Localization Performance and Detection Efficiency of a Compact GRB Monitor to Fly on a future Cubesat

Kaustubha Sen

Ph.D. Student

National Tsing Hua University, Taiwan



Thanks to our Collaborators

Chih-En Wu [1],
Hao-Min Chang [2],
Jakub Řípa [3],
Hsiang-Kuang Chang [1,2,3],
Andras Pal [4],
Norbert Werner [3],
Filip Munz [3],
Hiromitsu Takahashi [5],
Masanori Ohno [5],
Marianna Dafčíková [3],
Edoardo Borciani [6],
Chin-Ping Hu [9],
Che-Chih Tsao [7],
Chih-Hsun Lin [8],
Tsung-Che Liu [10],
Jean-Paul Breuer [3],
Masato Yokota [5],
Yasushi Fukazawa [5]

[1] Institute of Astronomy, National Tsing Hua University, Hsinchu, Taiwan

[2] Department of Physics, National Tsing Hua University, Hsinchu, Taiwan

[3] Institute of Space Engineering, National Tsing Hua University, Hsinchu, Taiwan

[4] Department of Theoretical Physics & Astrophysics, Masaryk University, Brno, Czech

[5] Graduate School of Advanced Science and Engineering, Hiroshima University, Hiroshima, Japan

[6] Department of Physics and Astronomy “Augusto Righi”, University of Bologna, Italy

[7] Department of Power Mechanical Engineering, National Tsing Hua University, Hsinchu, Taiwan

[8] Institute of Physics, Academia Sinica, Taiwan

[9] Department of Physics, National Changhua University of Education

[10] Department of Electrophysics, National Yang Ming Chiao Tung University

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Cubesat and Cubesat-class Instruments

Type	Mass (kg)	Maximum Dim. (m)	Orbit
Minisatellite	100-500	3–10	GEO, MEO, LEO, HEO
Microsatellite	10-100	1–5	LEO, HEO
Nanosatellite	1-10	0.1–1	LEO, HEO
Picosatellite	0.1-1	0.05–0.1	LEO, HEO
Femtosatellite	<0.1	0.01–0.1	LEO, HEO

- Cubesat and cubesat-class instruments fall under Nanosatellite category.
- They are
  - affordable,
  - have shorter development cycle,
  - can have various use cases.

Backstory

- We work in the design of Gamma-ray Instruments in the Medium Energy range (0.2 - 5 MeV).
- This current work is a future cubesat to be designed by our Czech colleagues in Masaryk university, Brno as an upgrade of their previous projects : GRB-alpha, GRB-beta, and VZLUsat.
- This above mentioned cubesats are not able to localize the GRBs while detection is possible.
- Thus, the current study is an exploration of various possible models and design parameters to be able to decide a future design.



Fig: ***GRB-alpha***

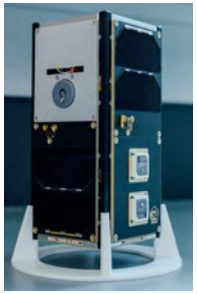


Fig: ***GRB-beta***



Fig: ***VZLUsat***

What's the Idea

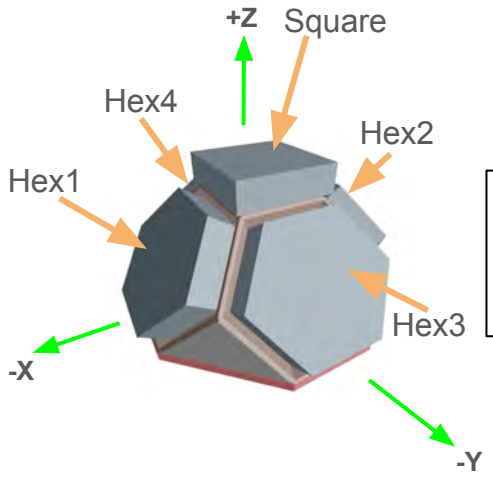
- 4 concept-models of the detector module
    1. Model-1: 4 hexagonal + 1 square
    2. Model-2: 4 hexagonal
    3. Model-3: 5 square (Inspired by GPM to be launched in 2028)
    4. Model-4: 4 square (Inspired by GTM to be launched in 2026)

- Model-1 and Model-3 is essential to study the improvement upon adding a 5th detector

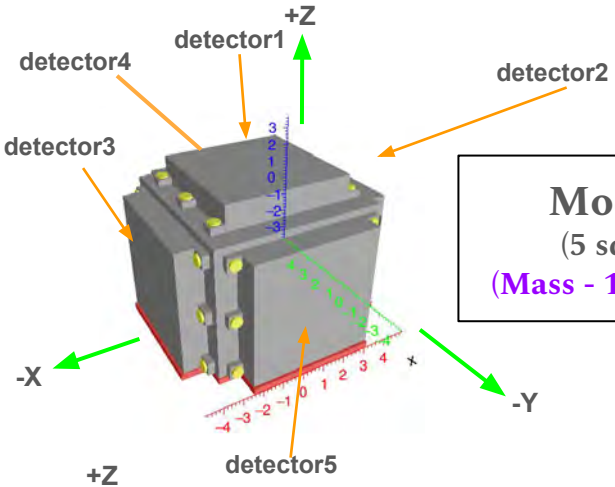
- Finally, we perform study of Detection Efficiency and Localization Capability of the four models.

Design and simulation

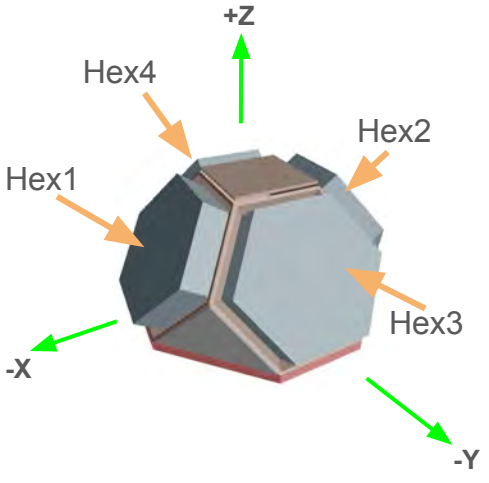
4 Models



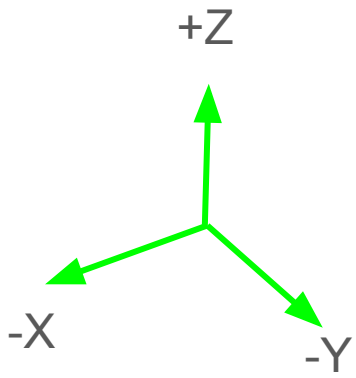
Model-1
(4 hexagon, 1 square)
(Mass - 687.315 g)

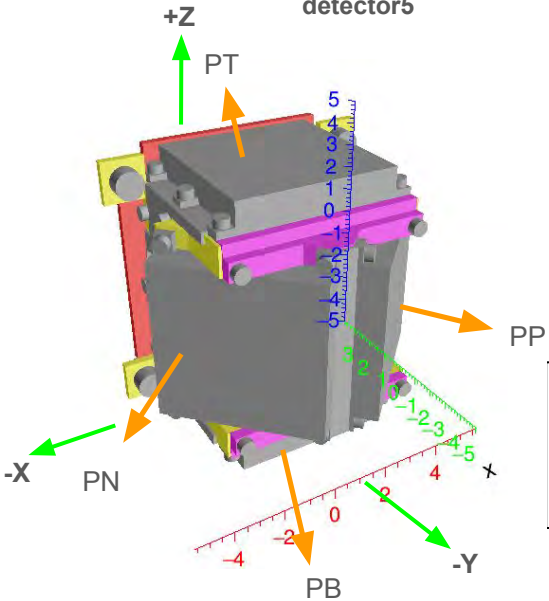


Model-3
(5 square)
(Mass - 1178.642 g)



