Spectral Deconvolution

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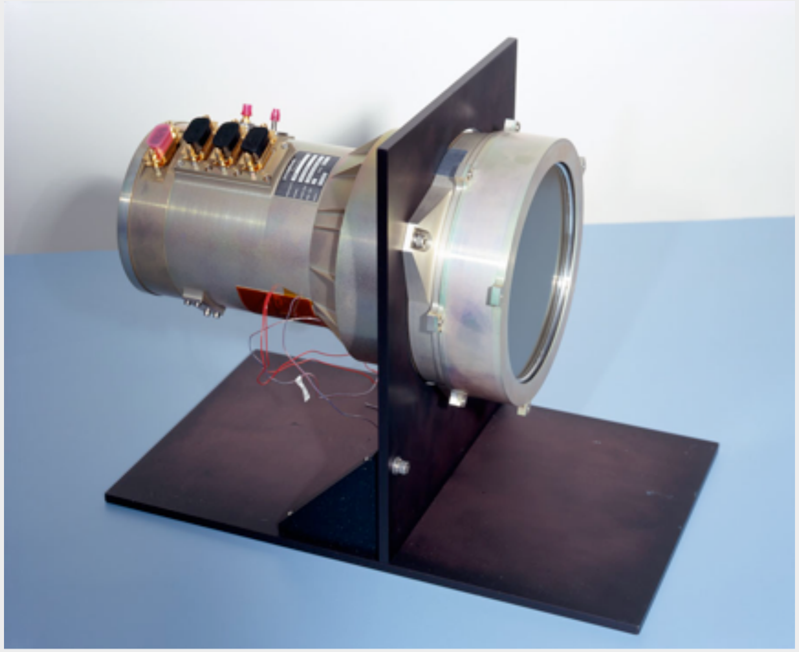
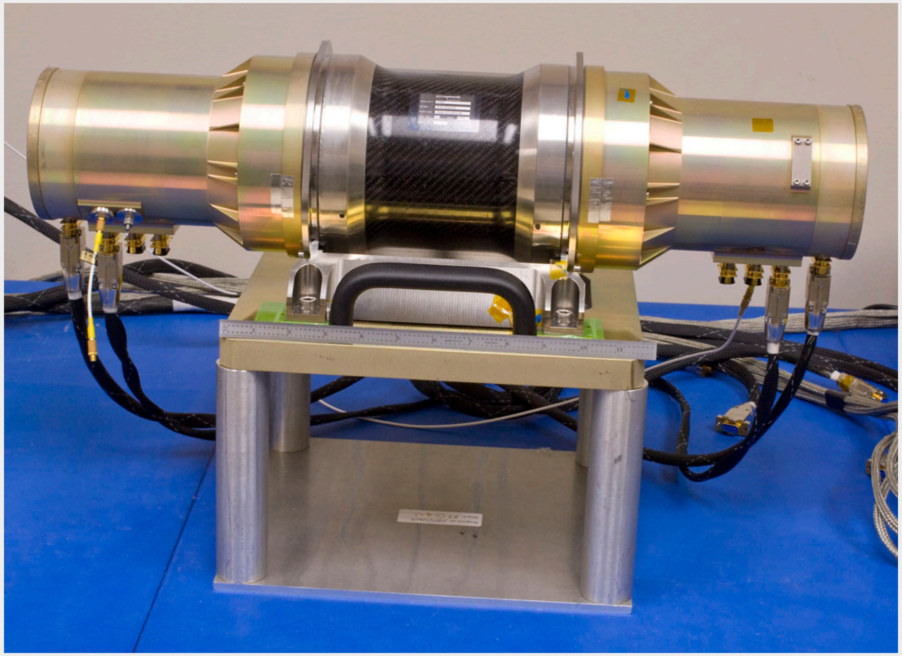
Themes – some you already heard from Justin Vadenbroucke and other speakers here:

- Photon and particle interactions in matter
- The same interactions that take place in an astrophysical source take place in our detectors!
- Photons: photoelectric effect, Compton scattering and pair production.
- The measurements are not direct, so deconvolution is necessary.
- There is no single ideal scintillator: tradeoffs between properties depending on the application:
    - Absorption (density, Z)
    - Spectral resolution
    - Pulse width
    - Size availability
    - Cost,
    - …
- Data fitting with likelihood:
    - Model comparison, parameter estimation, etc.

