COMPTEL Measurements of the Cosmic Diffuse Gamma-Ray Spectrum

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Summary

- We report an updated Cosmic Diffuse Gamma-Ray (CDG) spectrum from 4.2 to 30 MeV with finer energy binning using data from high-latitude observations.
- The latest 4.2–30 MeV results are in good agreement with our earlier estimates [1,2,3] and can be described by a power-law of spectral index –2.18 ± 0.28.
- The flux above 4.2 MeV is about a factor of ~5 lower than the pre-COMPTEL measurements [4,5,6] and show no evidence for any ‘‘MeV-bump.’’
- The measurements of the 4.2–30 MeV flux from the Virgo and South Galactic Pole directions show no significant differences in the CDG spectrum.
- The 4.2–30 MeV flux is compatible with the extrapolation of the EGRET extragalactic diffuse spectrum [7] from higher energies.
- The COMPTEL results represent the first significant detection of the CDG flux in the 9–30 MeV range.

[1] Kappadath S.C. et al., 1995, XXIV ICRC **2**, 230
[2] Kappadath S.C. et al., 1996, A&AS **120**, C619 (3rd Compton Symp.)
[3] Kappadath S.C. et al., 1997, Proc. of 4th Compton Symp. (in press)

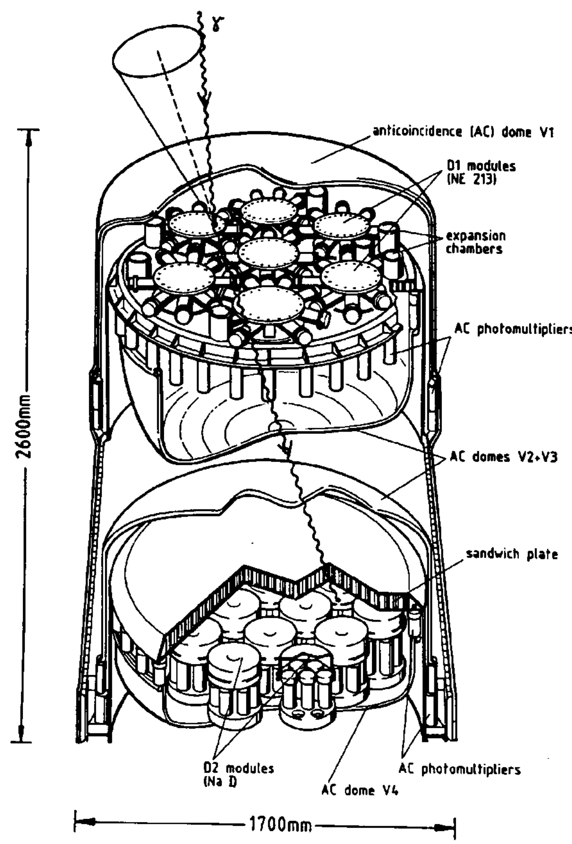
Introduction

- The preliminary COMPTEL Cosmic Diffuse Gamma-Ray (CDG) measurements from 0.8–30 MeV were presented at the XXIV ICRC [1] and the 3rd Compton Symposium [2].
- We present an updated CDG spectrum above 4.2 MeV using data from high-latitude observations of the Virgo and South Galactic Pole (SGP) directions.
- In this work the CDG flux refers to the total γ-ray intensity from high Galactic latitudes including the extragalactic diffuse flux, the Galactic diffuse flux and γ-ray point sources.
- The high latitude observations minimize the γ-ray contributions from the Galaxy.
- The data were accumulated only when the Earth is outside the COMPTEL field-of-view. This eliminates any contamination from the atmospheric γ-rays.
- The CDG measurement is made by first subtracting all known instrumental background and then attributing the residual flux to the CDG radiation.