Model-2
(4 hexagon)
(Mass - 643.709 g)

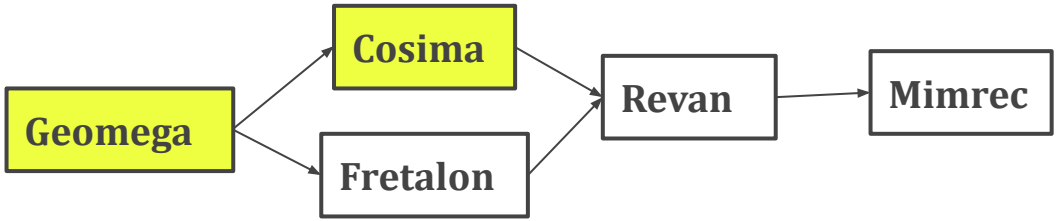




Model-4
(4 square)
(Mass - 1147.334 g)

MEGAlib

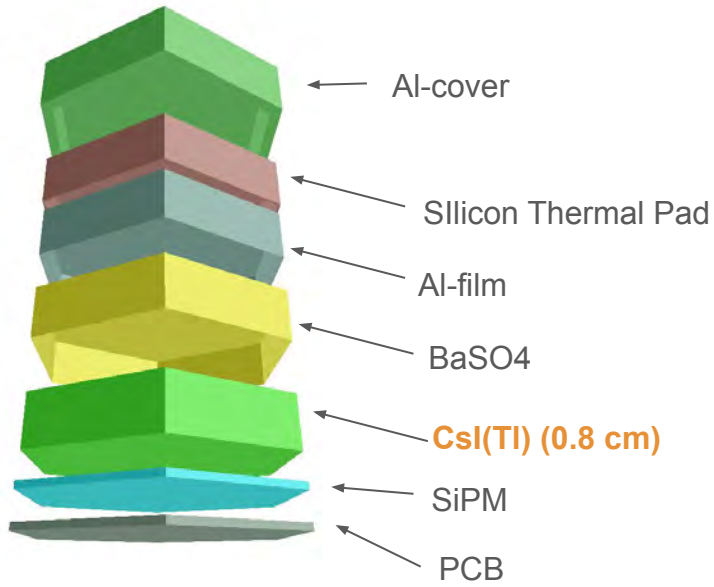
- The Medium-Energy Gamma-ray Astronomy library
- Developed by *Andreas Zoglauer et. al.*
- Main tools:
  - Geomega - creating the detector geometry
  - Cosima - Geant4 based simulation tool. Use Monte-Carlo
  - Fretalon - Calibration of measured data
  - Revan - Event Reconstruction
  - Mimrec - Event selection, Image Reconstruction



Design Considerations

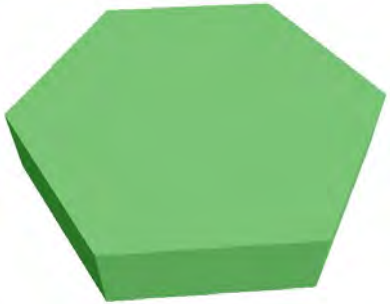
We considered the following aspects in our design :

- CsI(Tl) is the material used as scintillator
- We considered a 0.3 cm layer of Tungsten to protect the SiPM from radiation damage
- We also restrict the total weight budget of each model within 1.2 kg



Layers of a sensor unit. Except for the surface area, the layers are same

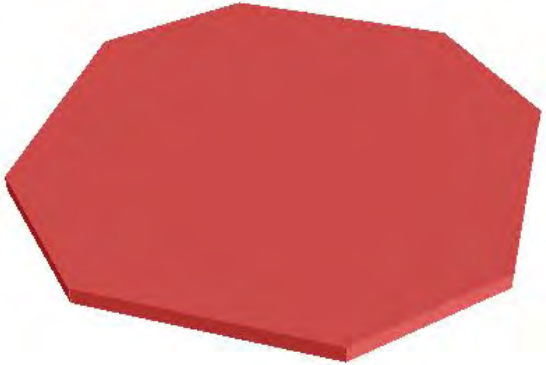
Sensors units



Hexagon
(12.5 cm^2 CsI)

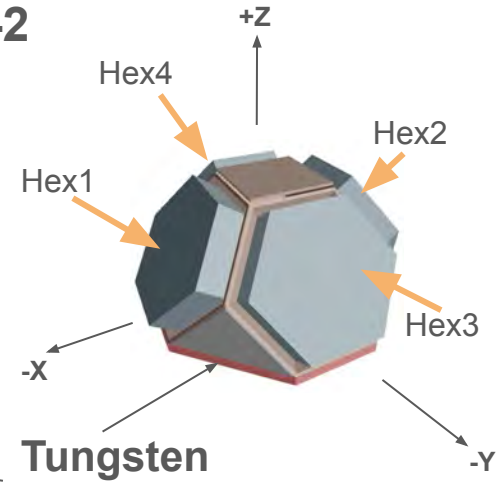


Top Square
(8 cm^2 CsI)



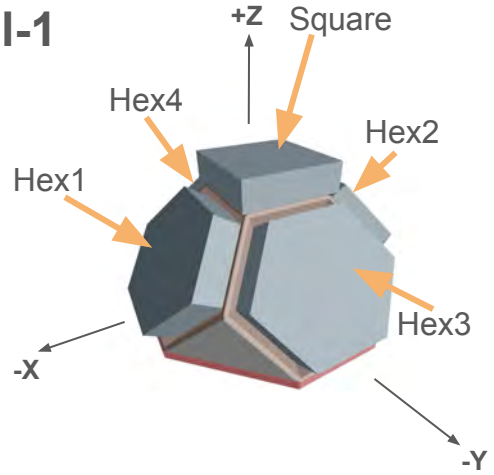
Tungsten Base
(0.3 cm thick)