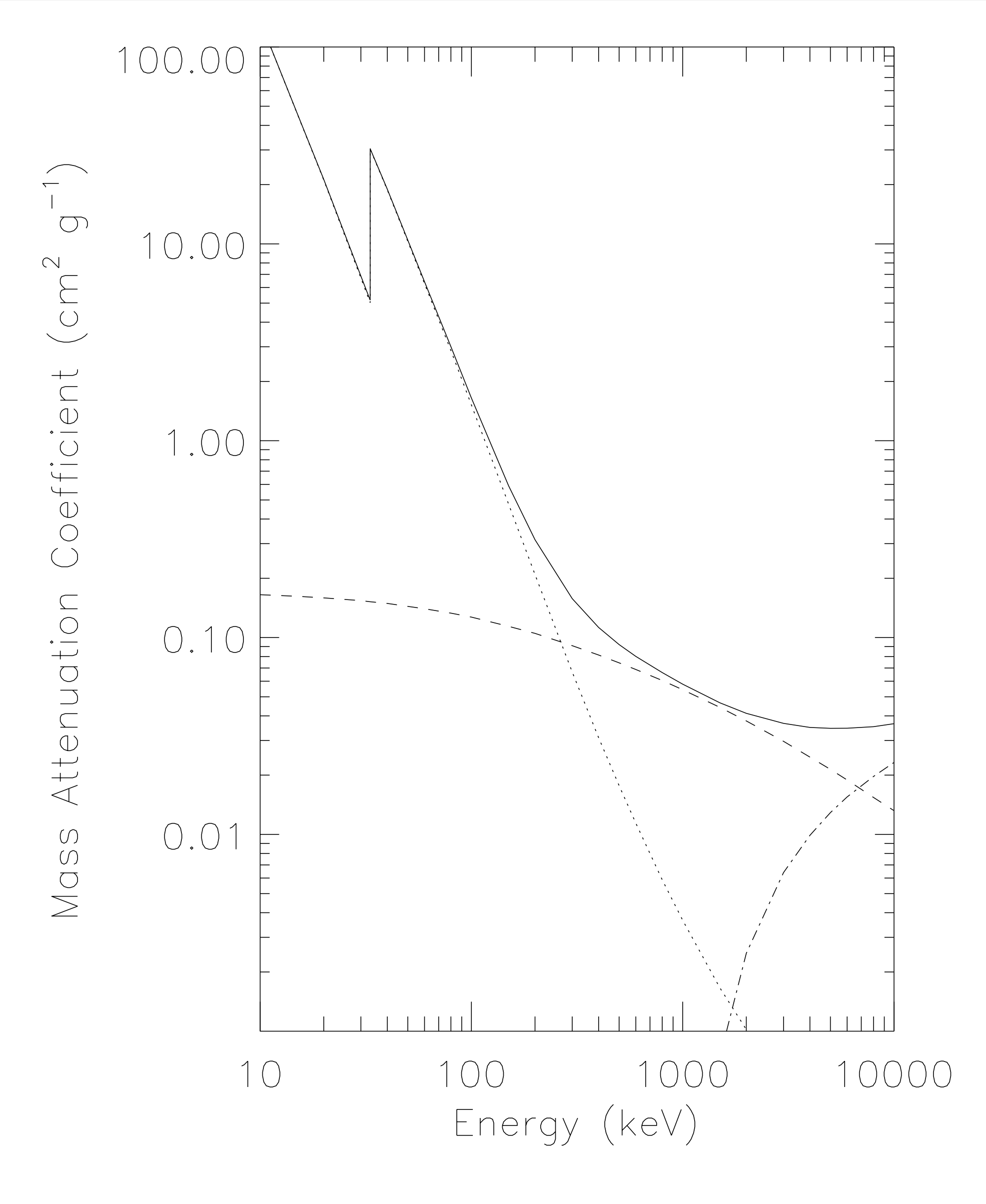


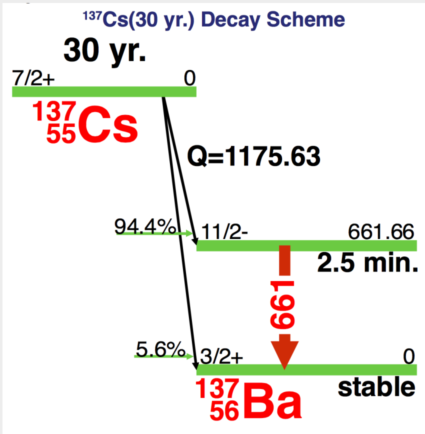


- Sodium iodide (NaI)
- 12.7 cm diameter X 1.27 cm thick
- 8 keV to 1 MeV

- Bismuth germanate (BGO)
- 12.7 cm diameter X 12.7 cm long
- 200 keV to 40 MeV

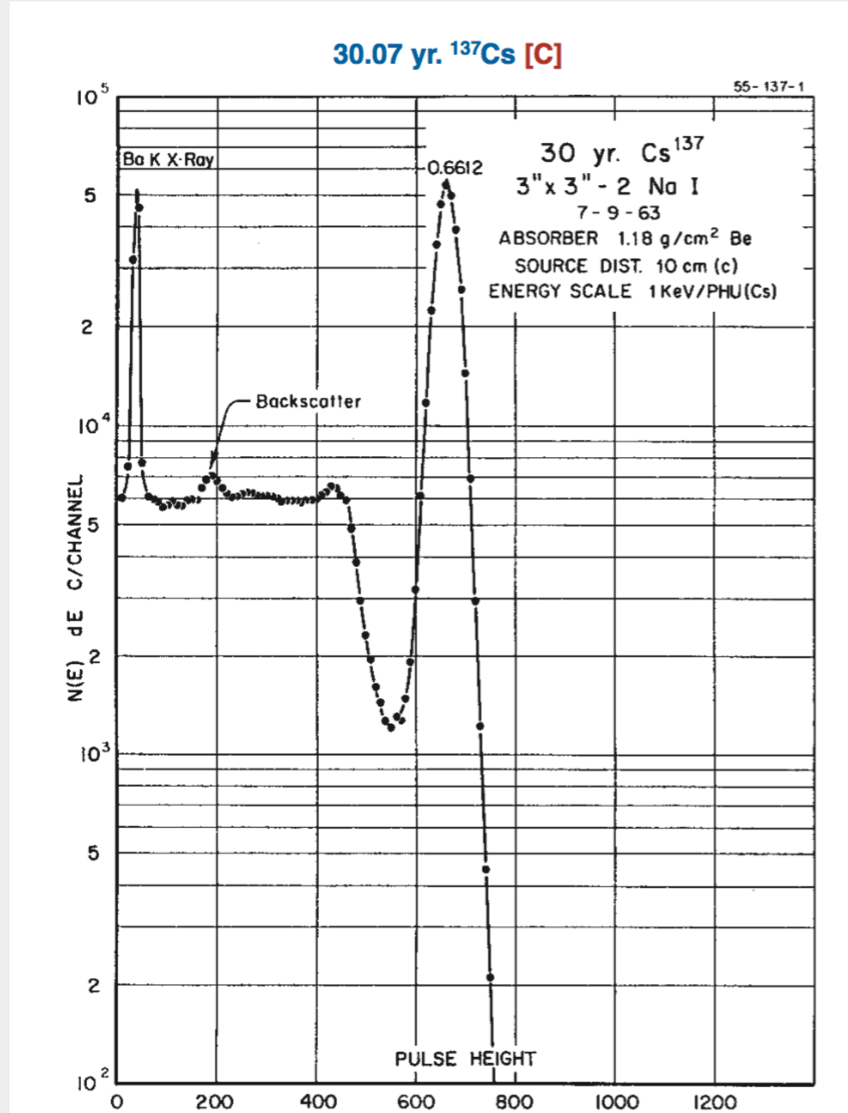
Mass attenuation coefficient μ:
$T/T0 = \exp(-\mu x)$,
where
x is the column density of NaI traversed in g cm^{-2}.