[4] Trombka J.I. et al., 1977, ApJ **212**, 925
[5] Schönfelder V. et al., 1980, ApJ **240**, 350
[6] White R.S. et al., 1977, ApJ **218**, 920
[7] Sreekumar P. et al., 1997, ApJ (submitted)

COMPTEL Instrument

- Each "telescope" event is defined by a coincident signal in the upper (D1) and lower (D2) detectors with the proper time-of-flight and no signal from any of the charged-particle shields.
- For each event COMPTEL measures:
  - the energy deposits in D1 and D2,
  - the interaction positions in D1 and D2,
  - the pulse-shape of the signal in D1,
  - the time-of-flight between D1 and D2,
  - the absolute time of the event.
- Energy Range:
  - 800 keV to 30 MeV
- Energy Resolution:
  - 5 to 10 %
- Effective Area:
  - 5 to 15 cm^2 sr
- Field-of-View:
  - ~ 1 sr



Background Components

- Atmospheric γ rays
  - » eliminated by selections on sky-viewing
- Neutron-Scatters in D1
  - » minimized by selections on the D1 pulse-shape (PSD)
- Accidental Coincidences
  - » eliminated by ToF fits
- Prompt Cosmic-Ray Induced Background
  - » eliminated by ToF fits and veto-rate extrapolation
- Thermal Neutron Capture (2.223 MeV) Background
  - » eliminated by veto-rate extrapolation
- Long-Lived Cosmic-Ray Induced Background
  - » estimated by spectral fitting
- Galactic Diffuse γ rays
  - » minimized by high Galactic latitude observations
- γ-ray Point Sources
  - » negligible contribution

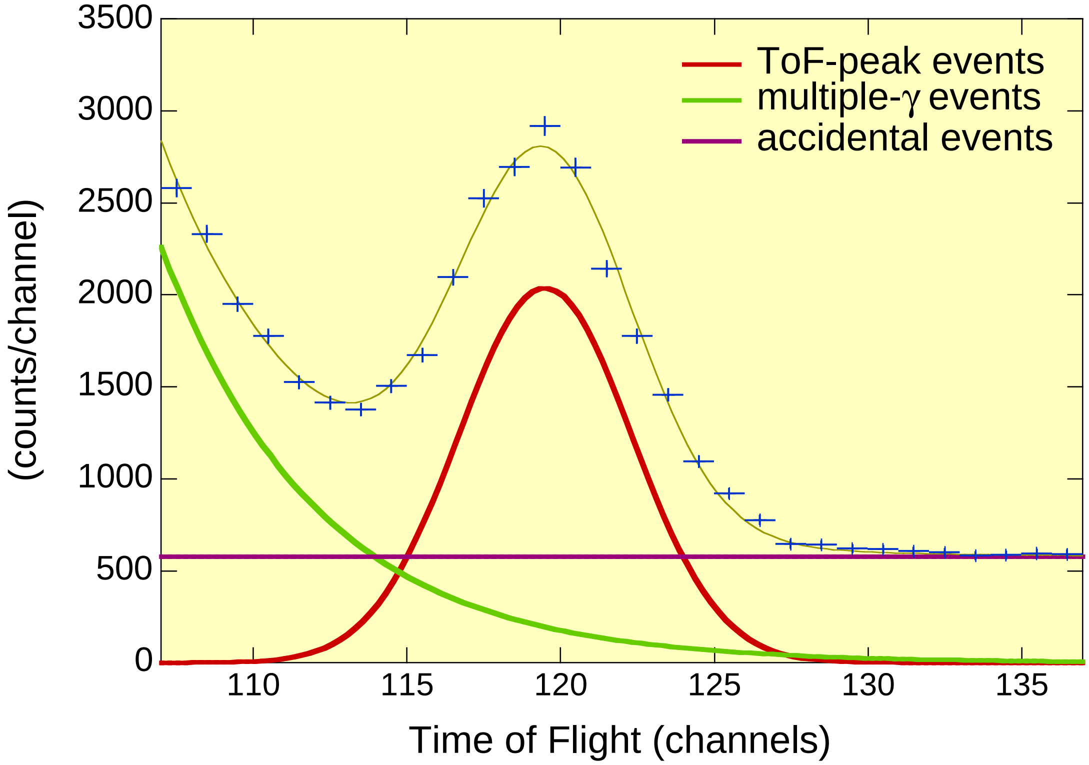
Data Analysis

- Ultimately, the internal background events are due to photons arising from cosmic-ray and neutron interactions with the instrument and spacecraft material.
- They can be broadly classified as:
  - ''prompt'' background events from showers and prompt cascading de-excitation of nuclei ($\tau_{1/2} < 1$ minute).
  - ''long-lived'' background events from radioactive isotopes with long half-lives.
- In addition to the standard event parameters (e.g. D1E, D2E, PSD, etc.) used to optimise the COMPTEL signal, the CDG analysis exploits three characteristics of the background:
  - the time of flight signature (to increase the S/N)
  - the modulation with the cosmic-ray intensity (for prompt background calculations)
  - the presence of de-excitation lines in the detector spectra (for long- lived background calculations)
- The Time-of-Flight (ToF) measurement is one of the most powerful tools to distinguish the signal from the background.

