A Broad-Band Gamma-Ray Spectrum of Cygnus X-1

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Observation Summary

Summary of COMPTEL observations of the Cygnus region.

"Viewing angle" is with respect to COMPTEL z-axis.

"Eff Exp" is an estimate of the total effective on-axis exposure.

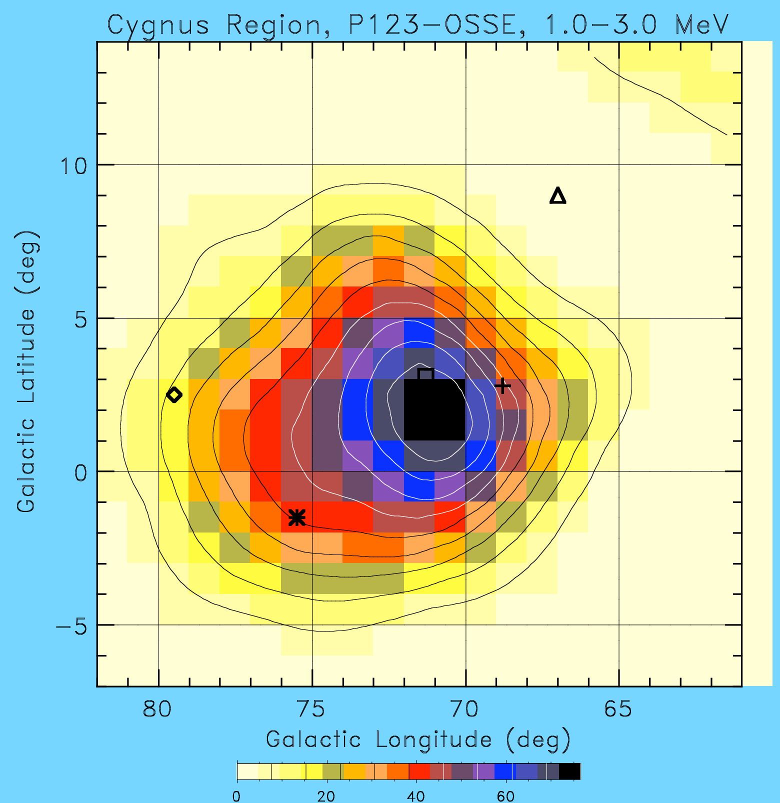
Viewing Period	Start Date	End Date	Viewing Angle	Effective Exposure
2.0	*30-May-1991*	*08-Jun-1991*	*1.7°*	*3.65 days*
7.0	*08-Aug-1991*	*15-Aug-1991*	*11.2°*	*2.72 days*
203	*01-Dec-1992*	*22-Dec-1992*	*7.0°*	*5.19 days*
212.0	*09-Mar-1993*	*23-Mar-1993*	*15.4°*	*2.71 days*
318.1	*01-Feb-1994*	*08-Feb-1994*	*4.5°*	*1.78 days*
328.0	*24-May-1994*	*31-May-1994*	*7.0°*	*1.56 days*
331.0	*07-Jun-1994*	*10-Jun-1994*	*7.0°*	*0.95 days*
331.5	*14-Jun-1994*	*18-Jun-1994*	*7.0°*	*1.34 days*
333.0	*05-Jul-1994*	*12-Jul-1994*	*7.0°*	*1.86 days*