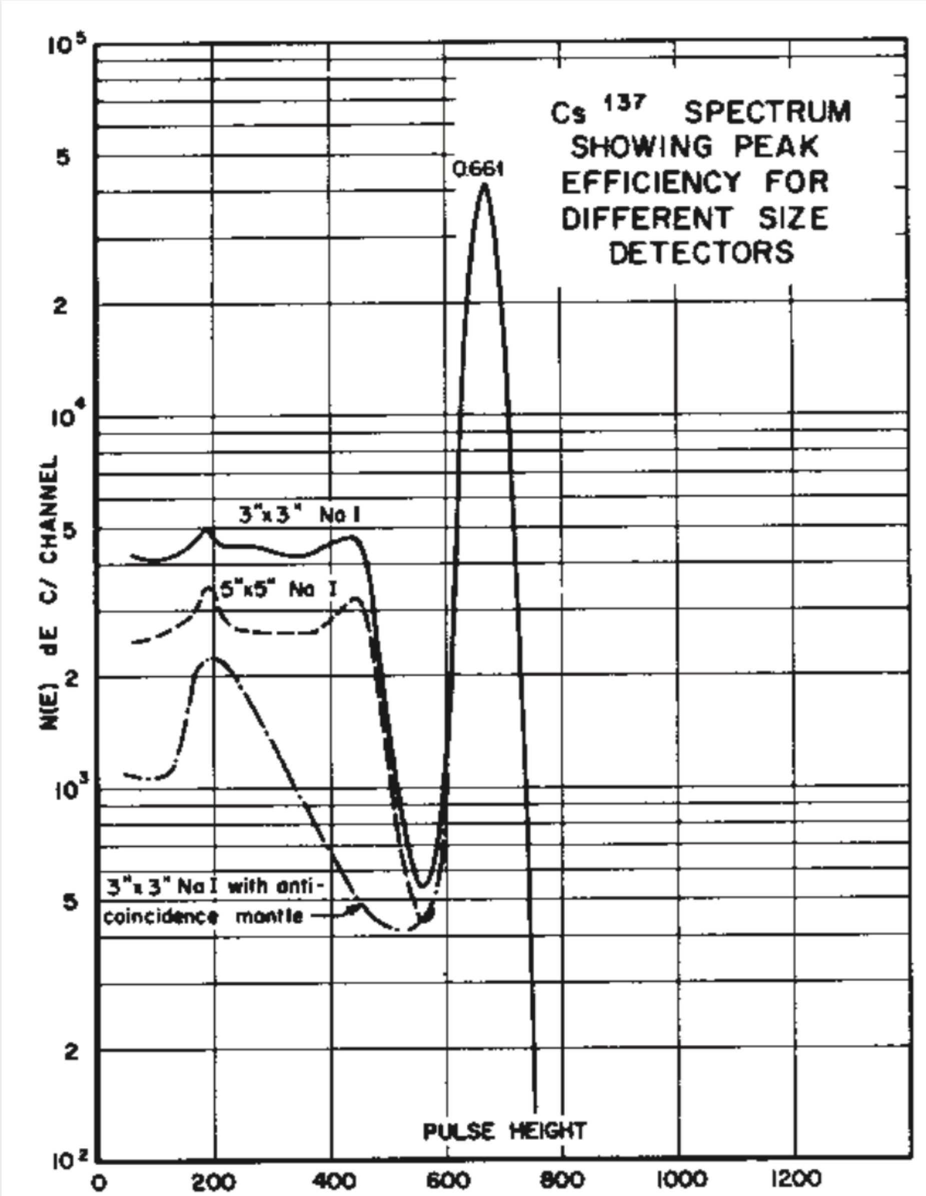


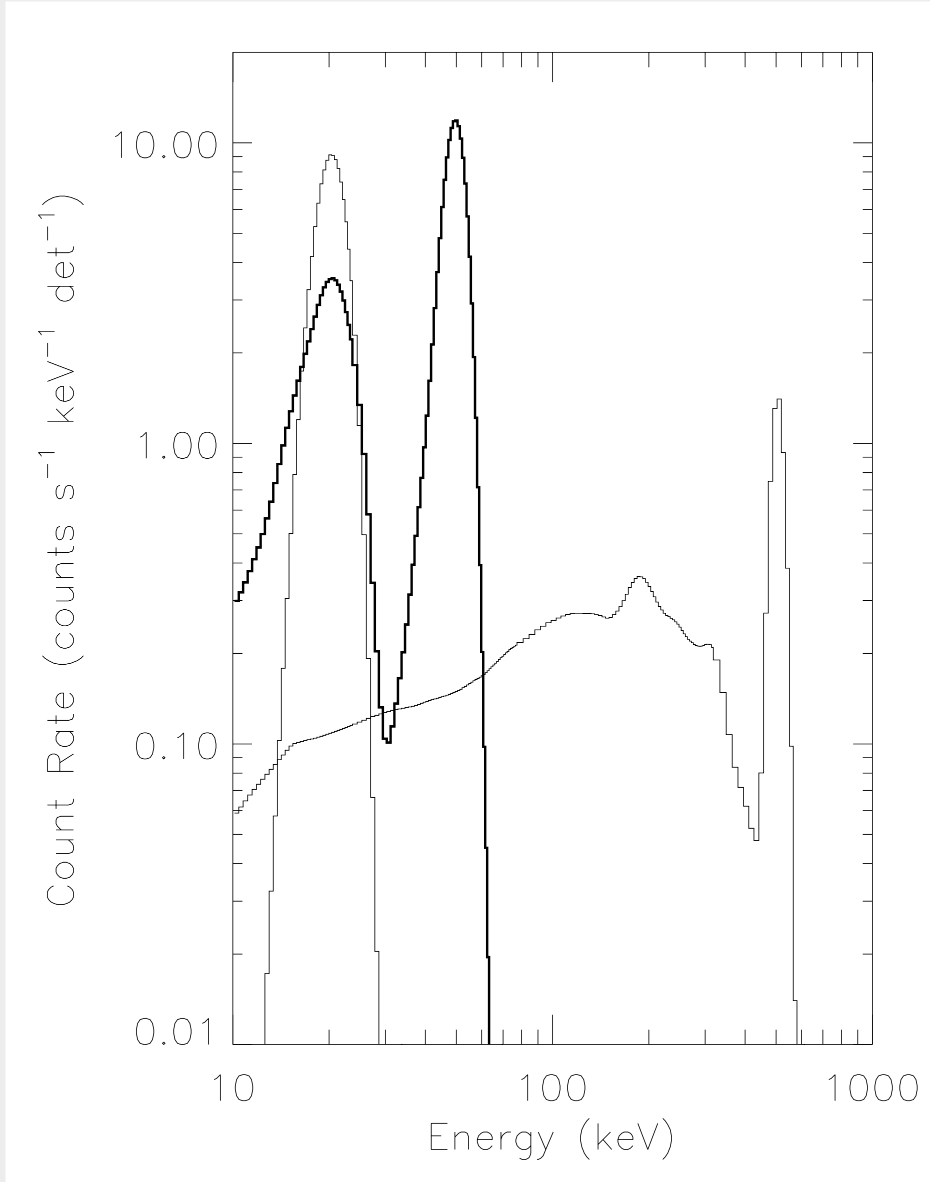


Scintillation Spectrometry: Gamma-Ray Spectrum Catalog