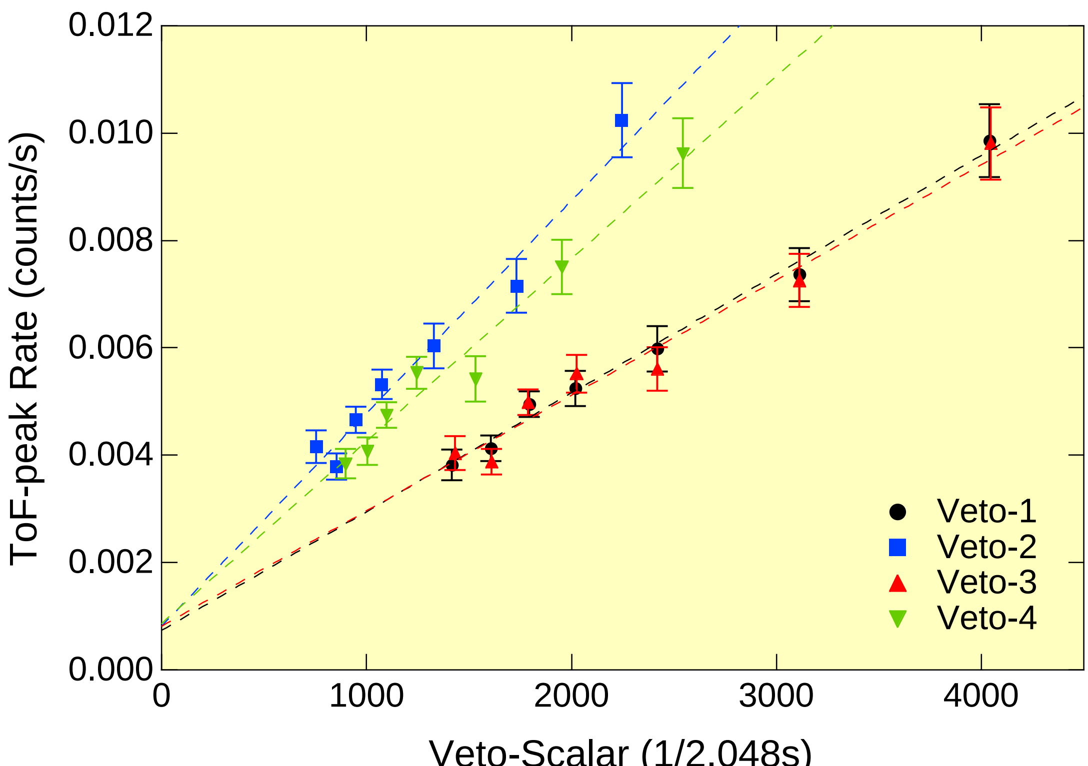
The ToF Spectrum

- An ideal γ-ray event (from within the instrument aperture that Compton-scatters off D1 into D2) will have a nominal ToF value of 5 ns (or 120 channels) corresponding to 1.5 m between the two detectors (the desired signal).
- Showers or multiple γ-rays from outside the aperture will have ToF values depending on the point of origin of the photons relative to the interaction location. These events are broadly distributed in ToF and reflect the distribution of matter around the detectors (accidental and multiple-γ events).
- However, multiple γ-rays generated in and around the D1 detector subsystem (due to its geometry) will also have ToF values close to the nominal 5 ns. These events contaminate the signal at channel ~120 and contribute to the ToF-peak.
- The ToF-peak events are determined by fitting the ToF spectrum. This isolates the background from the ToF-continuum.
- We now must determine the background in the ToF-peak (prompt and long-lived) before arriving at the desired CDG count rate.

A typical ToF spectrum.