Spatial Modeling of the Image Data

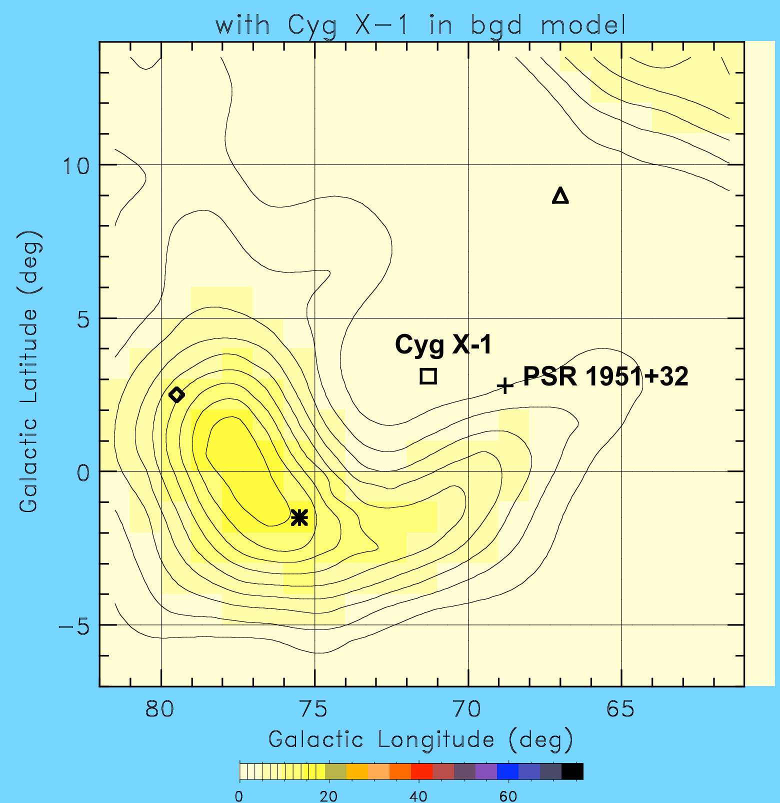
- ☞ A proper analysis of COMPTEL imaging data requires a detailed modeling of all spatial components.
- ☞ The Cygnus region is particularly difficult in that it lies directly in the galactic plane.
- ☞ We have defined several spatial components which are used in the image analysis. These include both known sources (galactic diffuse emissions, PSR 1951+32) and various ad hoc distributions derived directly from COMPTEL images.
- ☞ Each set of imaging data (one per energy band) has been fit with a number of different combinations of these model components.
- ☞ The following panel demonstrates the approach in modeling the 1.0-3.0 MeV data.

1.0-3.0 MeV Imaging

Raw likelihood map showing feature extending away from Cyg X-1

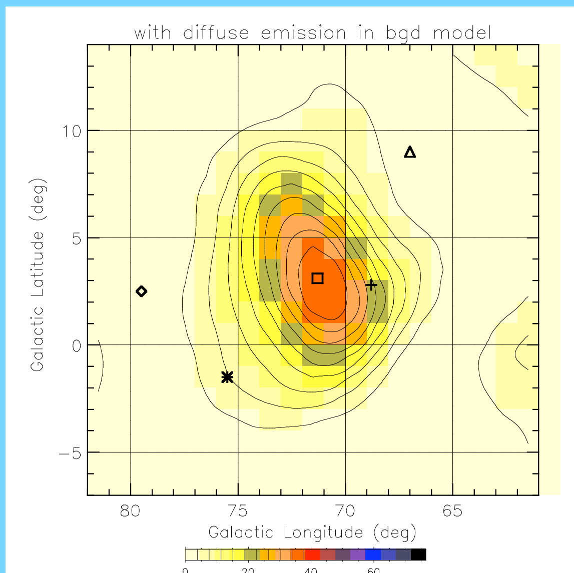


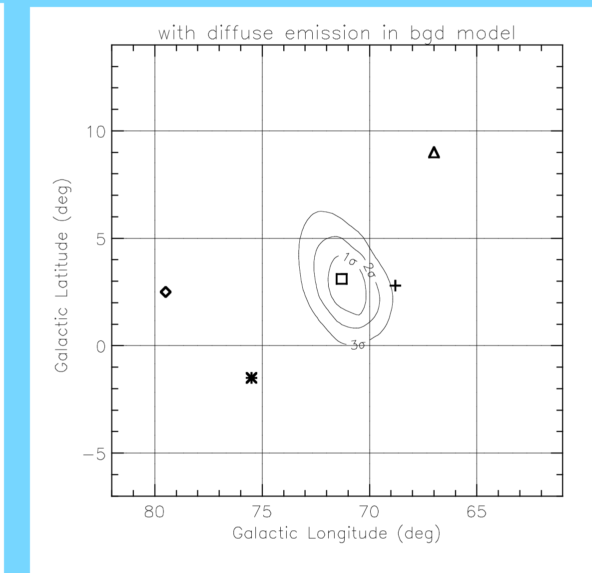
Including Cyg X-1 in bgd model shows the residual feature(s)



The maps in the following panel show how the residual emission can be modeled as either galactic diffuse emission or as a combination of two point sources.

