High Redshift Gamma-Ray Bursts

The ARGO telescope

(A high-Redshift Gamma-ray bursts Observatory)

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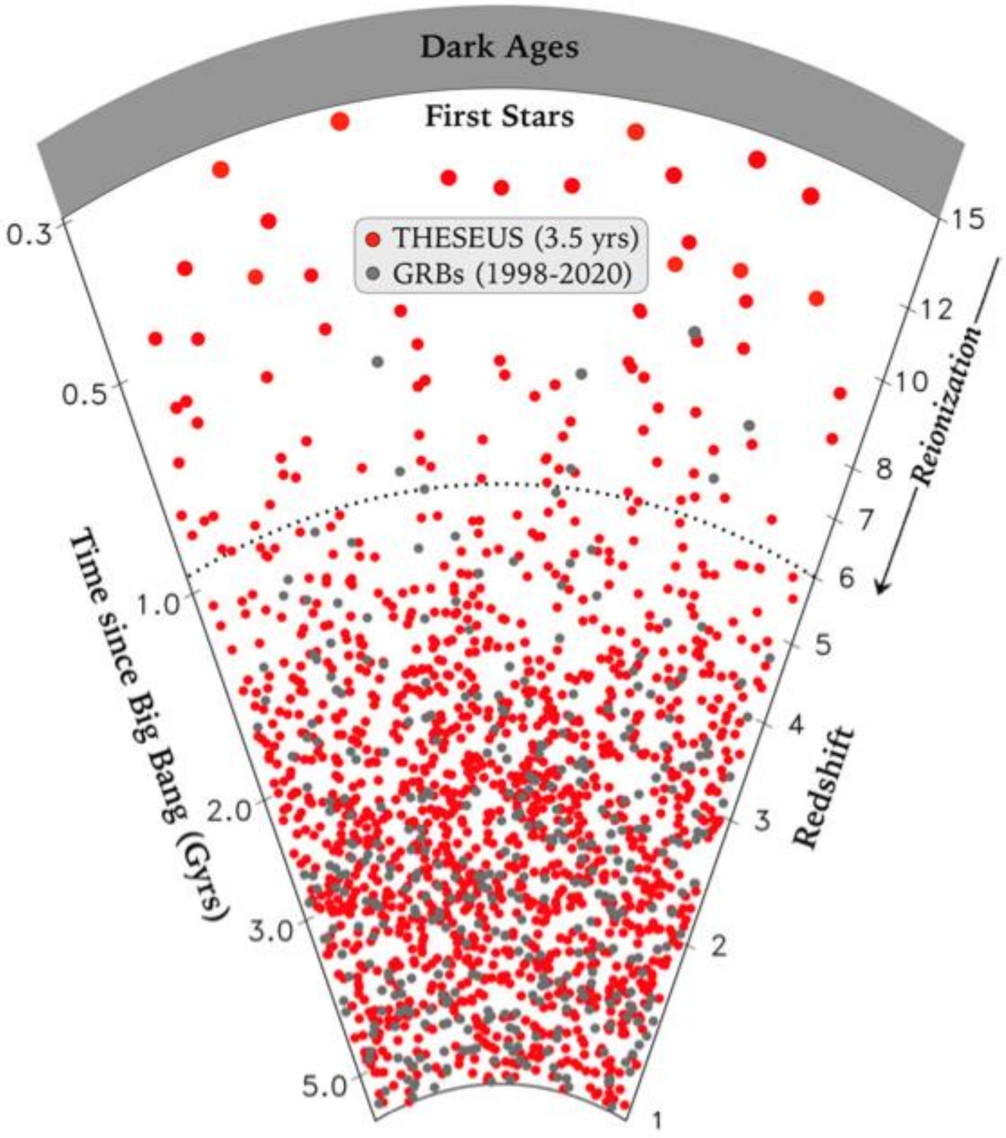
Scientific goals

- Primary: Studying long-duration high-z GRBs as a means of probing the high-z universe:
  - Using long high-z GRBs to improve the efficiency of selecting high-z objects
  - Investigate long high-z GRBs to assess the SFR in the early universe
- Secondary: Providing an archive of GRBs to assist future studies
- Note: high-z refers to $z>6$

Scientific background

- GRBs: short, rare, highly energetic events
  - Long GRBs: collapse of a massive star (supernova/hypernova)
  - Afterglow: lower energy radiation following the burst
- GRB can be detected to high z due to brightness, so can provide information about high-z galaxies
- GRBs can be used to facilitate further study high-z galaxies (chemical composition, metallicity), so can map galaxy evolution
- GRB redshift is determined with photometry of afterglows
- GRB can be used to study SFR: relation between z and SFR
- Efficient at selecting high-z objects because not affected by dust and very bright
- Past missions: Swift, INTEGRAL, Fermi, THESEUS

GRB distribution with redshift for GRBs detected before THESEUS, and predicted to be detected by THESEUS

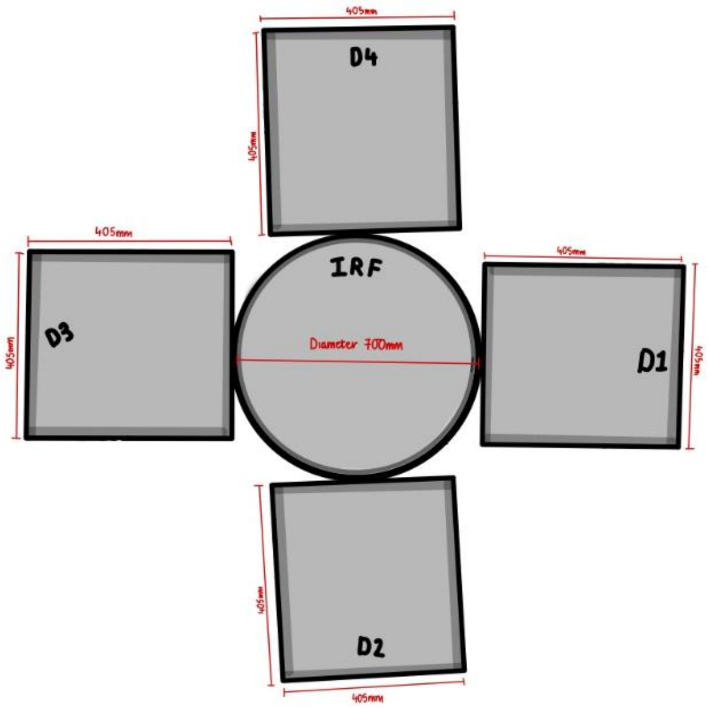


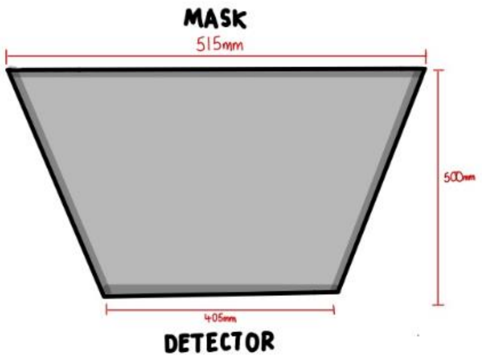
Instrument Requirements

- High energy of GRB requires instrument in higher range of spectrum, so gamma ray instrument with energy range 10-150 keV
- High-z GRB detection requires follow up for afterglows at optical/IR/X-rays, but very highly redshifted to longer wavelengths
- Maximize field of view, to get as much sky coverage as possible, to maximize detection of GRBs: four detectors with 2.21 sr
- Need good temporal resolution (short events) and good angular resolution to detect them accurately

Gamma Imaging Detector (GID)