R. L. Heath (1957, 1964)

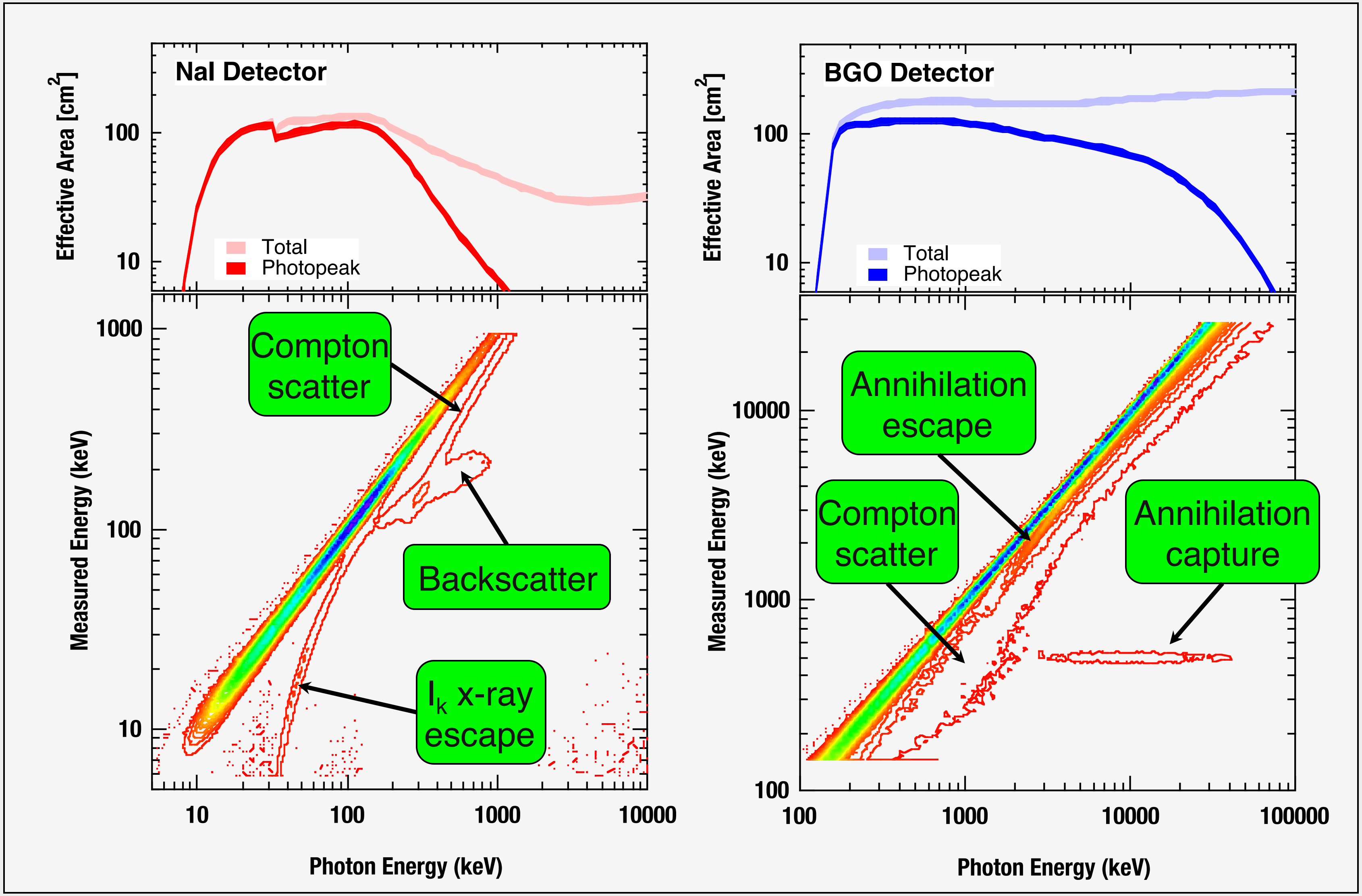
http://www4vip.inl.gov/gammaray/catalogs/catalogs.shtml




