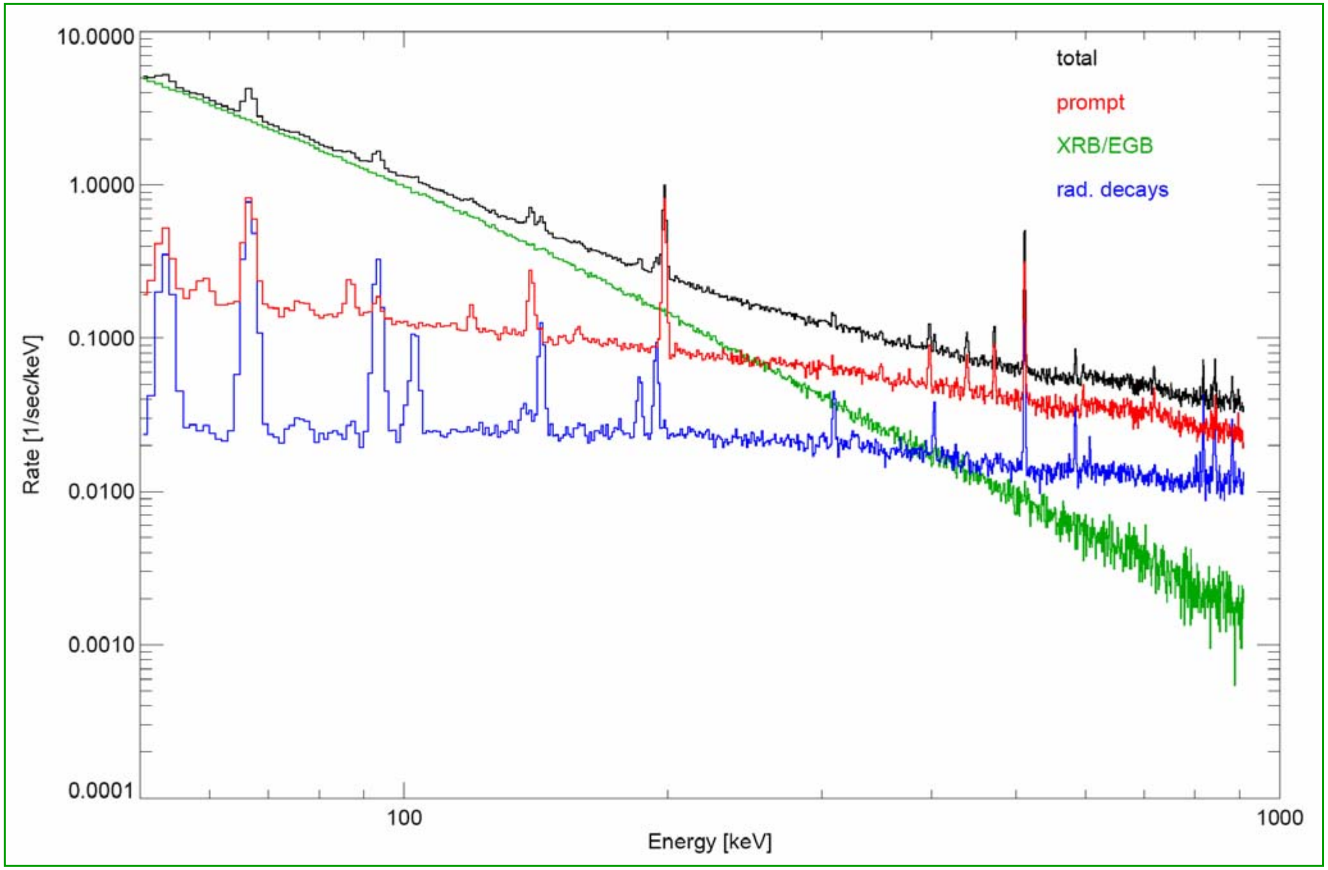
- MGGPOD does very well
- Prompt Background dominates for > 200 keV
- Diffuse cosmic photons drop below radioactive decays for > 400 keV
- Decays dominated by detector