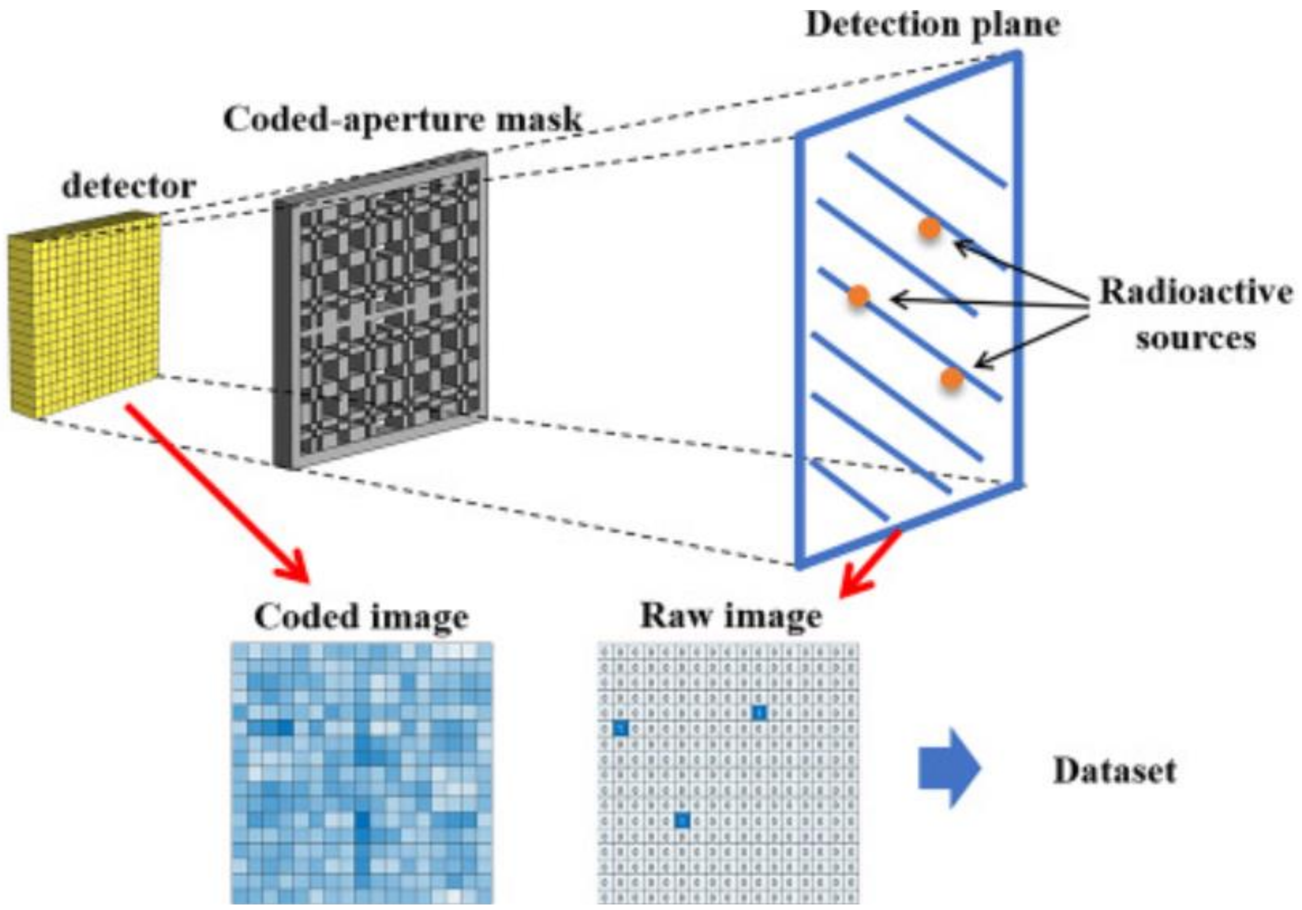
Energy Band	10 keV – 150 keV
# Detector Pixels	6561
Pixel Size	5mm x 5mm
Effective Area	820.125 cm^2
PCFOV	85 x 85 deg^2
FCFOV	10 x 10 deg^2
Angular Resolution	11.3 arcmin
Mass	500kg





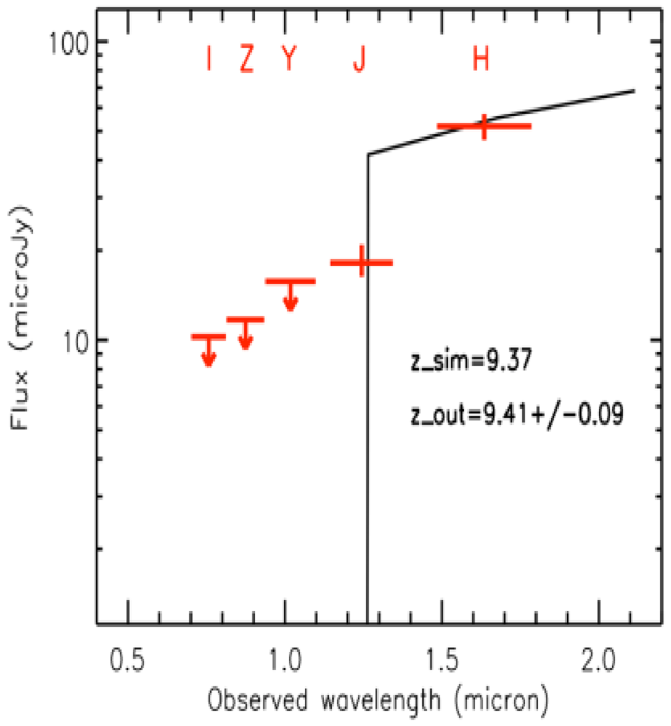
Coded Aperture Imaging

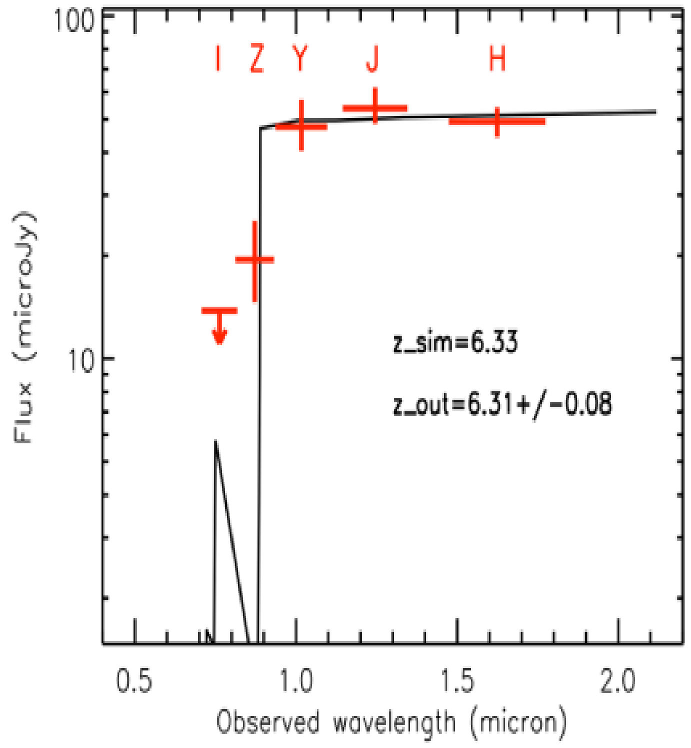
- 1mm thick Tungsten coded mask
- Coded area 515 x 515 mm^2
- Mask elements size 10 x 10 mm^2
- Utilises a 50 % open, random pattern to locate sources



Follow Up Observations with IRT (THESEUS)

- Off-axis Korsh Infrared Telescope
- Primary mirror – 0.7 meters
- FOV - 15' x 15'
- Wavelength range 0.7 -1.8 microns