The 9–30 MeV VGC for Phase III Virgo data



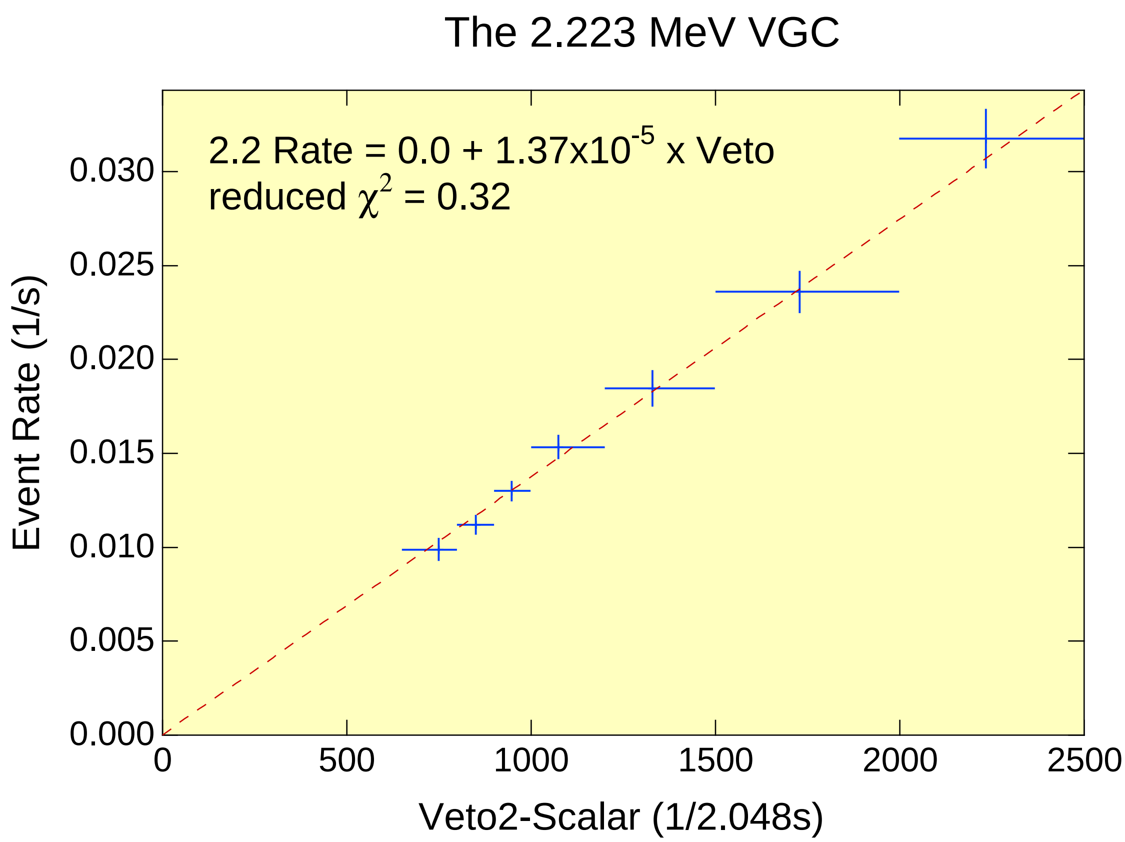
Prompt Background

- COMPTEL has 4 charged-particle shields (veto-domes) that directly measure the local and instantaneous cosmic-ray intensity (veto-scalars).
- The prompt background varies approximately linearly with the veto-scalars.
- The fitted ToF-peak rates are ordered by the veto-scalars to construct Veto Growth Curves (VGC).
- Assuming zero veto-scalar corresponds to zero cosmic-ray intensity, a linear extrapolation of the VGC is used to determine the prompt background.
- There is evidence for two origins for the prompt background [8]:
  - cascading nuclear de-excitations where the nuclei are excited to high quantum states and then decay by multiple γ emission on very short time scales. These photons correspond to nuclear energies and extend up to ~ 9 MeV.
  - electromagnetic showers from high energy primary electrons or photons/electrons produced (from pions) in nearby cascades. These photons span the entire energy range up to 30 MeV.

[8] Ryan J.M. et al., 1997, CHERBS Proc. (in press)

2.223 MeV Background

- Thermal neutron capture by the hydrogen in the upper detector (D1) produces a prompt 2.223 MeV ($\tau \sim 100\ \mu s$) background photon.
- As shown below, the 2.223 MeV rate is proportional to the instantaneous veto-scalars.
- This serves as a test of the linear relationship between the prompt background and veto-scalars.