Cs 137 SPECTRUM
SHOWING PEAK
EFFICIENCY FOR
DIFFERENT SIZE
DETECTORS
0.661
3"x3" NaI
5"x5" NaI
3"x3" NaI with anti-
coincidence mantle
N(E) dE C/ CHANNEL
PULSE HEIGHT
10⁵
5
2
10⁴
5
2
10³
5
2
10²
0
200
400
600
800
1000
1200


Count Rate (counts s^{-1} keV^{-1} det^{-1})
10.00
1.00
0.10
0.01
10
100
1000
Energy (keV)

GBM Detector Responses (Marc Kippen)



Count spectrum (binned)

=

DRM X photon model

so:

Photons = DRM^{-1} X Data ?

Count spectrum (binned)

=

DRM X photon model

so:

$$\text{Photons} = \text{DRM}^{-1} \times \text{Data}\ ?$$

NO!

DRMs are nearly singular, and the data have statistical fluctuations, so this “solution” is unstable.

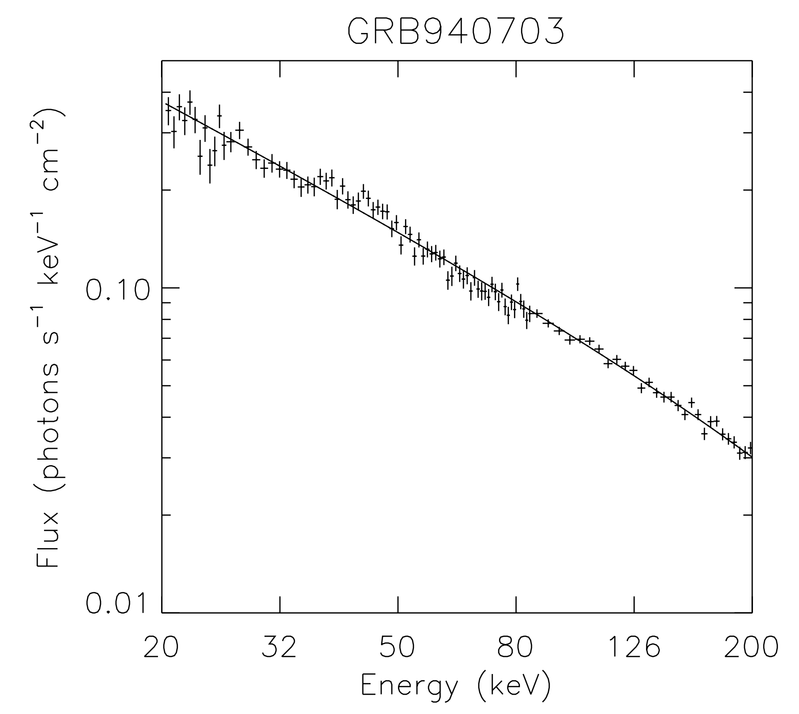
Forward-folding fitting

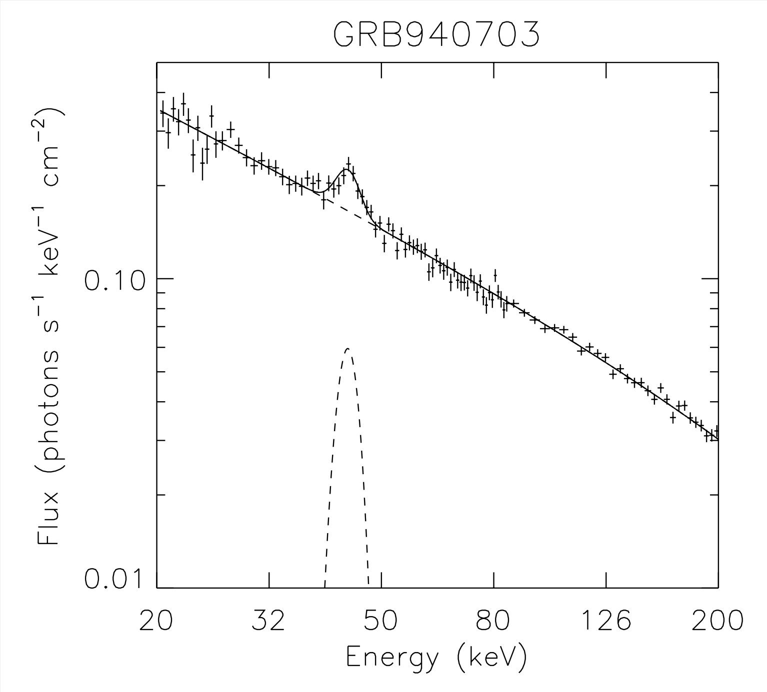
1) Assume a parameterized photon model.
2) Select a fitting statistic – likelihood (or χ^2)

3) Calculate the count model using the DRM,
4) Calculate the fitting statistics,
5) Change the photon model parameters to improve the fitting statistic,
6) Repeat steps 3 to 5 to optimize the model.