Power Requirements

Gamma Detectors	120 W (x4)
Infrared Telescope (IRT)	110 W
Thermal	70 W
Communications	138 W
Data Handling	82 W
AOCS	126 W
Propulsion	1 W
Total (with 20% margin)	1208.4 W

How we chose the detector:

- Operational Energy ranges
- Mass
- Extra requirements e.g. Germanium needs cooling
- Resolution and sensitivity
- Looking at past missions and understanding why they chose a particular detector

Gas Detectors	**Germanium detectors**	**Silicon detectors**	**Mercuric Iodide detectors**
MWPC (Multi wire proportional centre) can give position resolutions better than 1mm	Higher Z and denser than gas detectors → better efficiency Less energy required to produce electron pair = best energy resolution	Operates very similarly to Germanium	Greater atomic no. and density than CdTe → Greater detection efficiency
Operational range 1keV-100keV Geiger-Muller tube gives no info on originator of event	Operates at 70K so requires cooler - heavy	Larger band gap – lower energy resolution Impurities in material means small depth for interactions	Operational energy 10keV-80keV Suffers great charge trapping problems

CdTe Detectors:

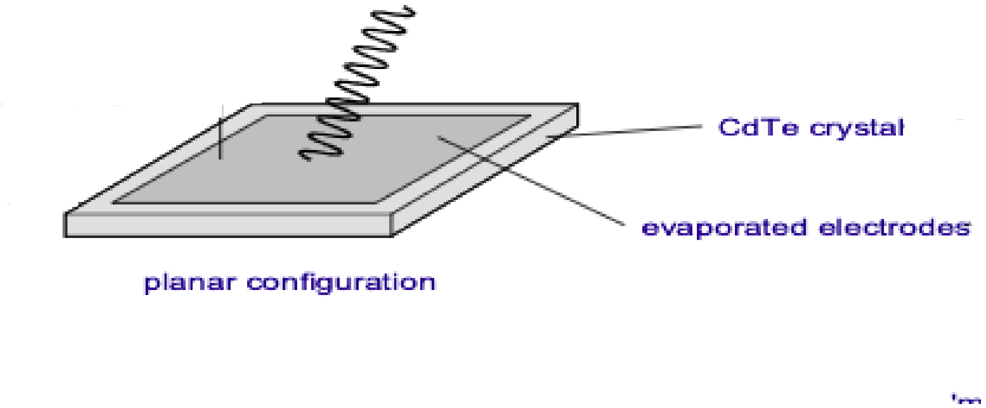
Why it's a good fit for our model:

- High Z, high density material

→ Provide good detection efficiencies with thin 2mm detectors

- Operational range between 5-250keV
- Can be used at room temperature

- Charge Trapping



Shielding

Shielding Material

- We came across BGO, CsI(TI) and Plastic Scintillators for Active shielding
- For passive, Lead and Tungsten where the materials considered.

BGO

High interaction probability and shielding efficiency
Low energy threshold (~150 keV)

CsI(TI)

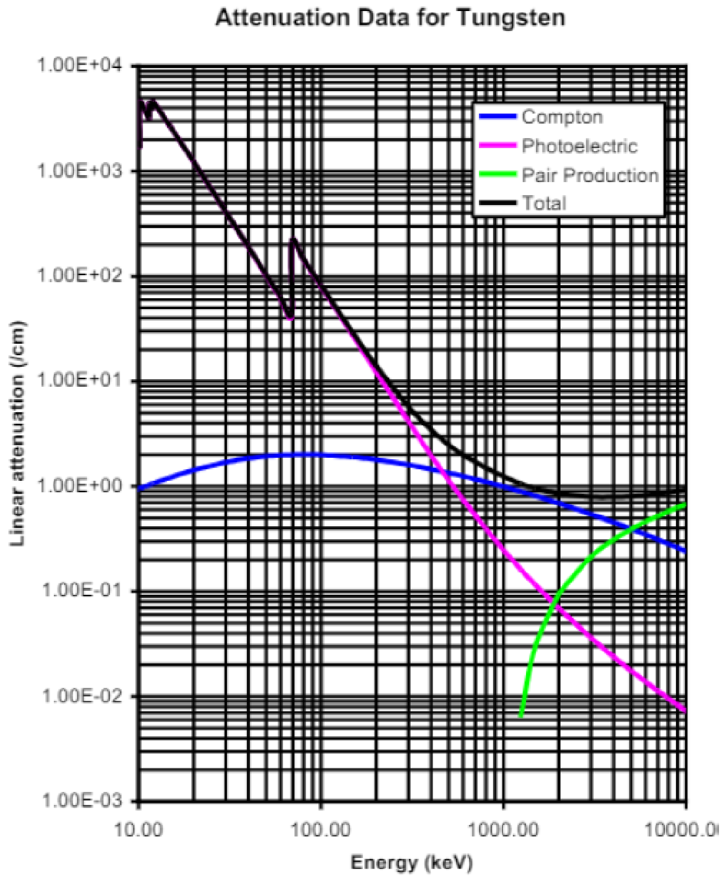
Low energy threshold (~100 keV)
Not dense as BGO, cheap and easier to build.

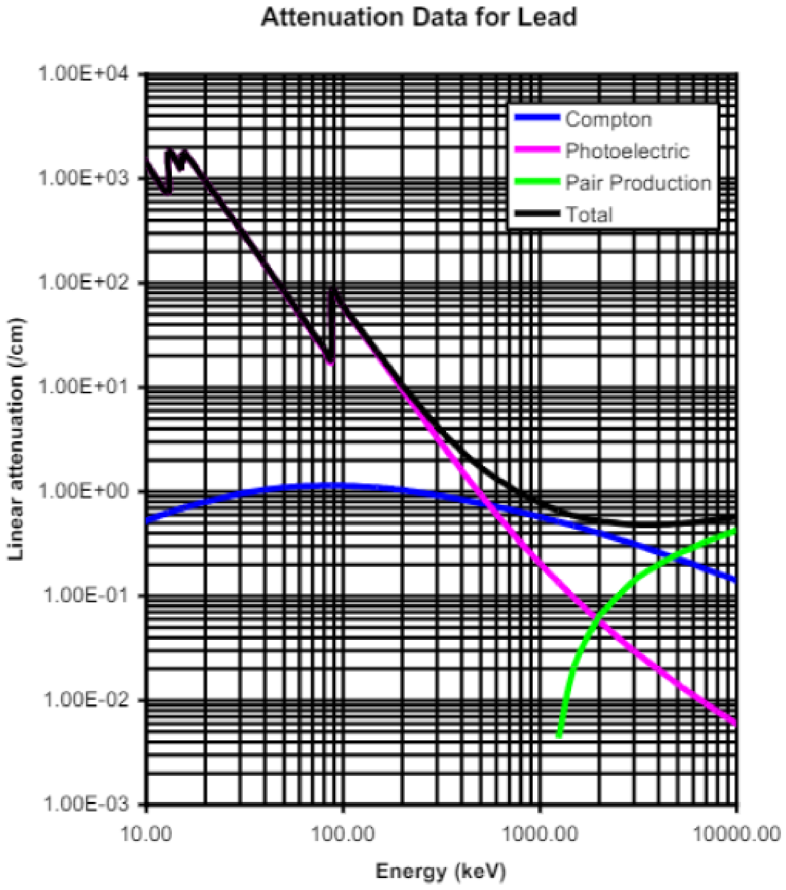
Plastic scintillators

Excellent for detection of gamma rays passing through without attenuating.
We need to detect and estimate the energy of gamma ray for our study, so this is not useful.