Model-2

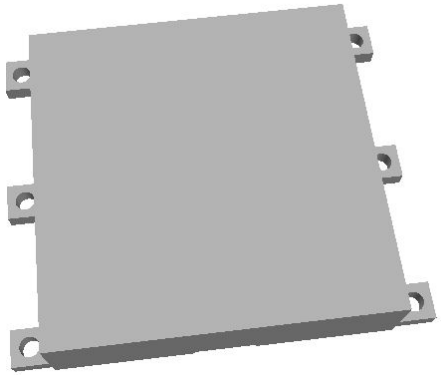


Tungsten
Base

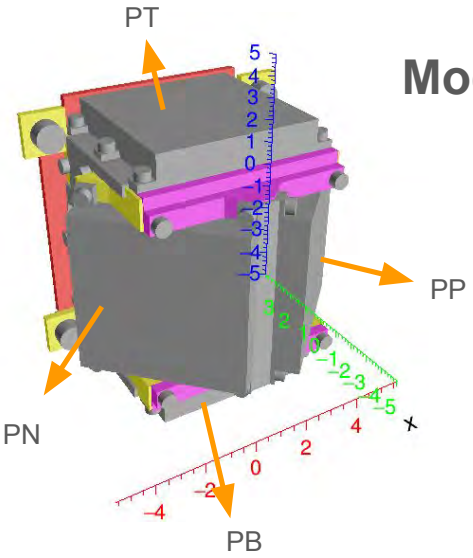
Model-1



Sensors units

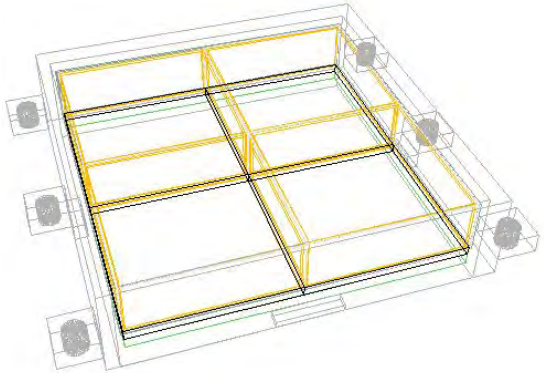


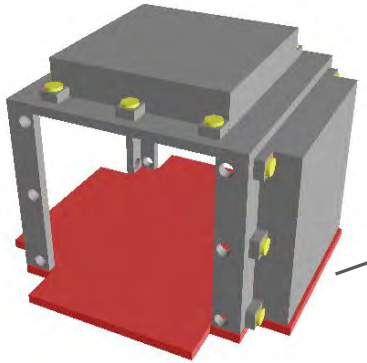
Square Detector
(23.04 cm^2 total CsI area)

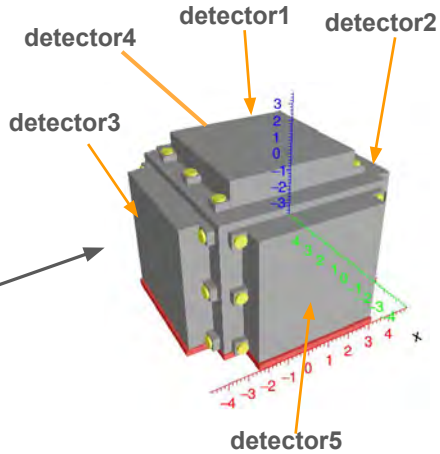


Model-4

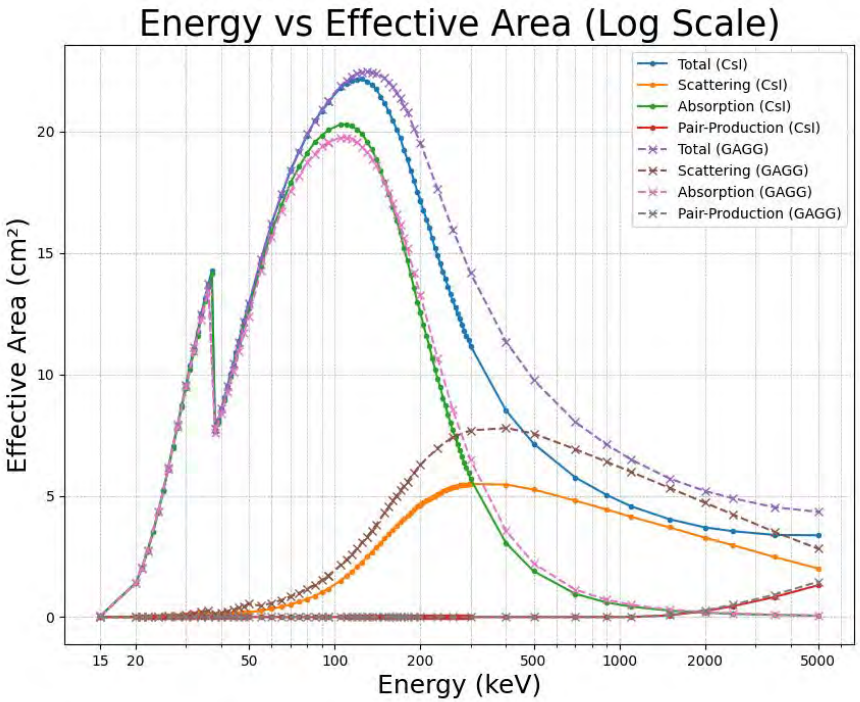
Model-3







Why CsI?

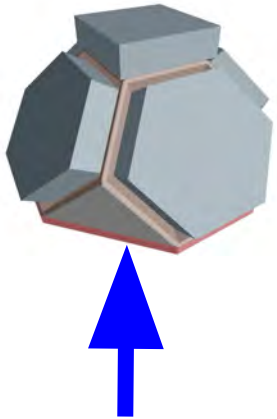


- If compared, GAGG is better than CsI in certain aspects like being hydroscopic, higher effective area etc.
- But CsI(Tl) is a cheaper alternative with satisfactory performance.
- Properties of CsI(Tl):
  - 4.5 g/cm^3 density
  - 16 ns decay time
  - 550 nm emission peak
  - 65,000 +/- 5000 light yield (even higher than GAGG)
- In our study we consider energy cut 50-300 keV

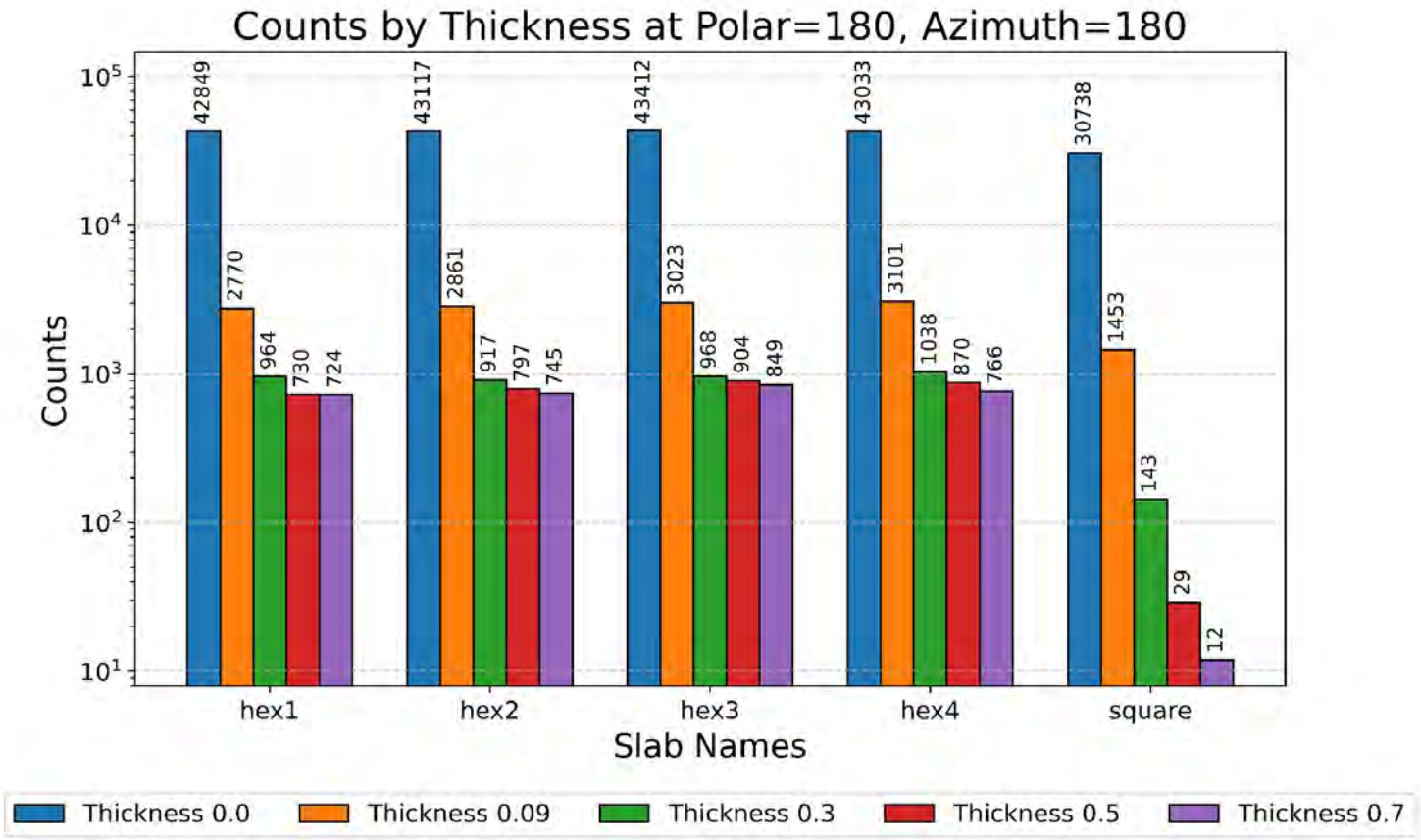
Why Tungsten?