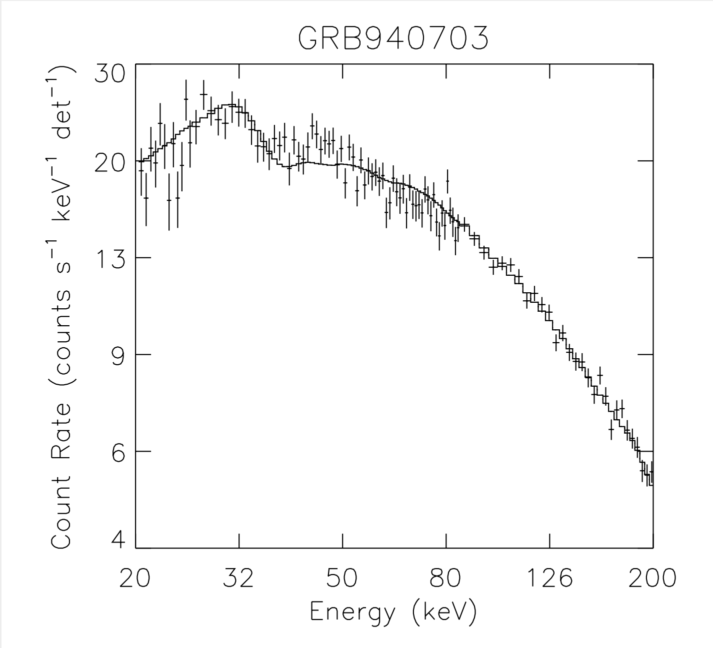
7) The answer is based upon the model that you assumed – the process cannot automatically find the "true" model.

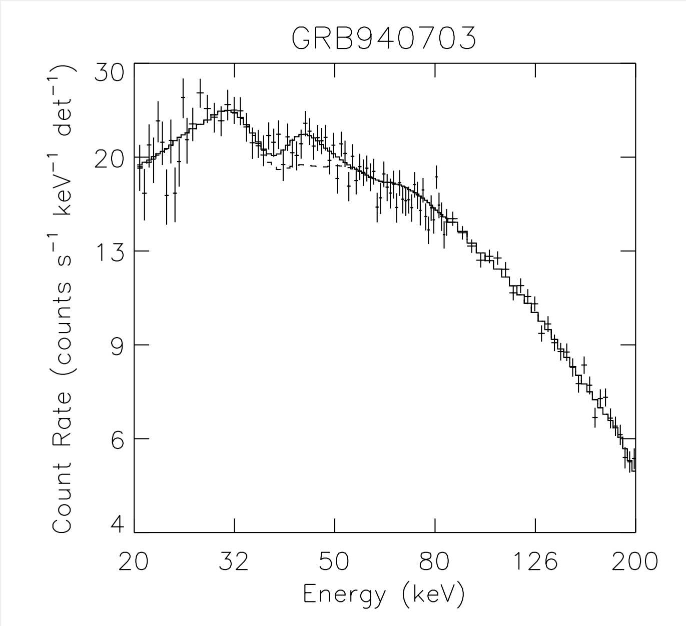
Typically analytic models are used, but one can also fit Monte Carlo models, in which the only parameter might be the normalization (intensity).





These graphs do NOT show the data. "Photons" are NOT the data, they are derived from the data and the model.

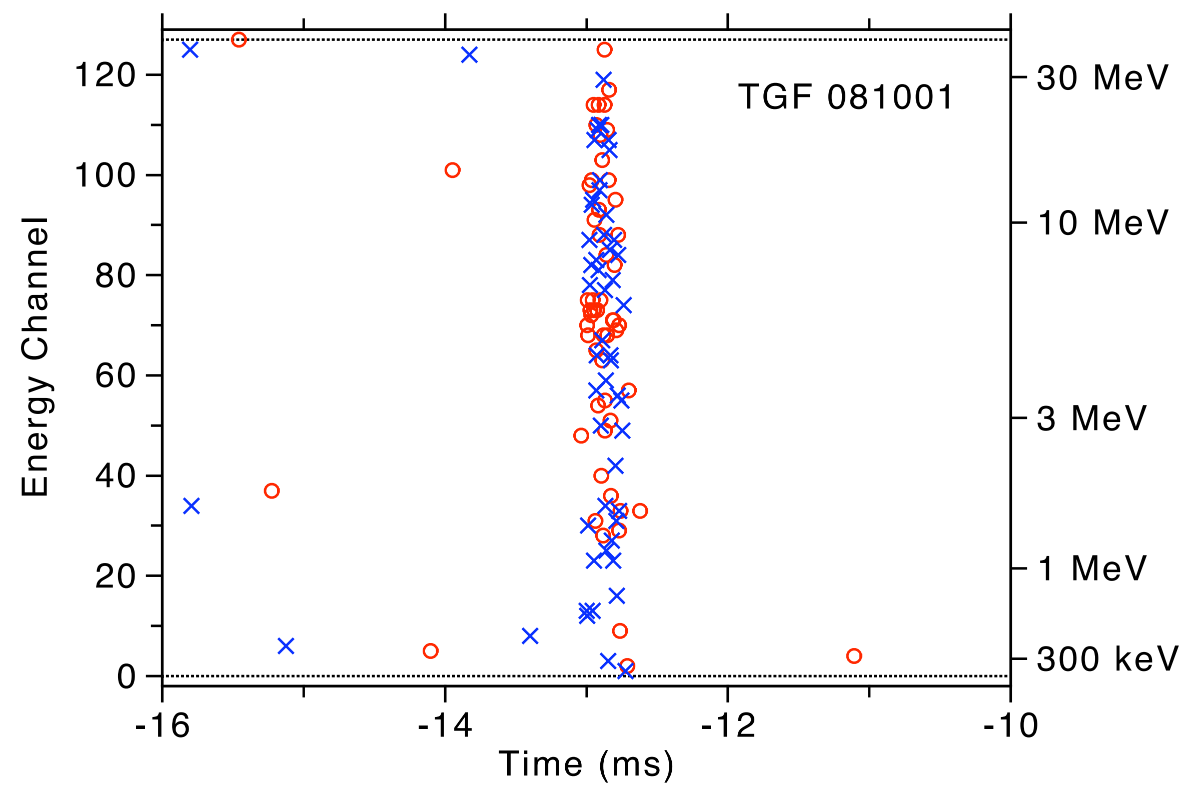




"Counts" as recorded by the detectors are the data.
Models are best compared by their fitting statistics: likelihood, X^2 (high count regime)

Issues

- Model comparison: unrelated versus nested
- Nested models: Wilk’s Theorem
- Is Wilk’s Theorem every valid for astrophysics?
- Fitting algorithms: brute force, Levenburg-Marquardt, Simplex, Markov Chain Monte Carlo, …
- Parameter estimation: error matrix (derivatives), mapping statistic, … (see Numerical Recipes)
- Ask the right question!
- If in doubt, simulate!