- Among Lead and Tungsten, tungsten is having more linear attenuation coefficient in our region of interest (around 150 keV).

Linear attenuation Curve for Tungsten and Lead



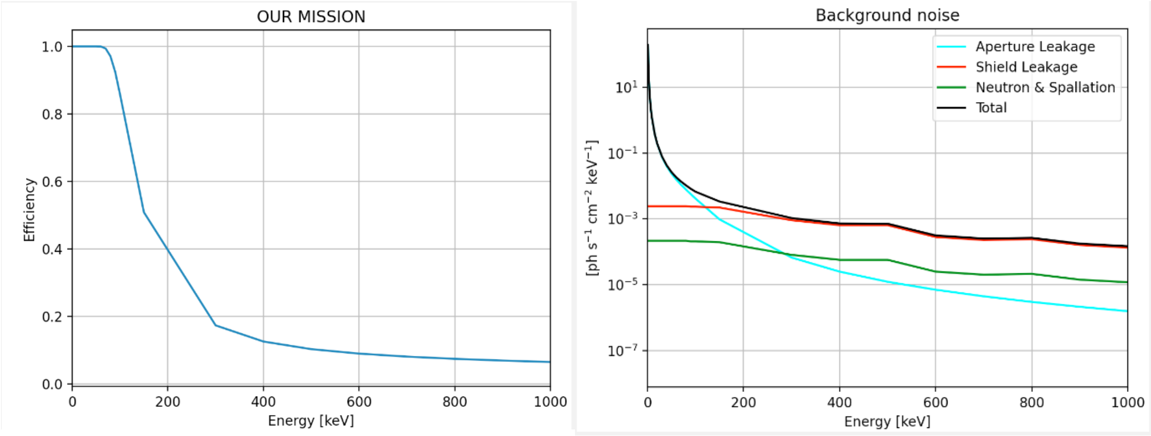


Passive Shielding over Active Shielding

- Active shielding makes it complicated as there are more tubes placed around the detector.
- It adds more mass to the payload.
- It adds additional electronics which we will have to power. Also, there might be some noise possible from the electronics.
- In addition to all this, we are interested in photons that are of low energy which does not produce more secondary electrons.
- Considering all of these, we choose to go with passive shielding and chose the shielding material as <u>Tungsten</u> (5 sides of detector).

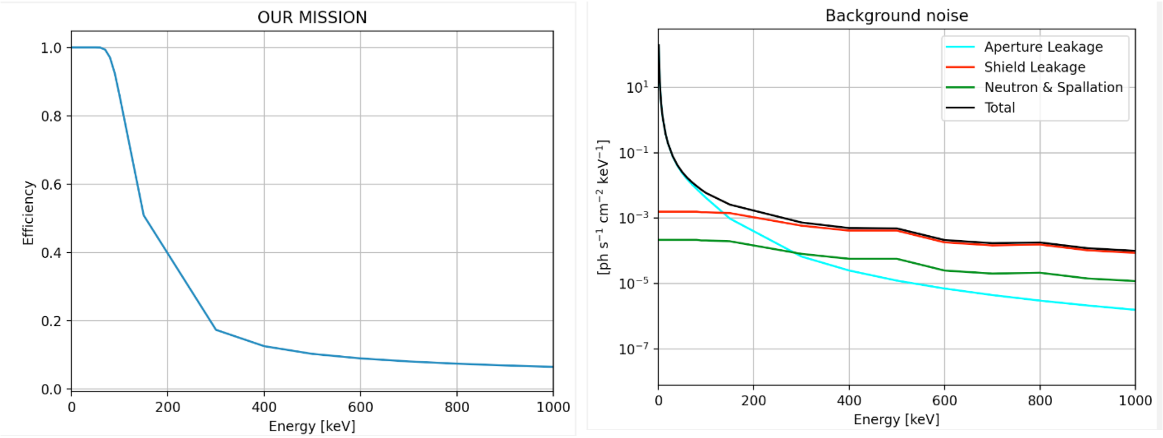
Shield Thickness

After trying different thickness, we fixed on thickness=2cm over sides and thickness=0.3 cm at bottom as it is giving optimum parameters



Shielding: Tungsten (ρ= 19.3g/cm^3), thickness=0.3cm

Shielding: Tungsten (ρ= 19.3g/cm^3), thickness=2cm



Attenuation Equation

$$I/I_o = \exp[-(\mu/\rho)x] \ .$$

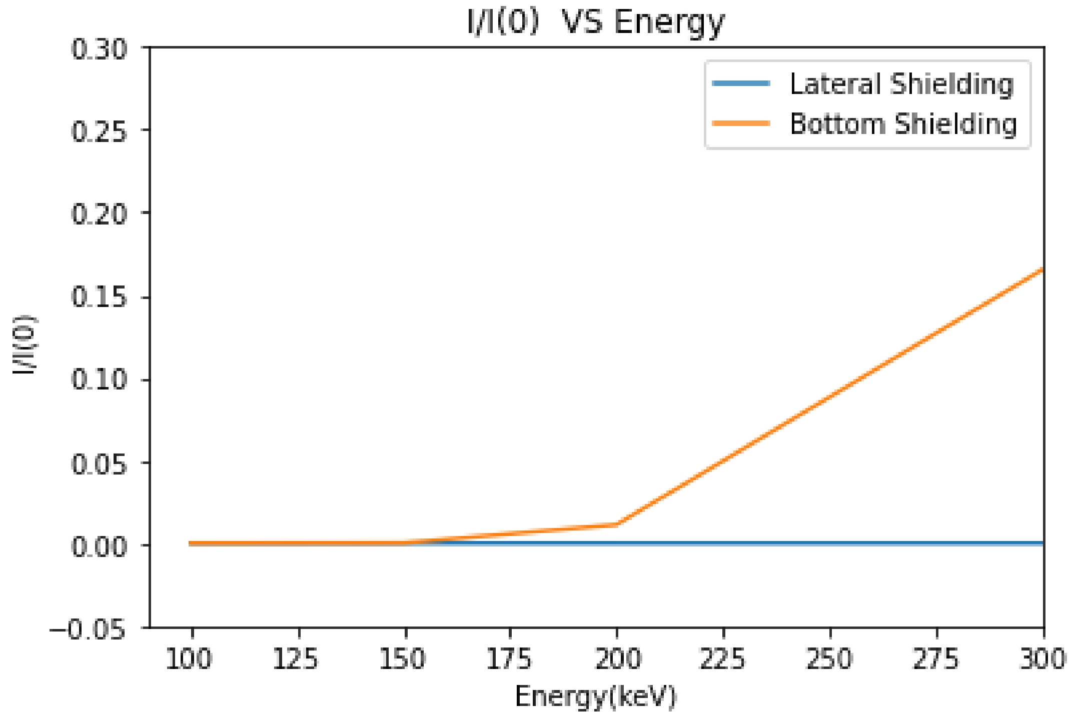


Figure: Attenuation for lateral (thickness=2cm) and bottom shielding (thickness=0.3 cm)

Orbit

<u>Advantages of LEO(Low Earth Orbit):</u>

-orbit can be tilted

-granting a low and stable background level in the high-energy instruments

-less fuel needed

-no need for powerful transmitting tools

-provides a good environment for science

<u>Disadvantages of LEO :</u>

-orbital periods are of the order of 90 minutes, which means that satellites will only be visible from 5 to 20 minutes per orbit, before it goes over the horizon (depending on altitude)
-no science data is recorded while the telescope is transiting the South Atlantic Anomaly(SAA) and polar regions
-LEO satellites are affected by an atmospheric drag that makes the orbit deteriorating gradually and the typical lifetime of a LEO satellite is 7–10 years
-both the satellite and the earth station antennas must be highly directional