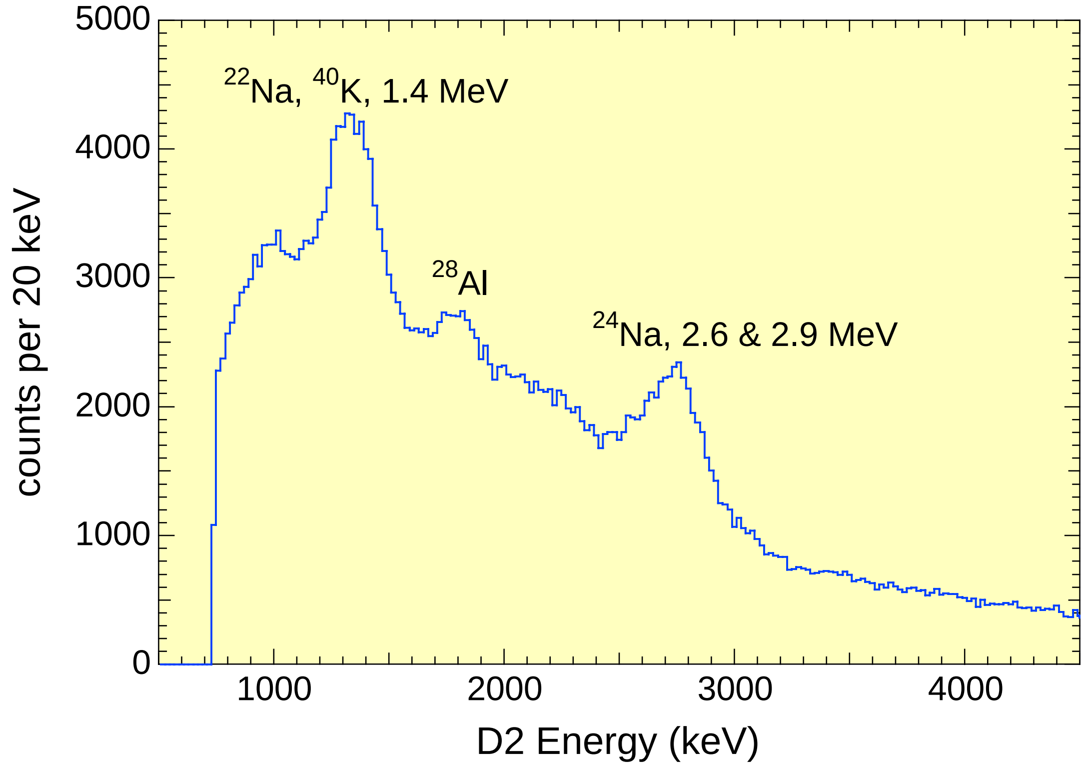


Long-Lived Background

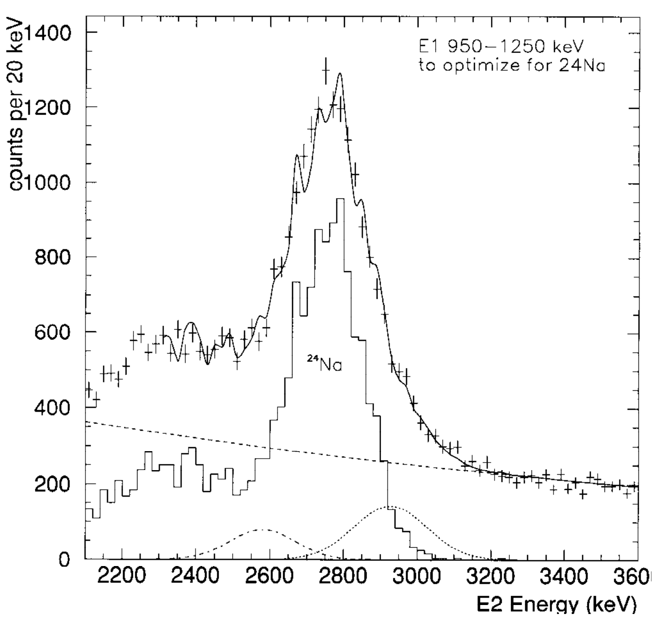
- Long-lived background events are present only below ~ 4.2 MeV and are identified by their characteristic decay lines in the individual detector spectra.
- At present, the identified radioactive isotopes are ^{24}Na, ^{22}Na, ^{28}Al and ^{40}K. Additionally there are unidentified line-like emission (in D2) at ~2.9, ~2.6 and ~1.4 MeV [9].
- This background builds and decays depending on the exposure to the SAA (where most of the activation occurs) and on the lifetime of the individual isotope.
- Due to the long-half lives their activity is not directly related to the instantaneous cosmic-ray intensity.
- Hence, in general the long-lived background is not a simple linear function of the veto-scalar.
- The complete calculation of the long-lived background is still incomplete! (work in progress)