- Primary reason is to prevent photons from the other side.
- This helps is the localization study by restricting the sources within a certain FoV
- Besides, they help protect the electronics from radiation damage
- 0.3 cm thick layer to prevent roughly 95-99% of the photons

Base Thickness Comparison



- Soft GRB
- Energy cut: 50-300 keV



Spectrum Model :

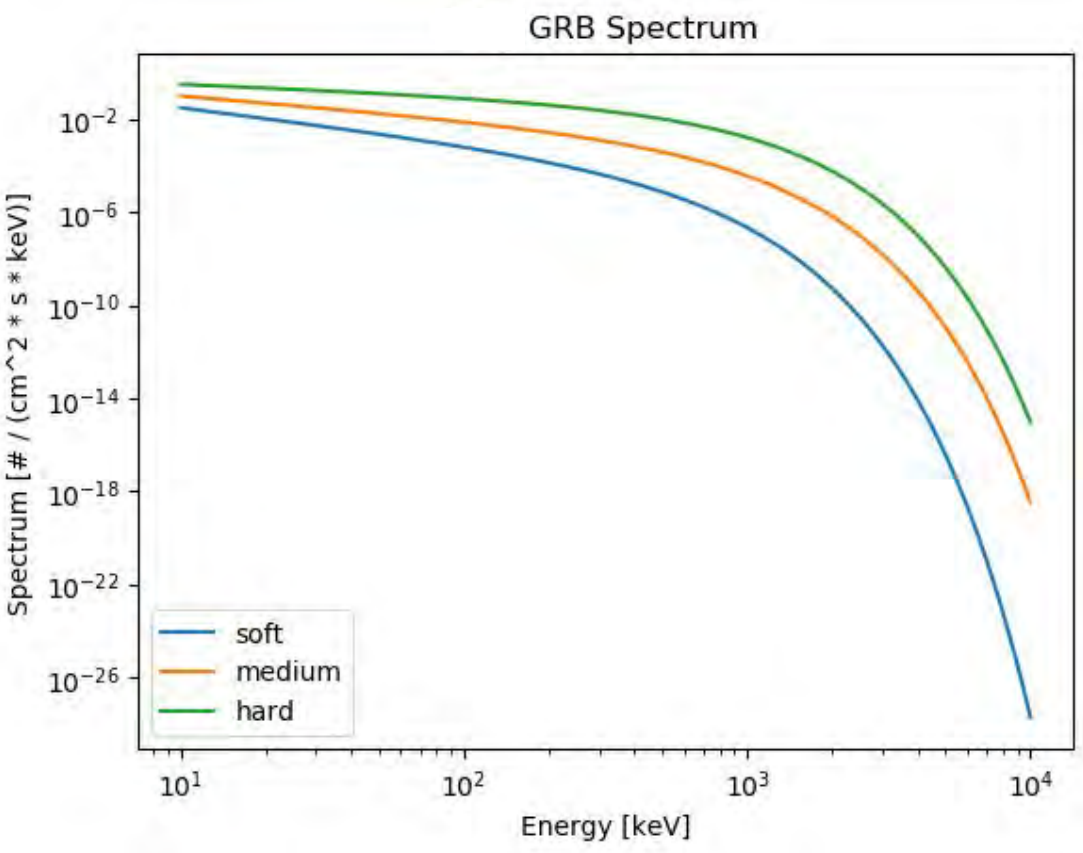
$$f_{CPL} \propto E^{\alpha} exp\left(\frac{-E(2+\alpha)}{E_P}\right)$$

, where α = Photon index,
E_P = Peak energy

Exponentially cut-off power law from Konus Wind Catalog

(Svinkin et al., 2016, Tsvetkova et al., 2017)