Weidenspointner et al., 2005

Some Simulation Results…
« MAX-TGRS » - veto off

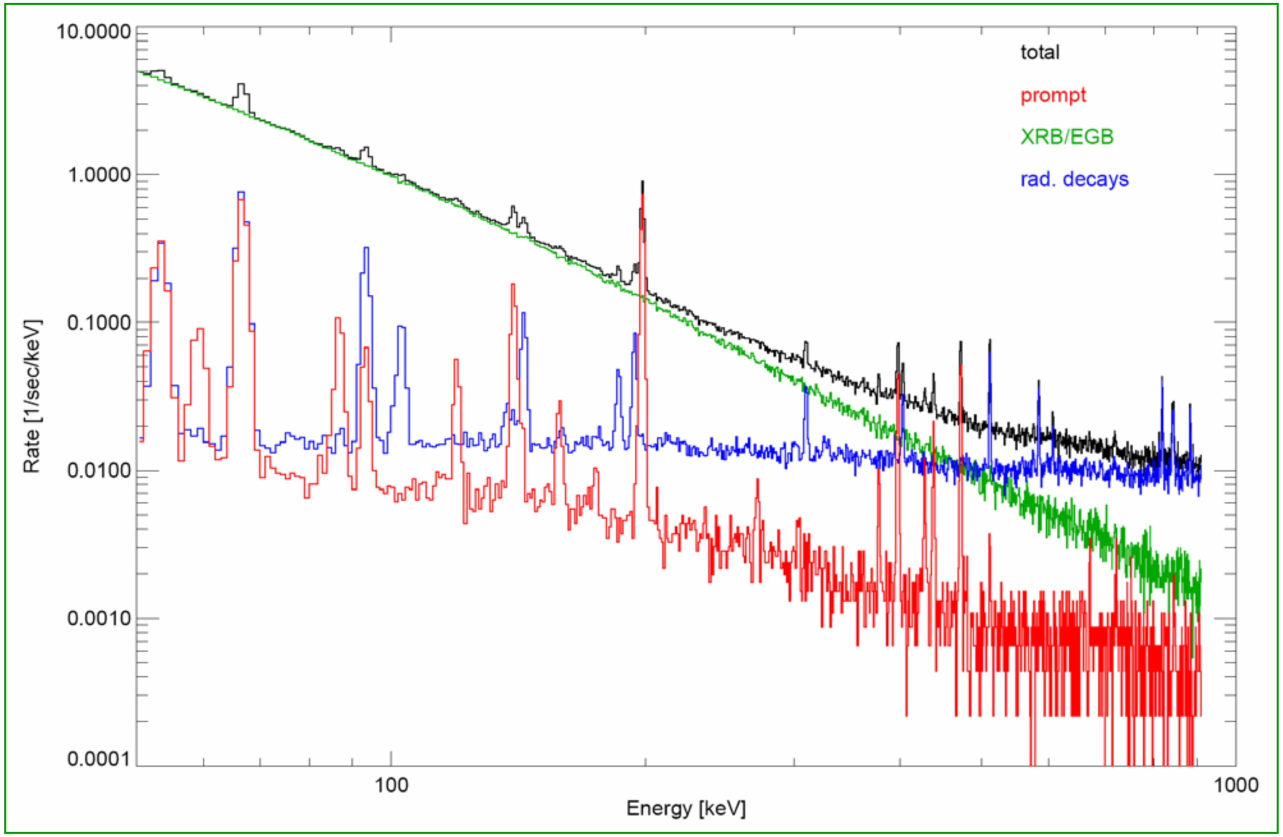
MAX-TGRS with
veto off
is very similar
to TGRS…