Orbit parameters of ARGO telescope:

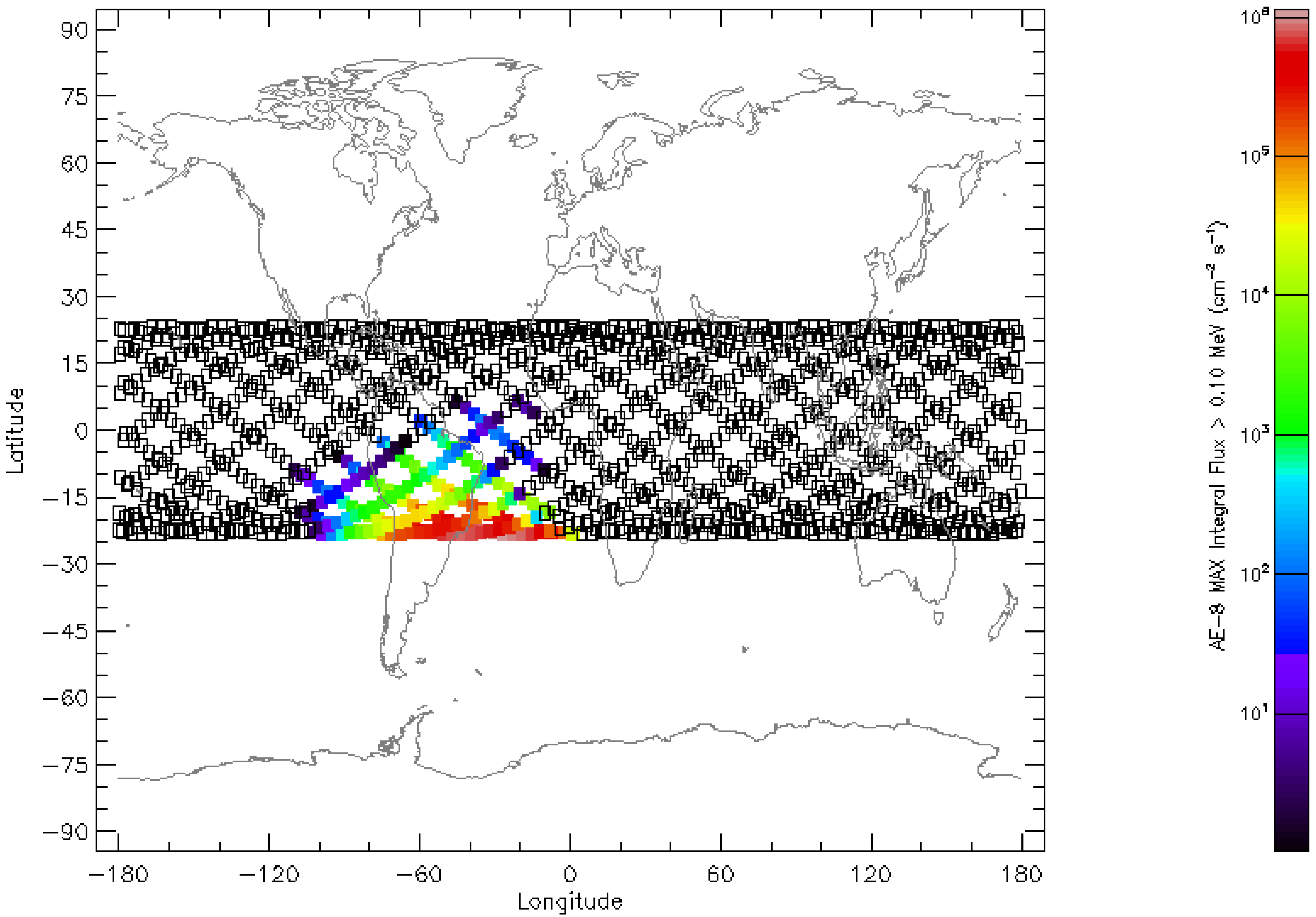
- Perigee altitude: 560km
- Apogee altitude: 700km
- Eccentricity:0.11
- Inclination angle: ~23°
- Orbital Period: ~97 minutes
- Revolutions/day:~15

Observing strategy:

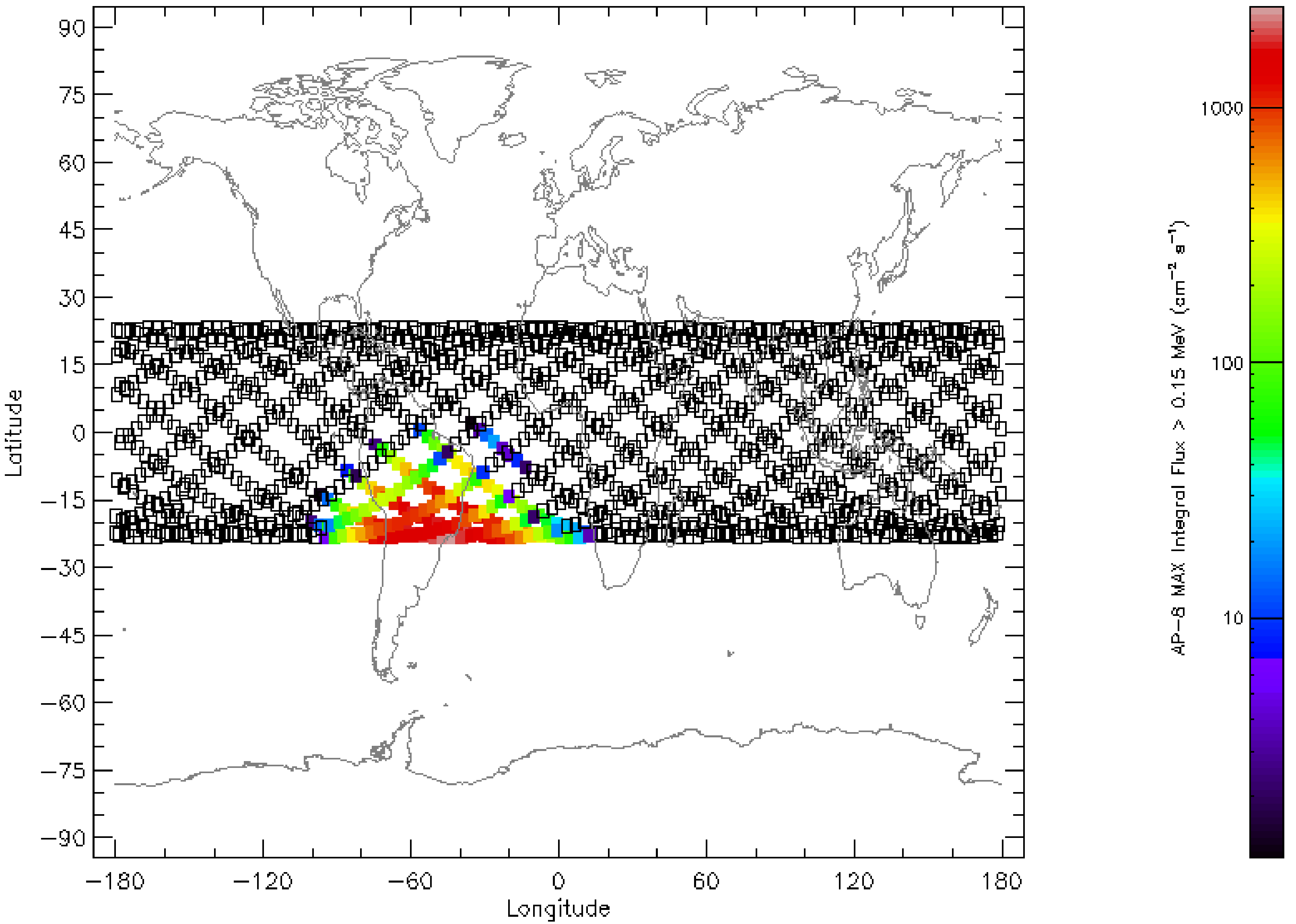
-avoid pointing at or near the Earth to maximize the detection of astrophysical photons
-GRB's happen any time, therefore more than one ground station is required
-the detectors look for an increase in radiation, locate the source and repoint the infrared camera