GRB Spectrum

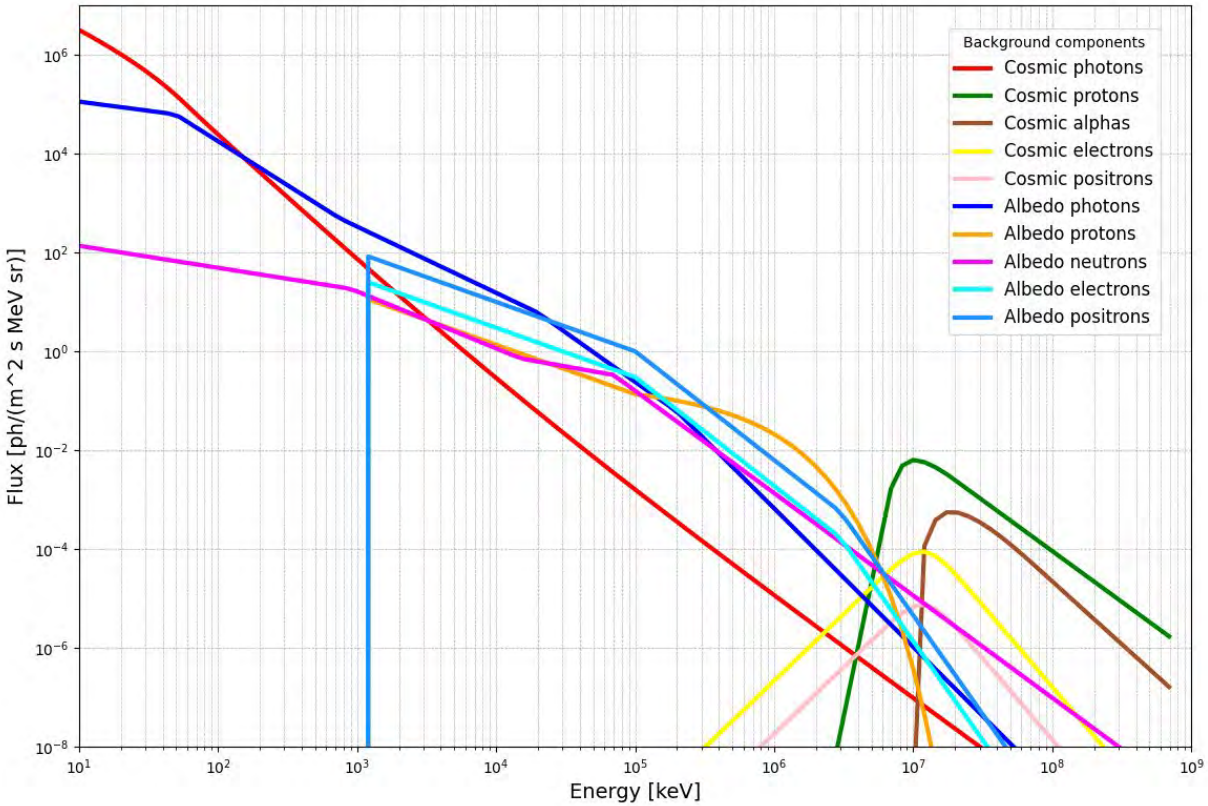


GRBs	α	E_P (keV)
Soft	-1.5	100
Medium	-1.0	300
Hard	-0.5	500

α = Photon index,
E_P = Peak energy

- Soft/medium => Long GRB (10s)
- Hard => Short GRB (0.5s)

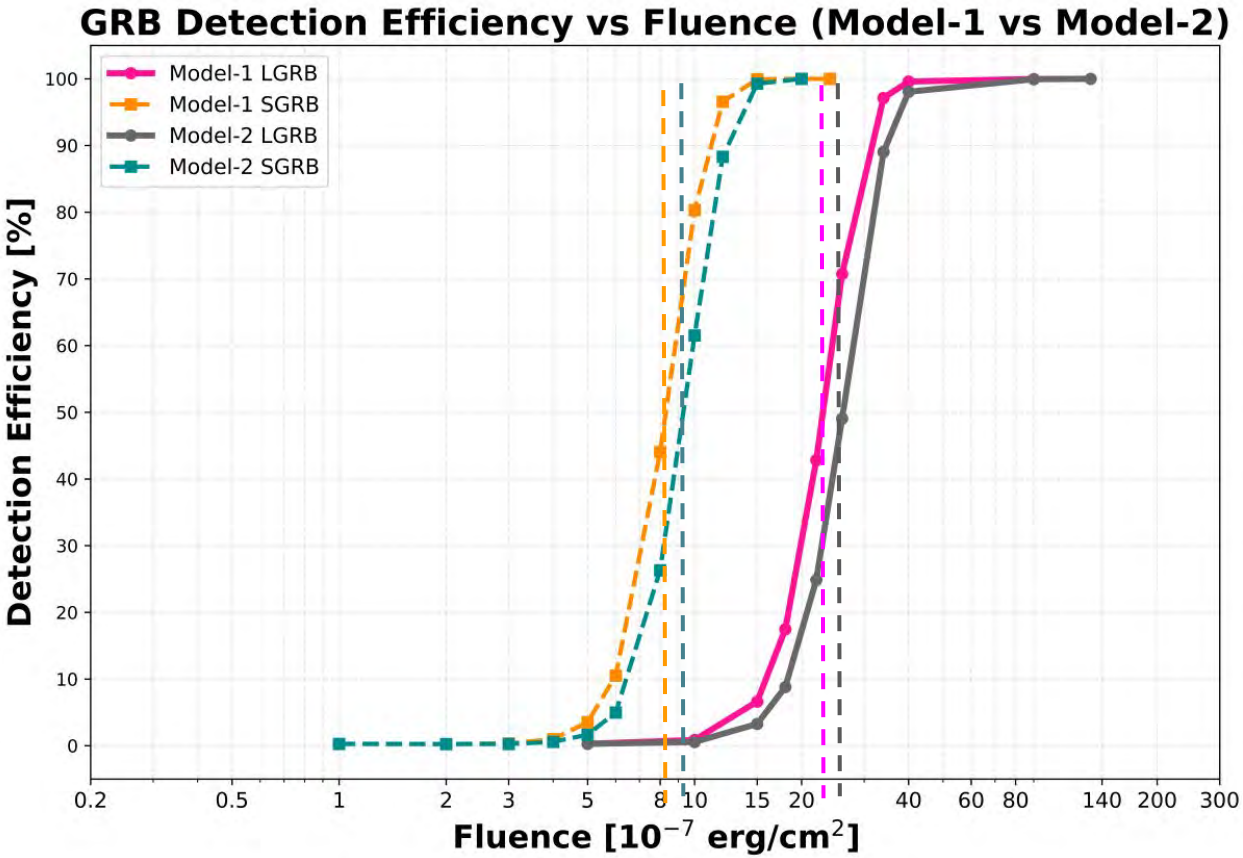
Background Spectra

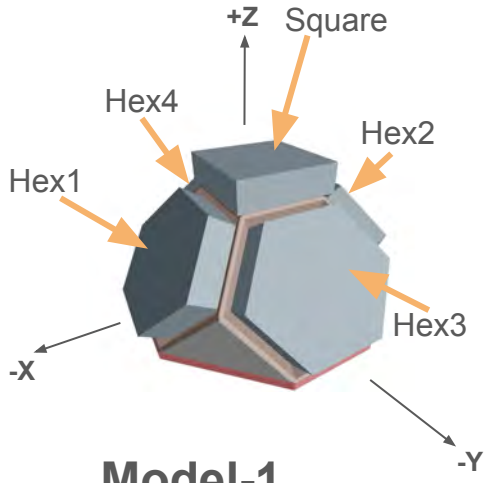


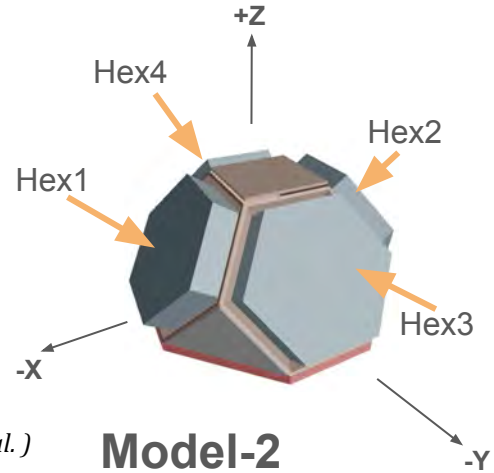
- Model from SPENVIS
- LEO (561 km)
- Orbital Inclination at 97°
- Sun-synchronous Polar Earth Orbit
- 10 keV to 1 TeV

Models	Bkg Count Rate (50 - 300 keV)
Model-1	15.5
Model-2	20.5
Model-3	36.5
Model-4	36.8