Terrestrial Gamma-ray Flash (TGF):
data from two GBM BGO detectors

Runaway Electron Avalanches by Relativistic Feedback

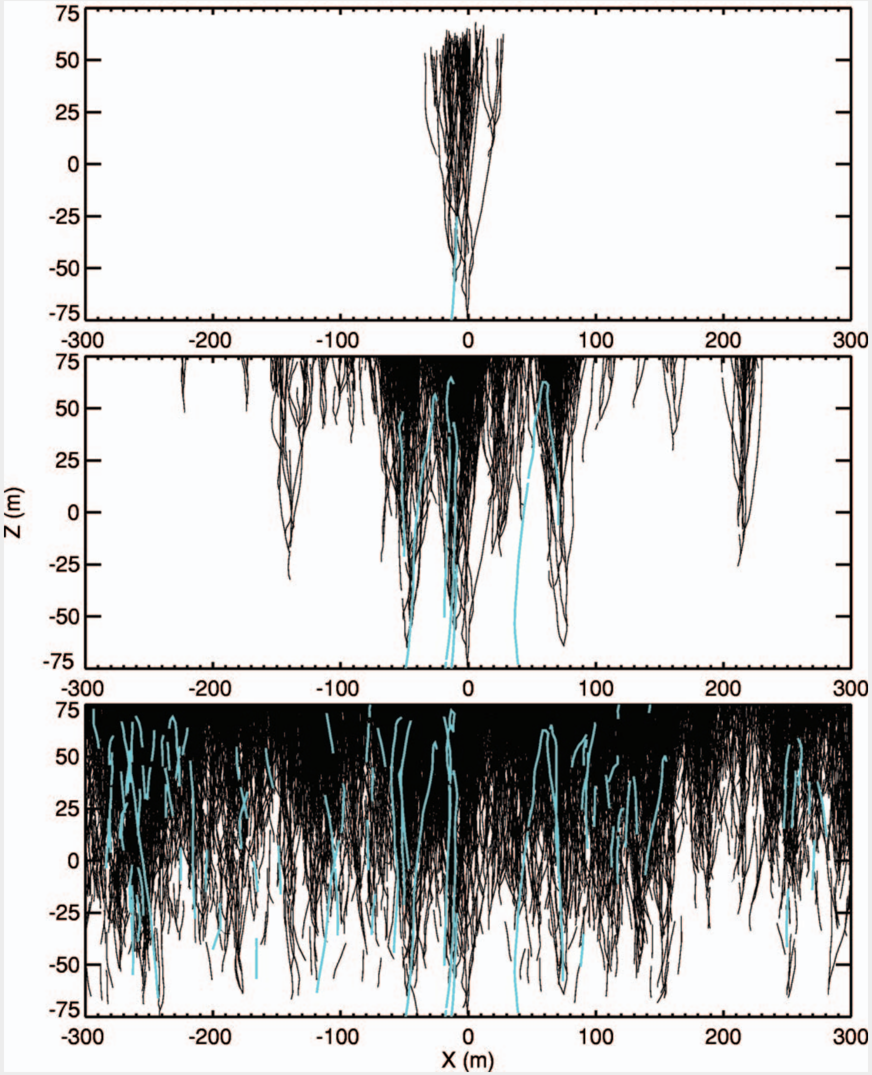
J. Dwyer (2007)

E = 750 kV / m
for 150 m,
➔110 MV potential

Initial avalanche from a single 1 MeV seed electron.

Additional avalanches produced by x-ray and positron feedback.