Components	Unit Weight (kg)	Quantity	Total Weight (kg)
Mask Support Structure	100	4	400
Electronics	100	4	400
Power Supply	25	4	100
Star Sensor	30	4	120
Heaters	25	4	100
S/C Systems	650	1	650
CdTe Detector Material	2	4	8
Secondary Instrument IRF(from THESEUS)	110	1	110
Lateral Tungsten Shielding (2 cm thick)	355	4	1420
Bottom Tungsten Shielding (3mm thick)	158	4	632
Tungsten Coded Mask (50% closed)	3.97	4	15.88
			3955.88
		with 20 % margin	4747.056

World map of trapped electrons:



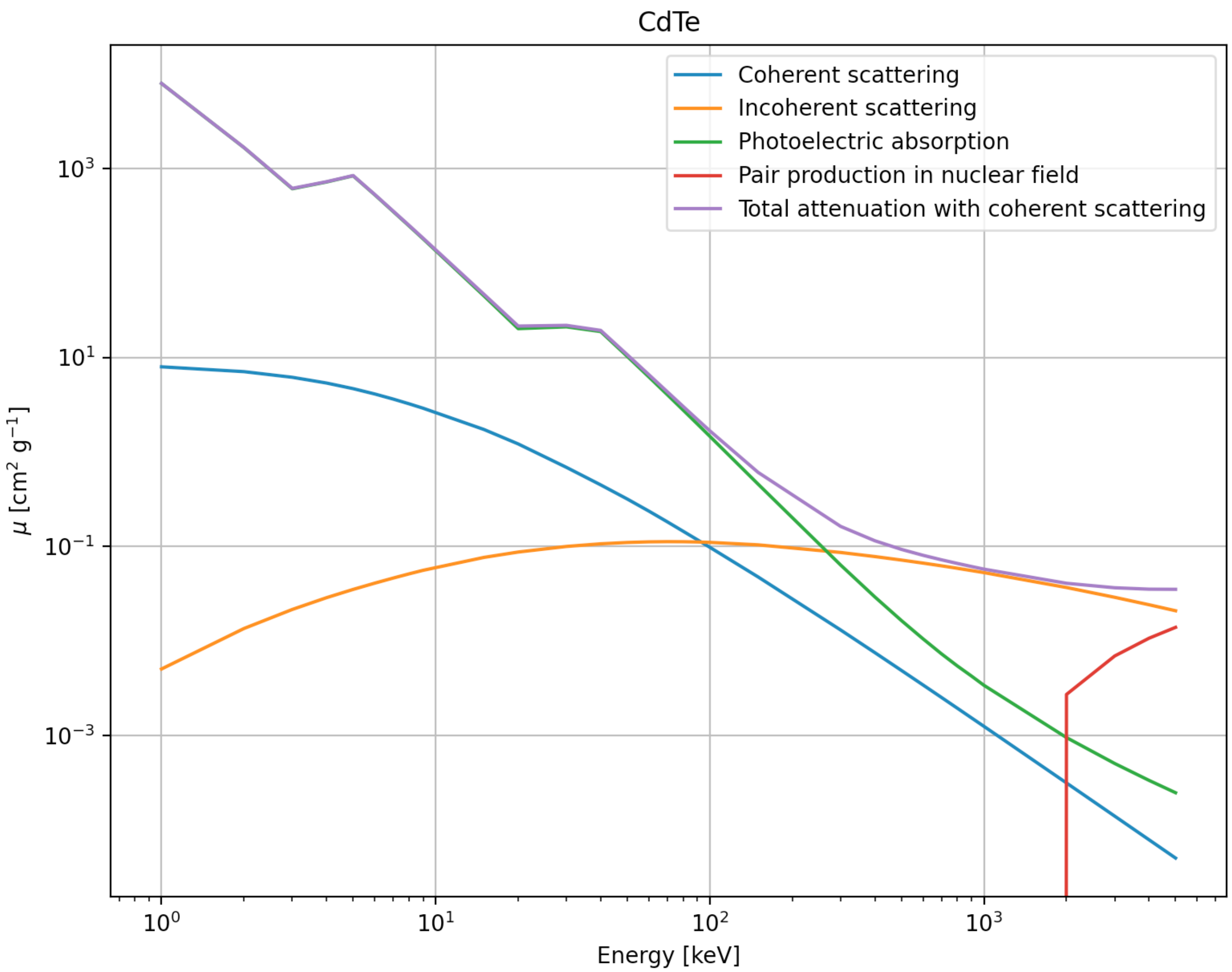
World map of trapped protons:



Results
Sensitivity curve

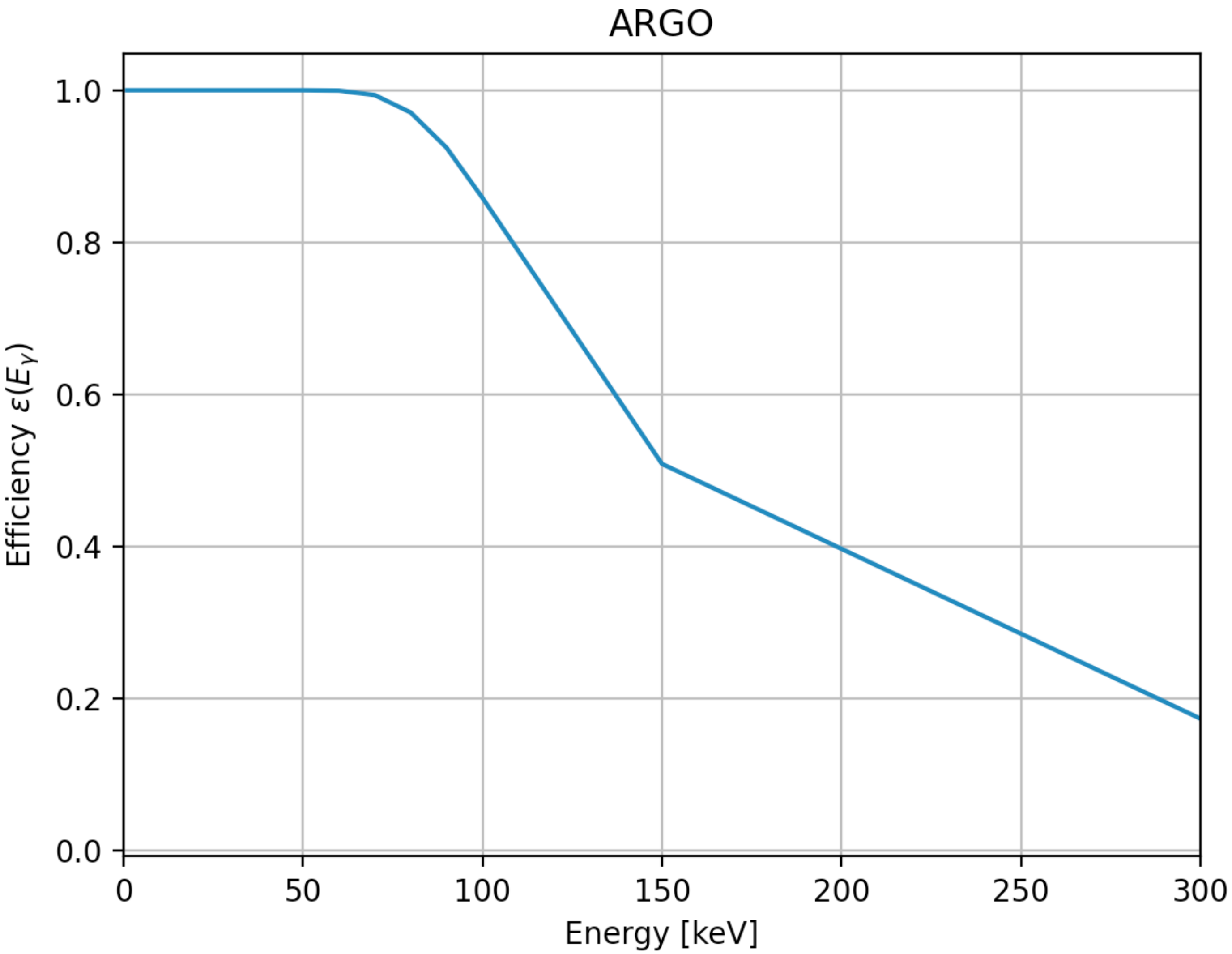
Parameters (summary)