Results







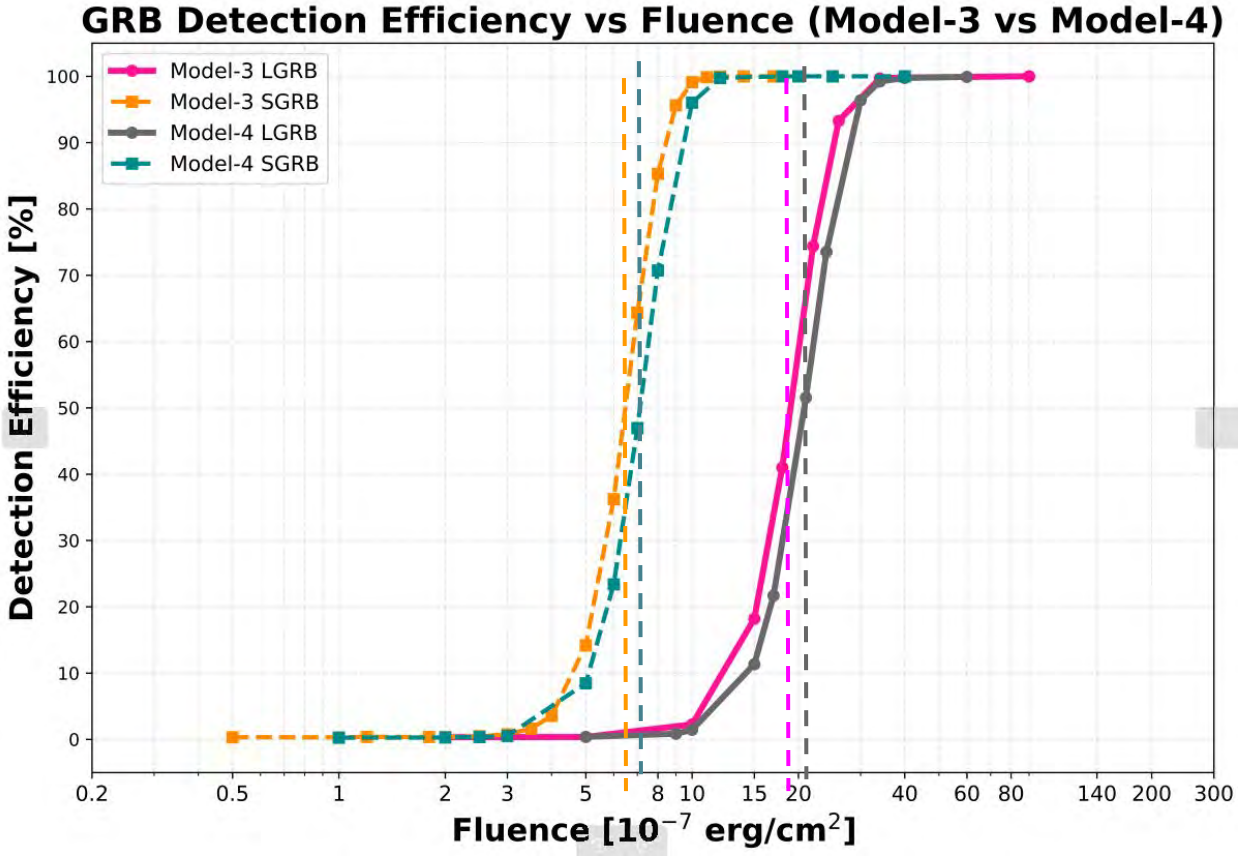
Model-1 SGRB: 9 SGRBs/year

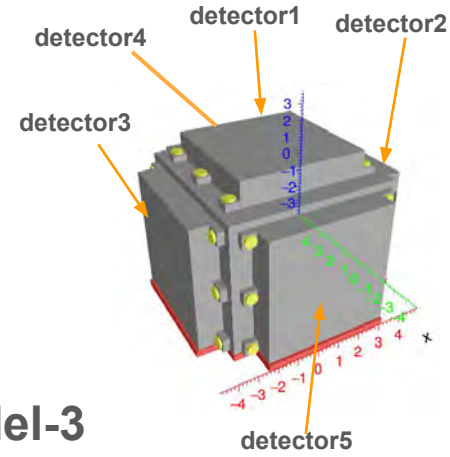
Model-1 LGRB: 150 LGRBs/year

Model-2 SGRB: 7 SGRBs/year

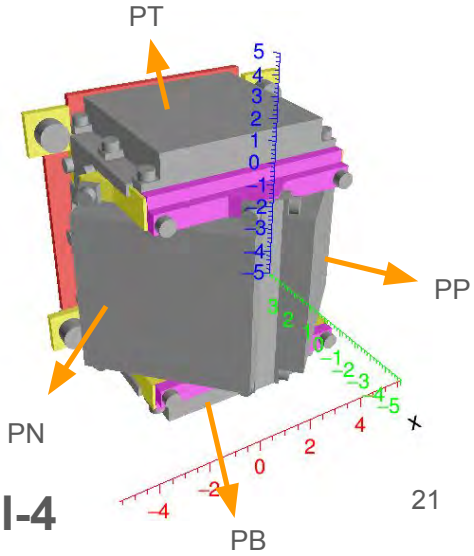
Model-2 LGRB: 130 LGRBs/year

(A von-Kienlin et. al.)





Model-3



Model-4

(A von-Kienlin et. al.)