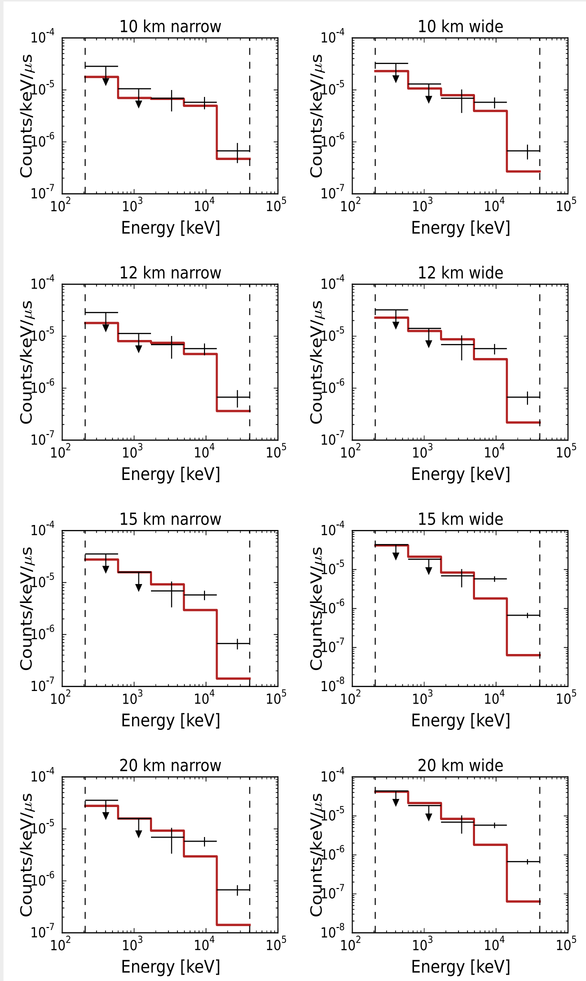
Black = Electron
Blue = Positron

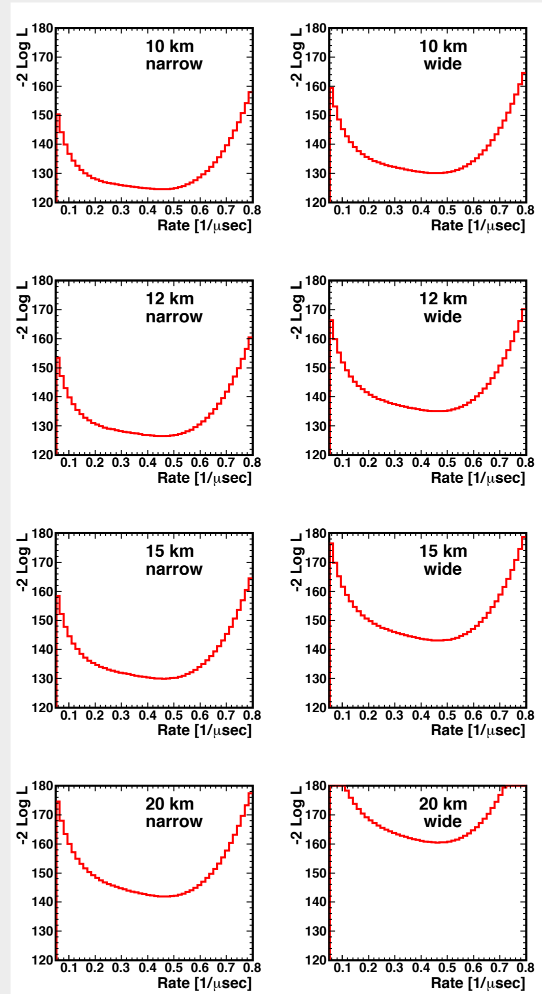


t < 0.5 μs

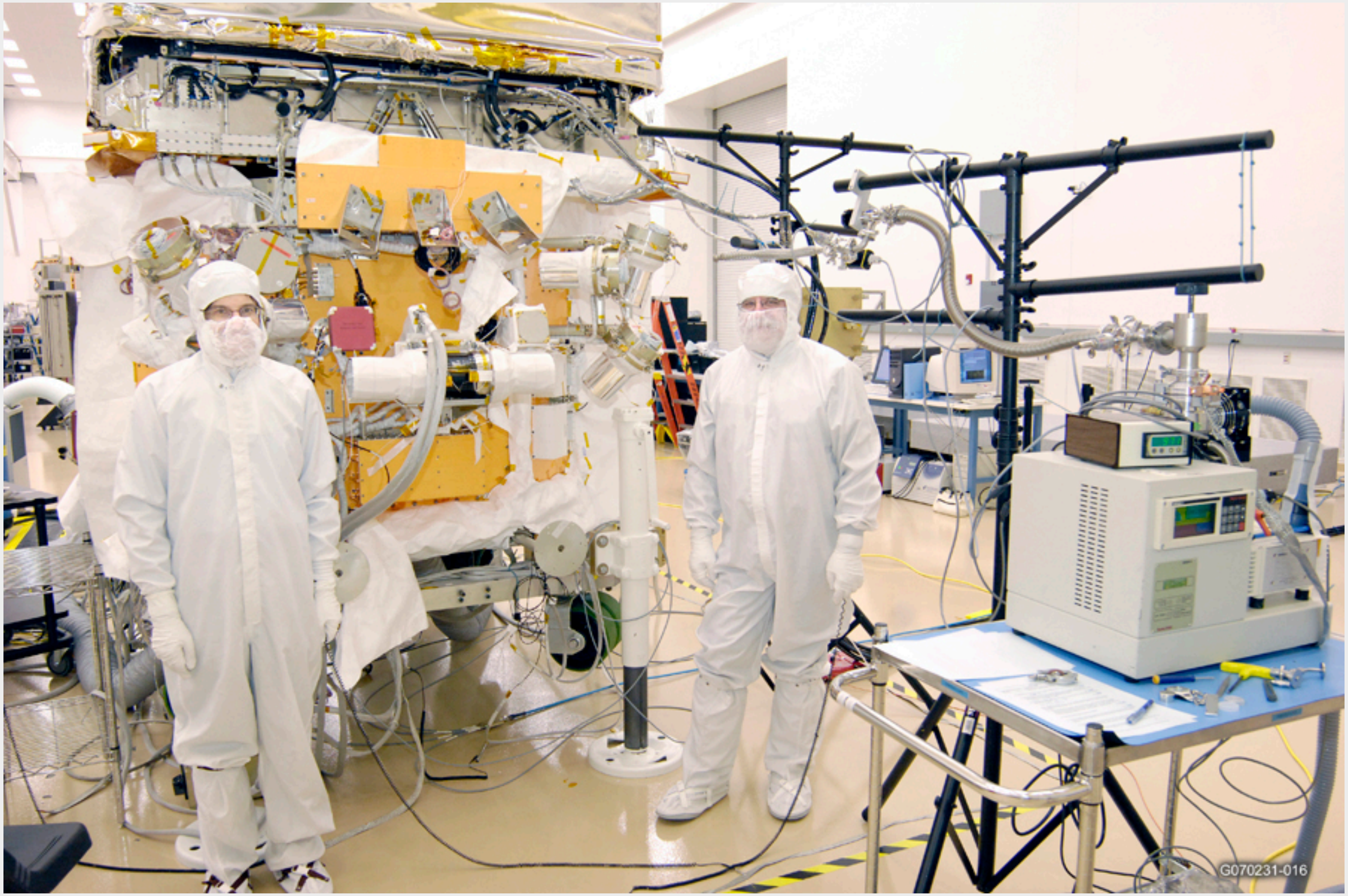
t < 2 μs

t < 10 μs





The actual fits are performed using Poisson likelihood at the full 128 spectral channel resolution of the GBM data. (B. Mailyan, submitted.)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