Parameter	Value	Parameter	Value	Parameter	Value
$x_{detector}$	0.2 cm	$x_{shielding}$	2.0 cm	T	20 s
$A_{detector}$	820.125 cm^2	$\rho_{shielding}$	19.3 g cm^{-3}	FOV	2.21 sr
$\rho_{detector}$	5.85 g cm^{-3}	$F(R_C)$	0.7	σ	3.0



Mass attenuation coefficient for the detector material

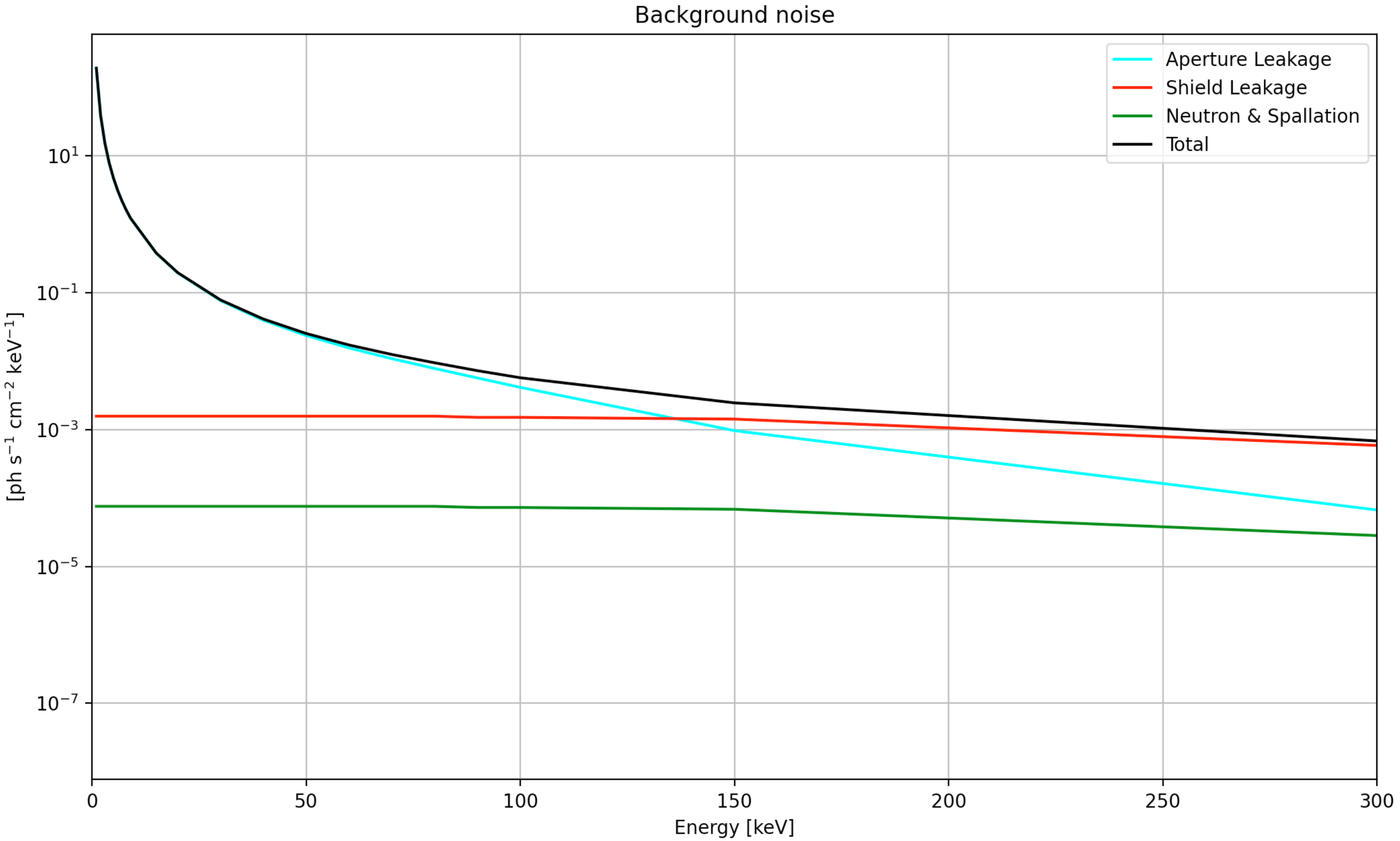
Efficiency



$$\varepsilon(E_\gamma) = (1 - e^{-\mu x})$$

where $x = x_{\mathrm{detector}} \cdot \rho_{\mathrm{detector}}$

Background noise



-Aperture Leakage:

$$B_{CDB}(E_\gamma)=\varepsilon(E_\gamma)\left[\frac{dN(E_\gamma)}{dE_\gamma}\right]_{CDB}\Omega \ \ counts \ \ cm^{-2}s^{-1}keV^{-1}$$

where

$$\frac{dN(E_\gamma)}{dE_\gamma}=87.4E_\gamma^{-2.3} \ \ photons \ \ cm^{-2}s^{-1}keV^{-1}sr^{-1}$$

-Shield Leakage:

$$B_{ph}(E_\gamma)=B_{ph5cm}(E_\gamma)e^{(1-x/5)} \ \ counts \ \ cm^{-2} \ \ s^{-1} \ \ keV^{-1}$$