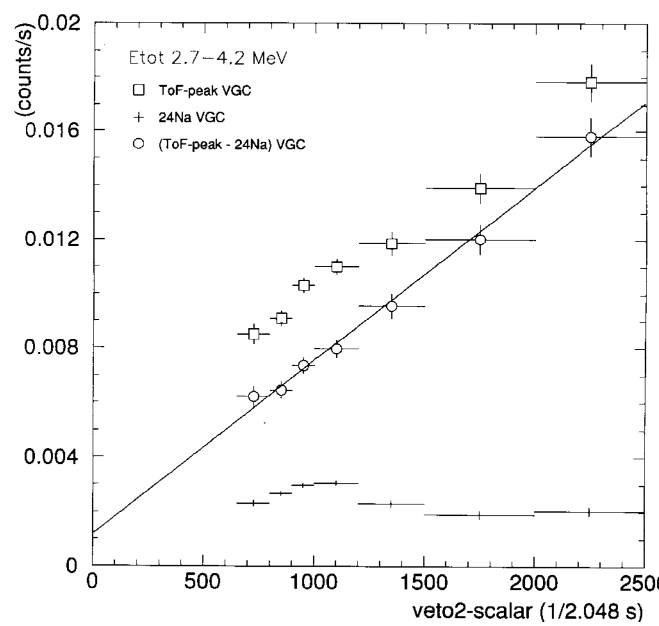
[9] Weidenspointner G. et al., this meeting

Activation lines in the D2 Energy spectrum



The ^{24}Na fitting technique and the basic method for long-lived and prompt background corrections below ~ 4.2 MeV