Model-3 SGRB: 13 SGRBs/year

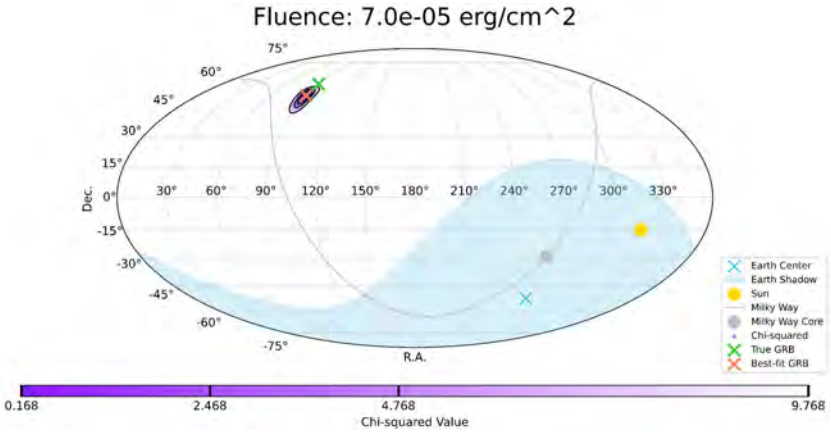
Model-3 LGRB: 180 LGRBs/year

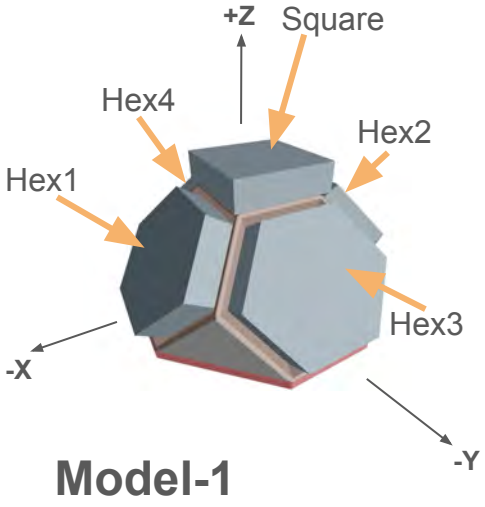
Model-4 SGRB: 10 SGRBs/year

Model-4 LGRB: 165 LGRBs/year

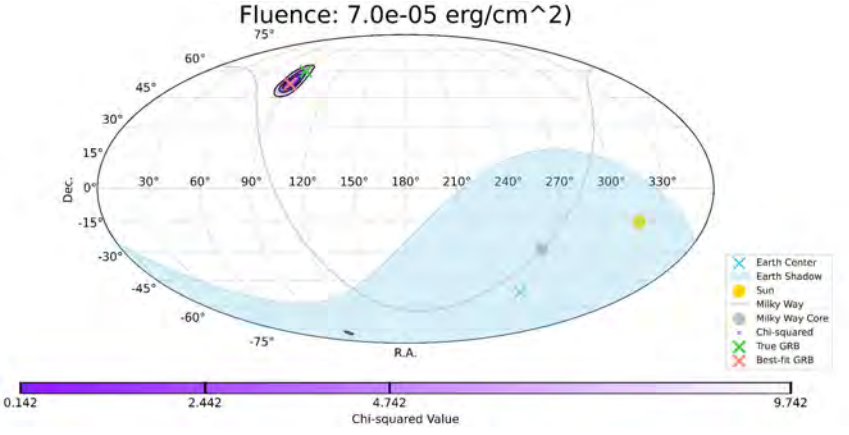
Bright GRB

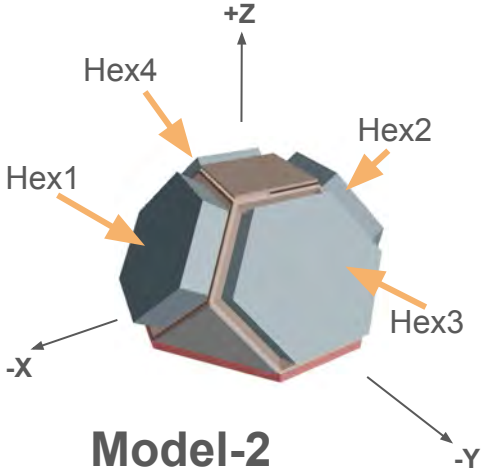
- Energy cut: 50-300 keV
- GRB dir: (30,90)
- Fluence: 7e-05 erg/cm^2





Model-1

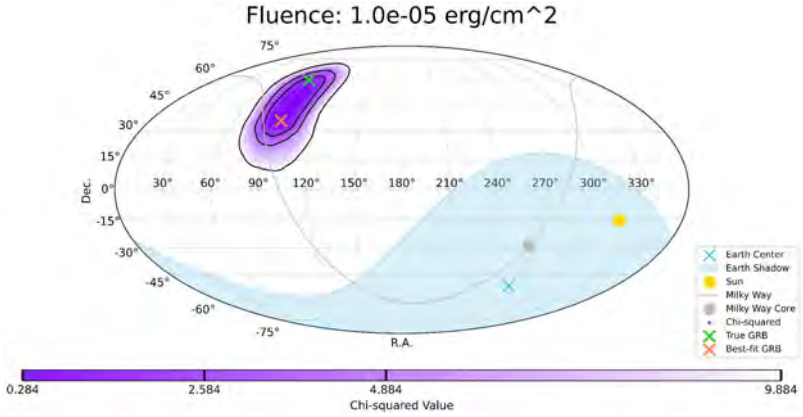


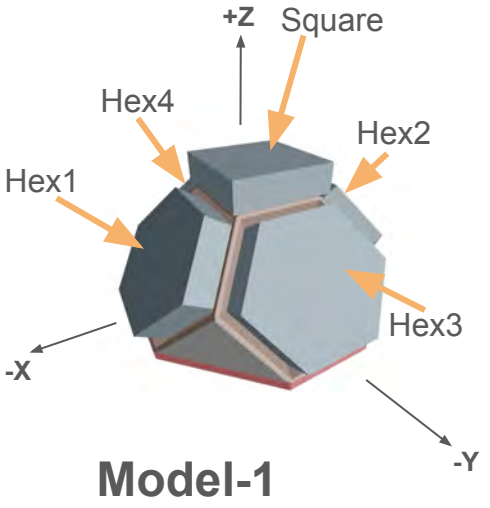


Model-2

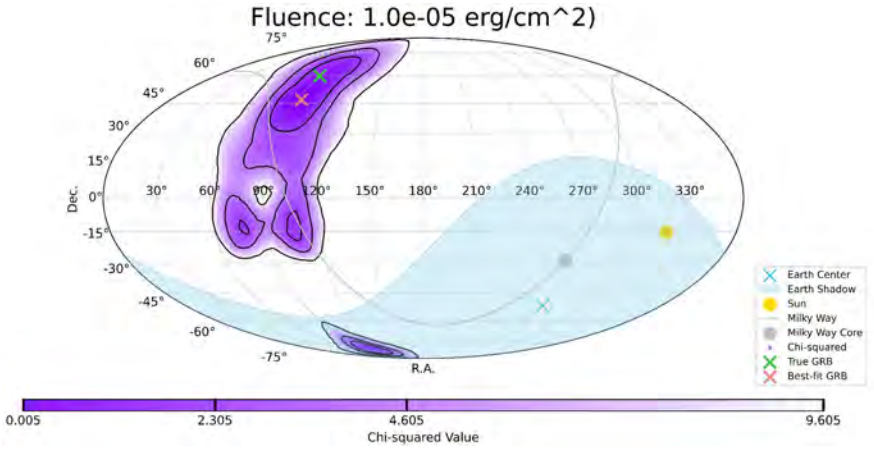
Dim GRB

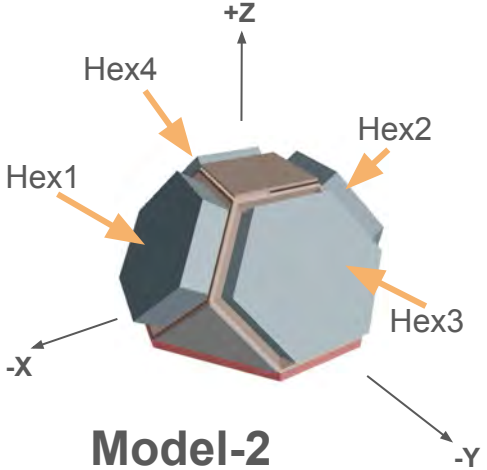
- Energy cut: 50-300 keV
- GRB dir: (30,90)
- Fluence: **1.5e-05 erg/cm^2**