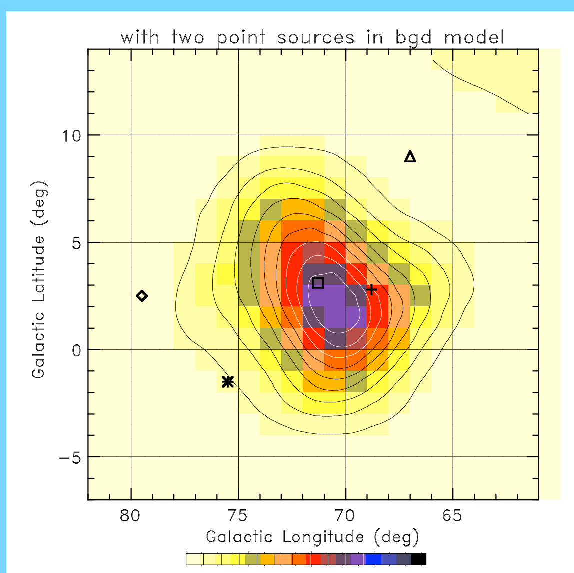
1.0-3.0 MeV Spatial Modeling

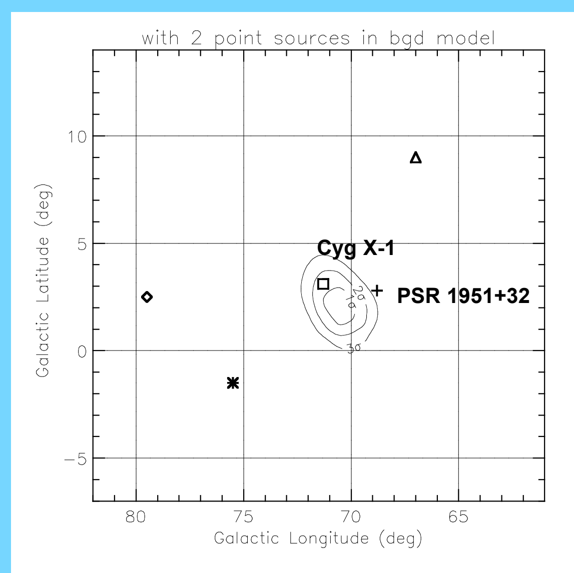




<= diffuse emission

In both cases, the fit to the data is improved significantly. The remaining emission can be accounted for entirely by Cyg X-1.