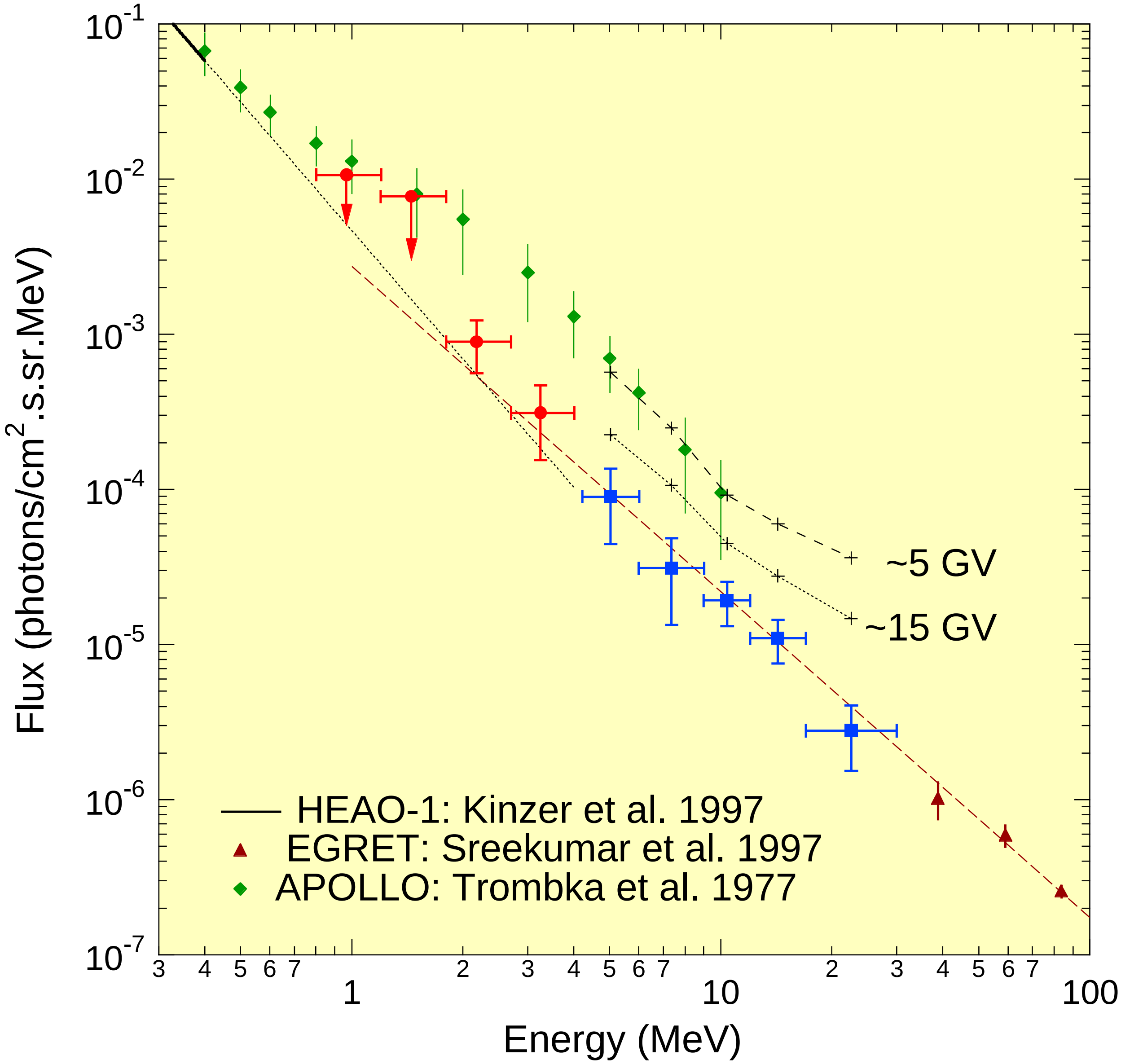


Flux Calculation

- Above ~ 4.2 MeV (in the absence of long-lived background), the VGCs are fitted with a straight line to determine the residual count rates at zero veto-scalar corresponding to the CDG count rate.
- Below ~ 4.2 MeV, we first compute the activity of each of the long-lived isotopes and subtract their contributions to the VGCs. The VGCs are then corrected for the prompt background to determine the CDG count rate.
- The CDG response is determined from Monte-Carlo simulations of a 2π diffuse power-law source propagated through a detailed COMPTEL mass model.
- Although the results come from high latitude observations, they still include flux from:
  - Galactic diffuse γ-radiation (Virgo Obs.)
    - < 5 % at 1 MeV to < 35 % at 15 MeV
  - γ-ray point sources in the FoV
    - specifically, 3C 273 and 3C 279 (Virgo Obs.)
    - < 1 % at 1 MeV to < 4 % at 15 MeV