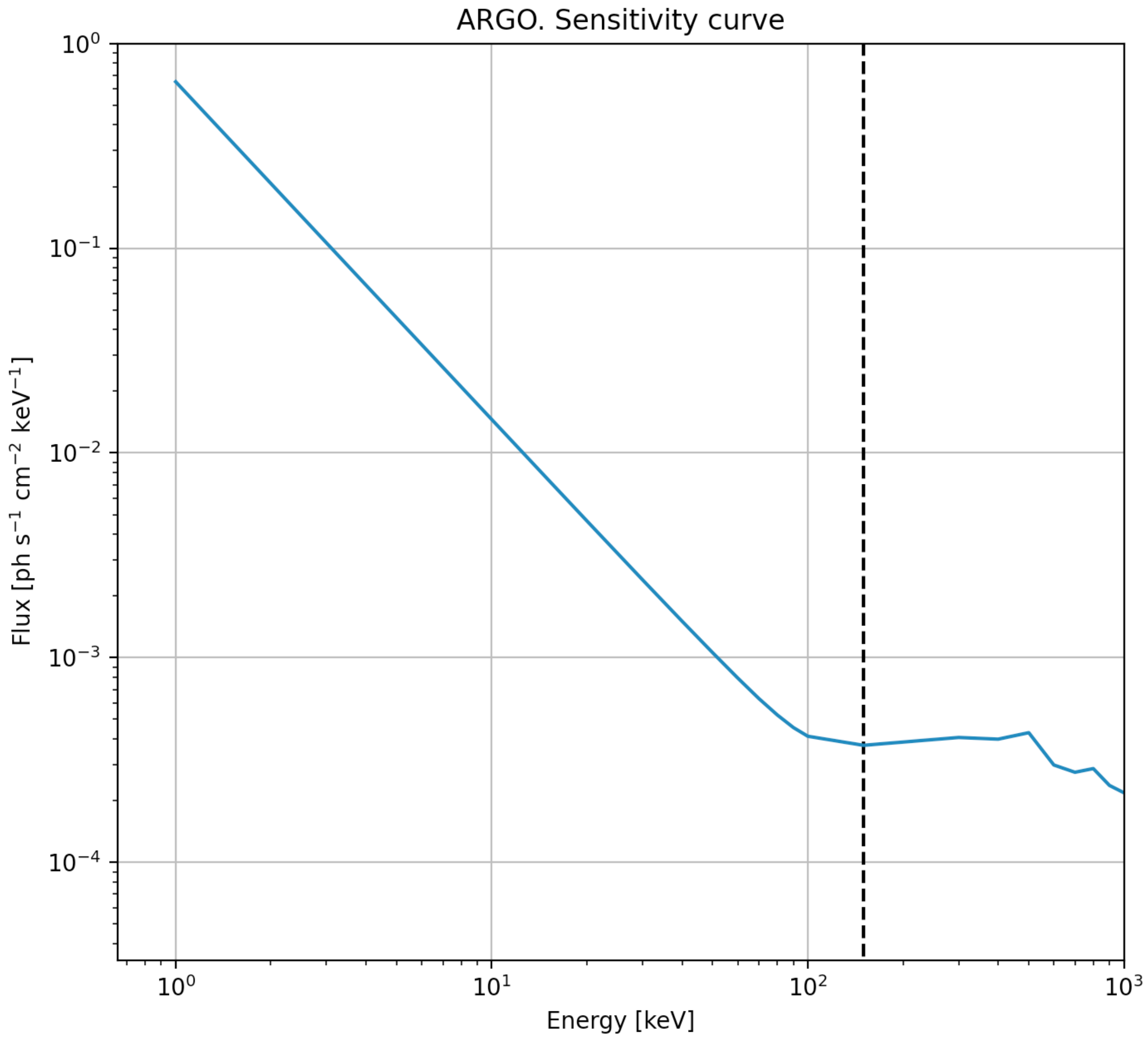
-Neutron and Spallation:

$$B_{n+s}(E_\gamma)=\mathrm{F}(R_c)\times\frac{\rho_Q x_{det}A_{det}}{\rho_{NaI}(2cm)(2200cm^2)}\times B_{fig}(E_\gamma)$$

-Total:

$$B_T(E_\gamma)=B_{CXB}(E_\gamma)+B_l(E_\gamma)+B_{n+s}(E_\gamma)$$

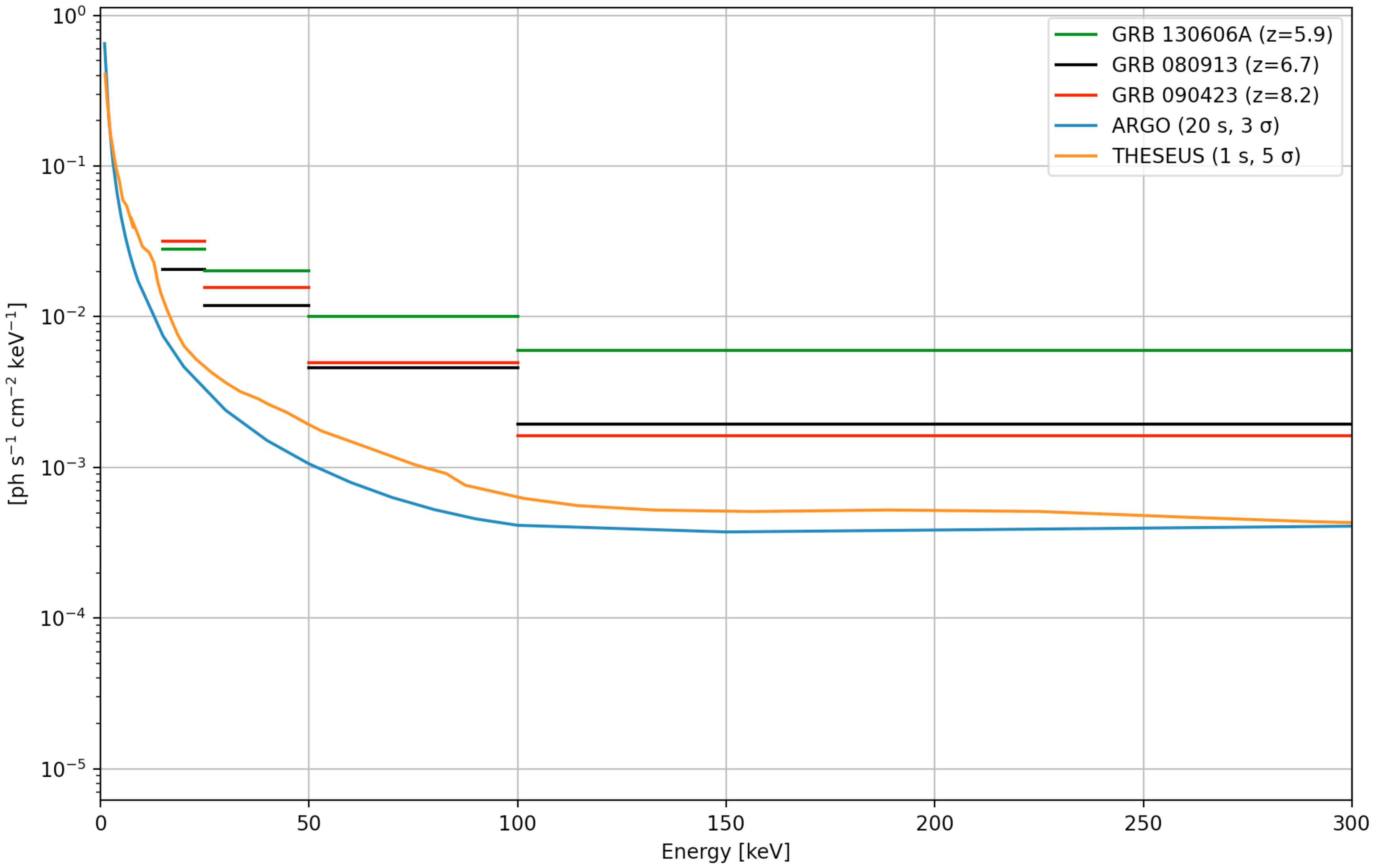
Sensitivity



$$F_{min} = \frac{\sigma}{\varepsilon(E_\gamma)} \sqrt{\frac{4B(E_\gamma)}{AT\Delta E}} \quad photons \ \ cm^{-2} s^{-1} keV^{-1}$$

*Each detector

Comparation ARGO vs THESEUS



Rate of expected GRBs

- Based on Ghirlanda et al. 2021, expected rate of detected high-z ($z>6$) GRBs is 4.52 GRBs per sr per year.
- So, expect to find 40 high-z GRBs in a year. SAA: 34 in a year
- THESEUS: 42 total (3.45 years)
- For $z>8$ rate is 1.62 per sr per year.
- So, expect to find 14.3 GRBs with $z>8$ in a year. SAA: 12.2 in a year

Conclusions

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