Model-1

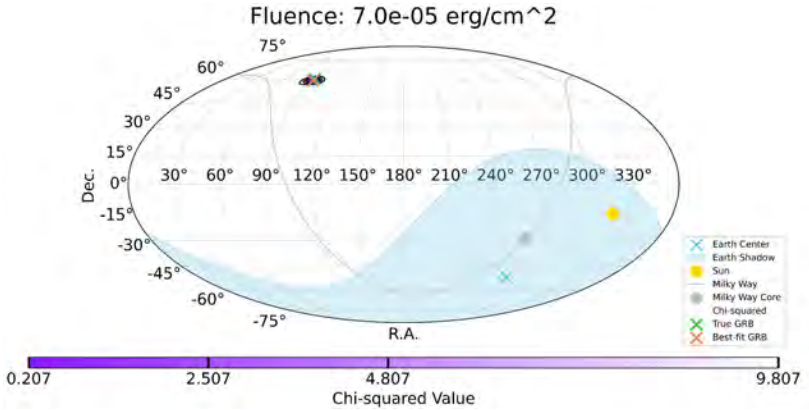


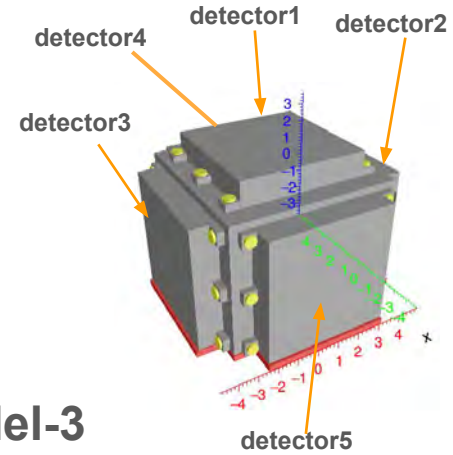


Model-2

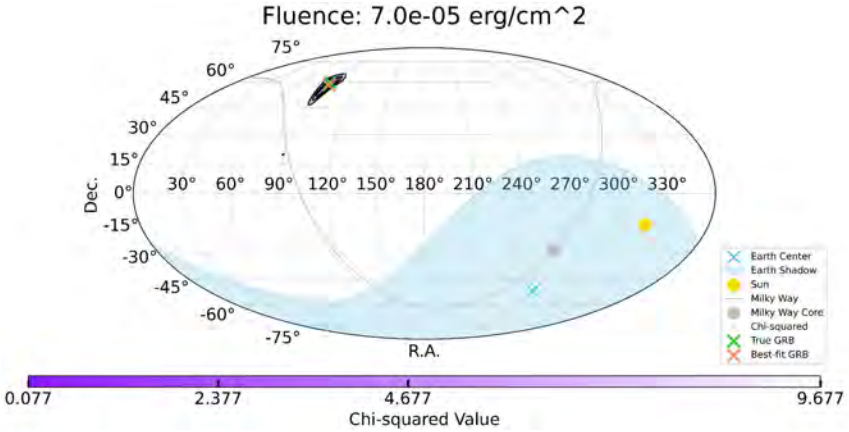
Bright GRB

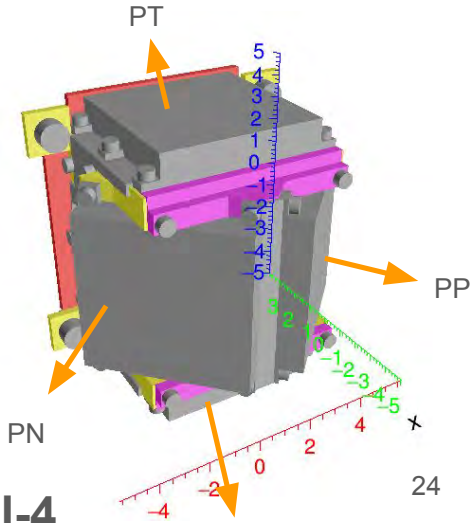
- Energy cut: 50-300 keV
- GRB dir: (30,90)
- Fluence: **7e-05 erg/cm^2**





Model-3

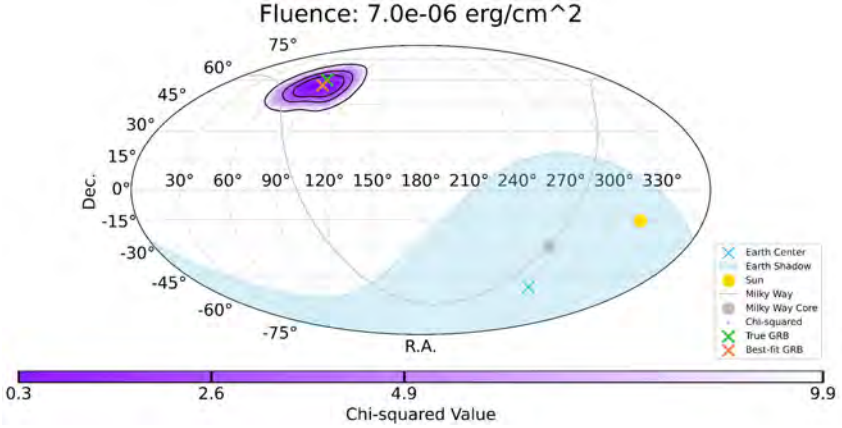


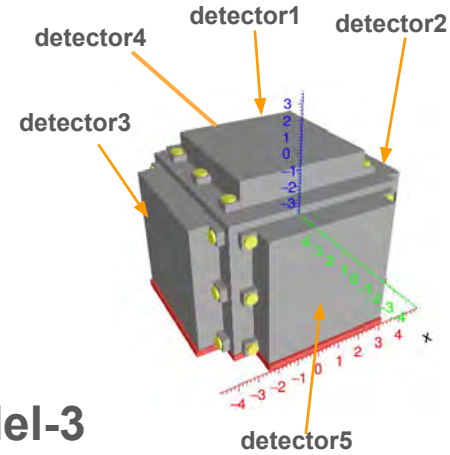


Model-4

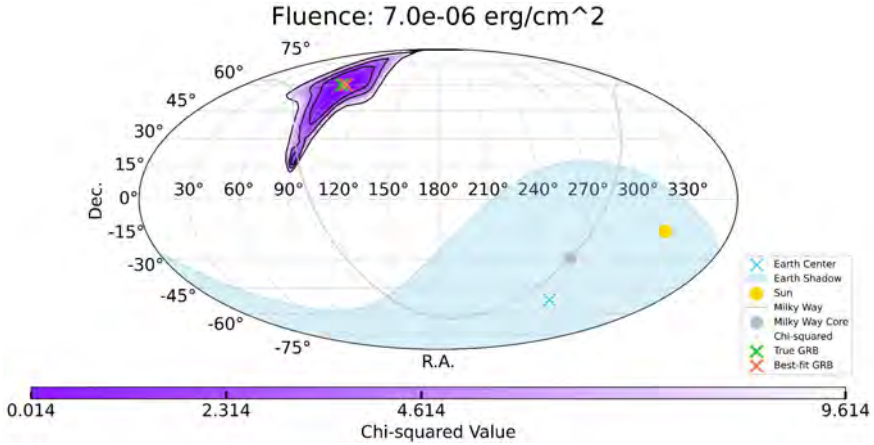
Dim GRB

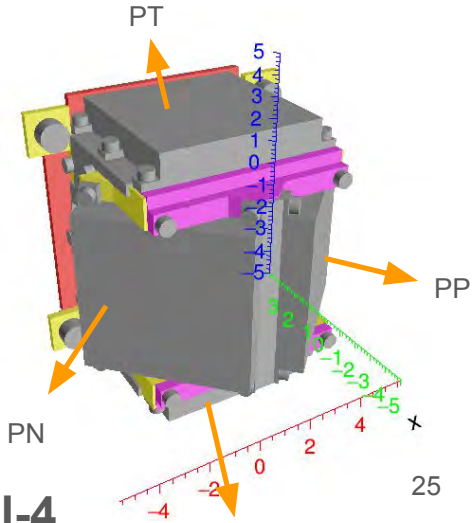
- Energy cut: 50-300 keV
- GRB dir: (30,90)
- Fluence: **7e-06 erg/cm^2**





Model-3





Model-4

Conclusion

1. We can observe improvement in the detection efficiency and localization capability upon adding an extra detector.
2. The thickness of the Tungsten can be reduced upon adding the bus which is not added in our study.
3. The project is still in the proposal phase.
4. The finalized model will be decided upon weight and budgetary constraints

Thank you for your patience