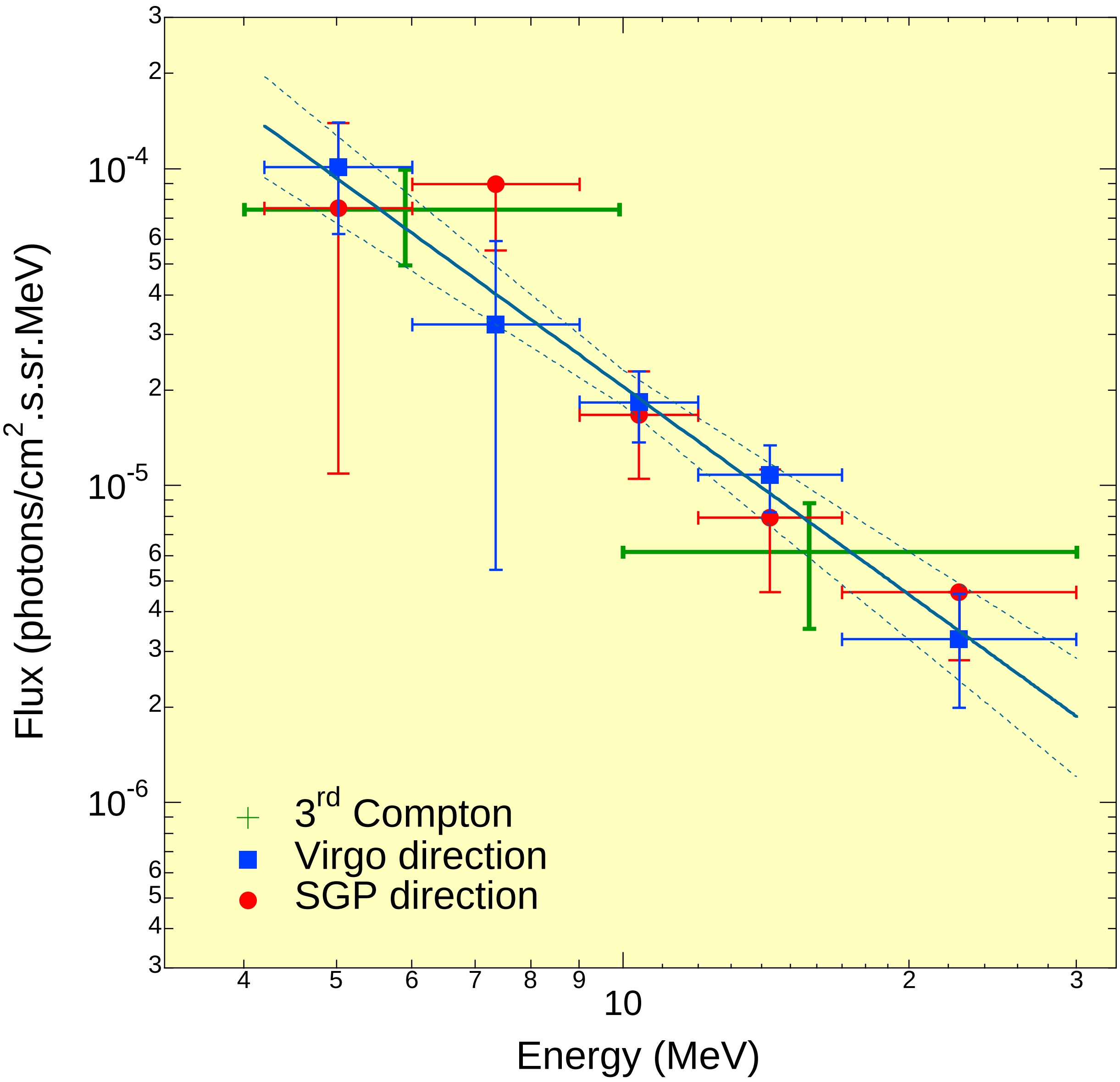
The CDG Spectrum - I

- The latest CDG spectrum above 4.2 MeV (blue squares) together with our earlier estimates below 4.2 MeV (red circles). Also shown is the ‘‘apparent flux’’ at rigidity ~5 GV and ~15 GV prior to any prompt or long-lived background correction.



The CDG Spectrum - II

- The measured CDG spectrum from the Virgo and South Galactic Pole directions. Also plotted is the power-law fit to the COMPTEL data in the 4.2–30 MeV range.



[10] Kinzer R.L. et al., 1996, ApJ **475**, 361

Systematic Errors

- The ToF fit function:
  - The true shape of the ToF-continuum is not known. It can be modeled by a quadratic or an exponential function. The two different ToF-continuum functions gives ~ 3–5 % difference in the extrapolated CDG rates.
- The linear-extrapolation of prompt background:
  - Although the 2.2 rate is consistent with zero at zero veto-scalar, it can be used to calibrate the veto-scalars by allowing for a non-zero intercept in the VGC fit. Using the 2.2 veto-intercept gives ~ 10–20 % variation in the extrapolated CDG rates.
- The Veto-Dome used for extrapolation:
  - The CDG extrapolation can be performed using any of the 4 independent veto-scalars. The different veto-dome scalars gives ~ 7–10 % variation in the extrapolated CDG rates.
- The COMPTEL response calculation:
  - The COMPTEL response has been derived for an 2π diffuse $E^{-2.5}$ power-law source. We estimate ~ 10 % error in the CDG effective-area calculation.
- Hence we estimate a total systematic error of ~ 25 % for the CDG flux measurements above 4.2 MeV.