Some Simulation Results… « MAX-TGRS » - veto on

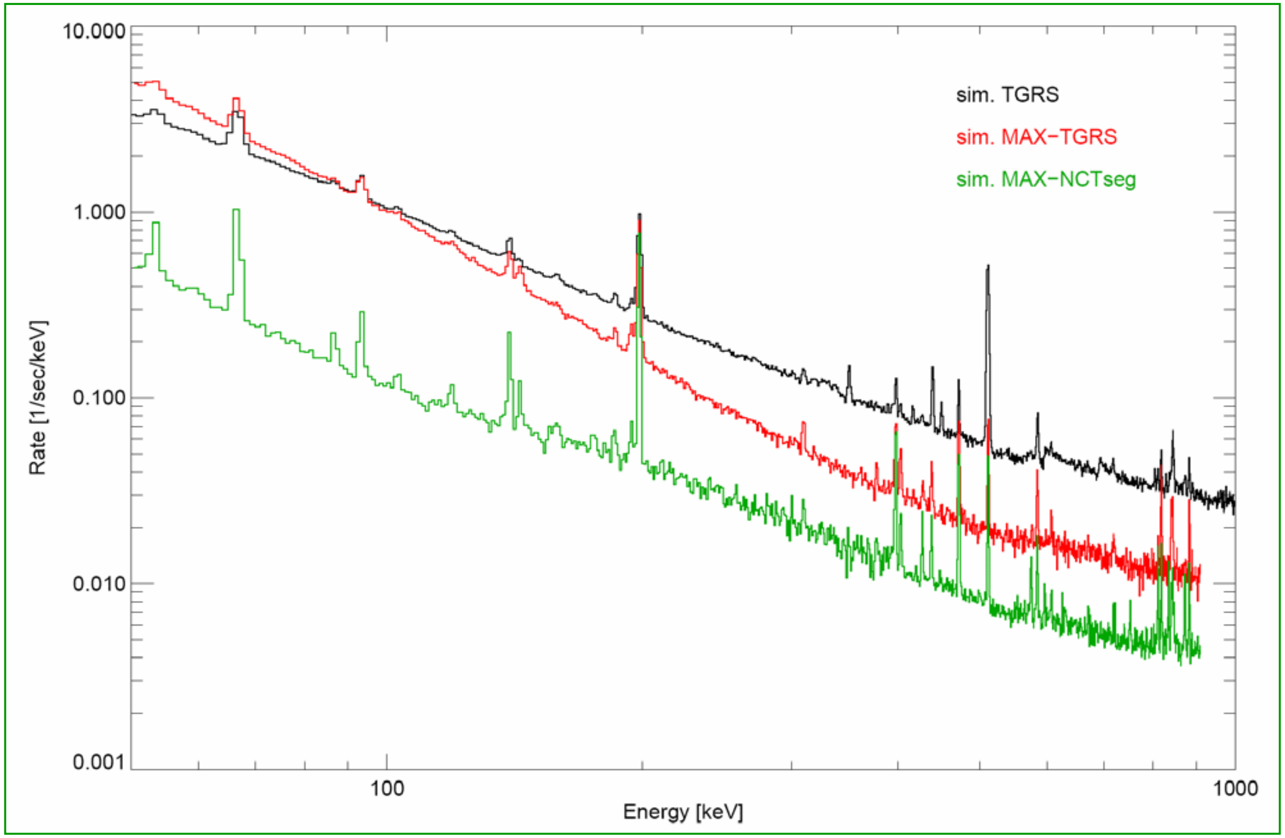
MAX-TGRS with veto on:

- Prompt background reduced by factor 10
- Radioactive decays hardly affected (dominated by decays in detector)
- Total background reduced by factor ~2-3 above ~400 keV



Some Simulation Results… TGRS, MAX-TGRS, & MAX-NCTseg

- TGRS & MAX-TGRS: veto reduces total background by ~ 2 above 300 keV in continuum; by ~10 at 511 keV
- Segmentation: reduces total background again by ~2 above 300 keV (although volume 2× larger); by ~10 in XRB/EGB



⇒ « back of the envelope » scaling is tricky…

Some Simulation Results…
Preliminary Sensitivities

- Lens effective areas 1191 cm^2 and 661 cm^2 at 511 keV and 847 keV, respectively
- 3σ significance for observation time of 10^6 s

Sensitivity [ph/cm^2/s]

	MAX-TGRS	MAX-NCTseg	Compton small
511 keV	$(3.0\text{-}6.0)\times10^{-6}$	$(2.0\text{-}4.0)\times10^{-6}$	1.3×10^{-6}
847 keV	$(3.5\text{-}6.9)\times10^{-6}$	$(1.9\text{-}3.7)\times10^{-6}$	-
847 keV (3% FWHM)	$(1.3\text{-}2.5)\times10^{-5}$	$(0.7\text{-}1.3)\times10^{-5}$	2.0×10^{-6}

$\Rightarrow$ Compton detector appears most promising

Some Simulation Results…
Preliminary Efficiencies

In ±2σ energy interval:

	MAX-TGRS	MAX-NCTseg	Compton small
		Photopeak Efficiency [%]	
511 keV	38	41	6*
847 keV	27	32	6*
		Background Rate [cts/s]	
511 keV	2.1×10^{-1}	1.1×10^{-1}	1.0×10^{-3} *
847 keV	5.1×10^{-1}	1.7×10^{-2}	2.1×10^{-3} **

* energy interval of optimum sensitivity

** as *, but for broad line

Conclusions & Prospects

- Tools for detailed detector modelling are available – and we have begun to use them
- Much remains to be improved for each concept:
  - veto design
  - detector size/geometry, segmentation
  - event selections
  - detector materials and passive materials
  - …
- Neverthless: even first « guess » gives preliminary
  line sensitivities close to 10^{-6} ph/cm^2/s …
  equivalent to at least 100 SPI telescopes !!!
- Compton detector seems most promising
- Segmented detector might be a simpler alternative