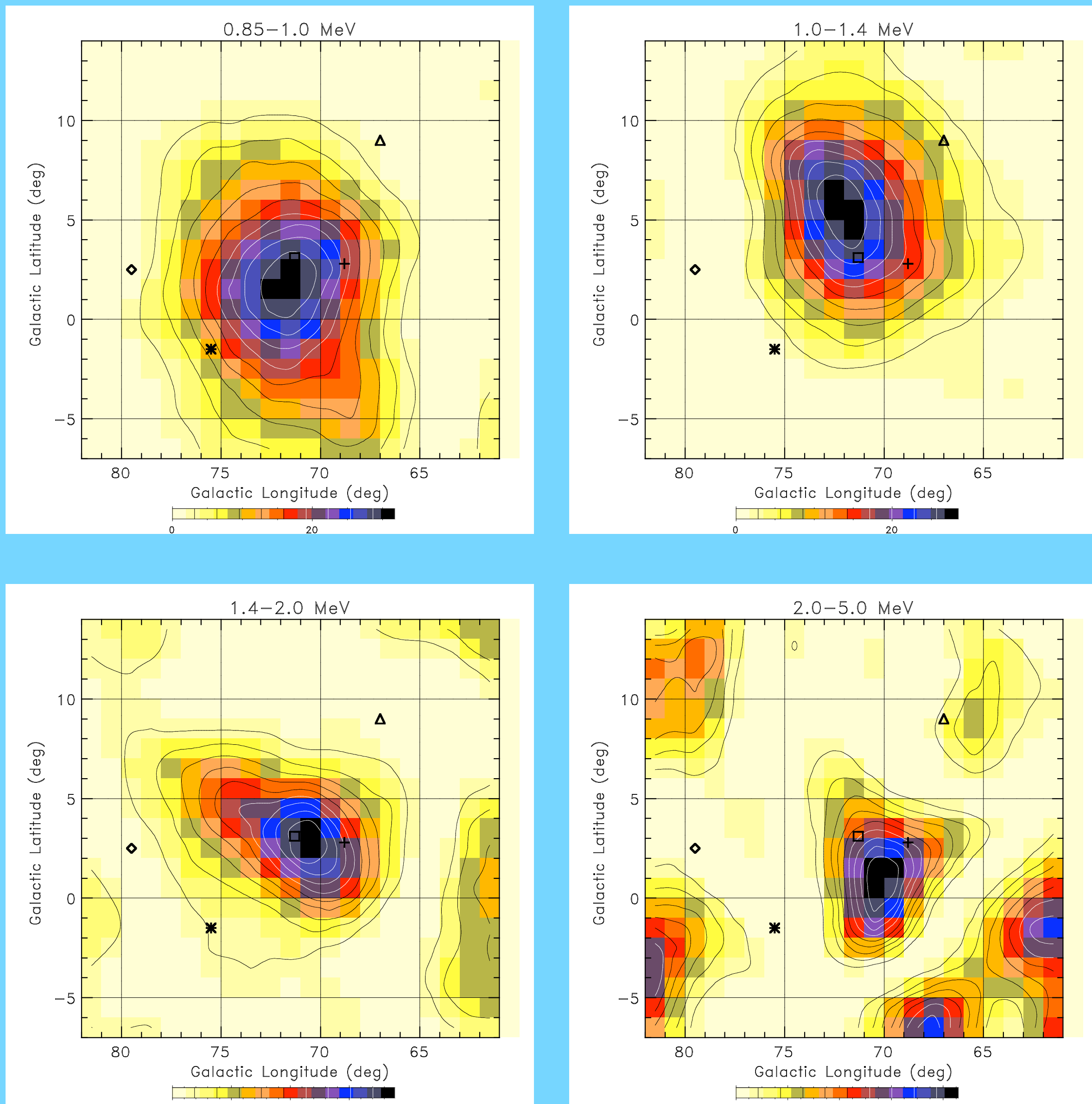




Both point sources used in this model are consistent with EGRET sources.

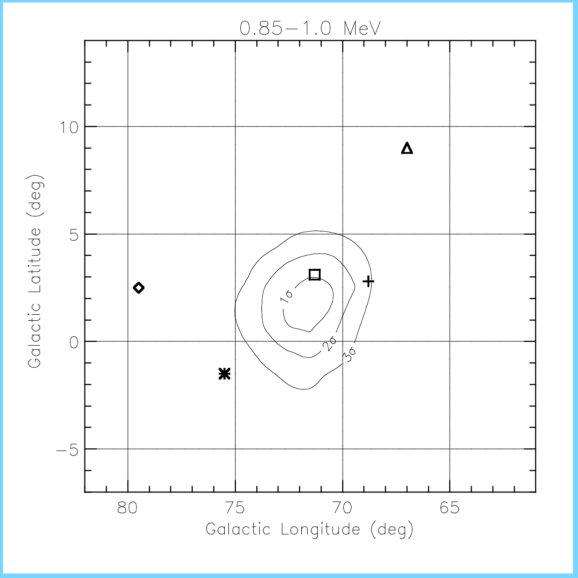
<= two point sources

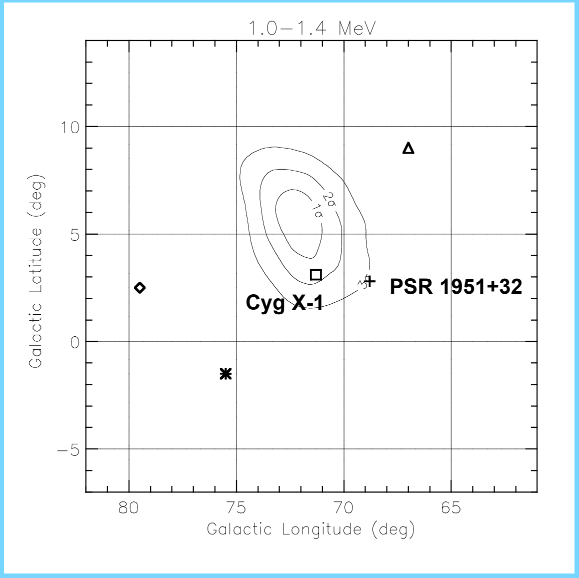
Residual Likelihood Maps



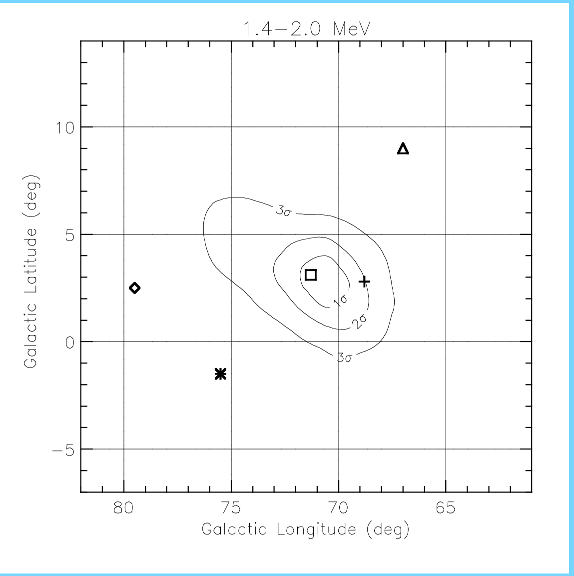
Residual likelihood maps for some of the data points in the final spectrum presented in the following panels.

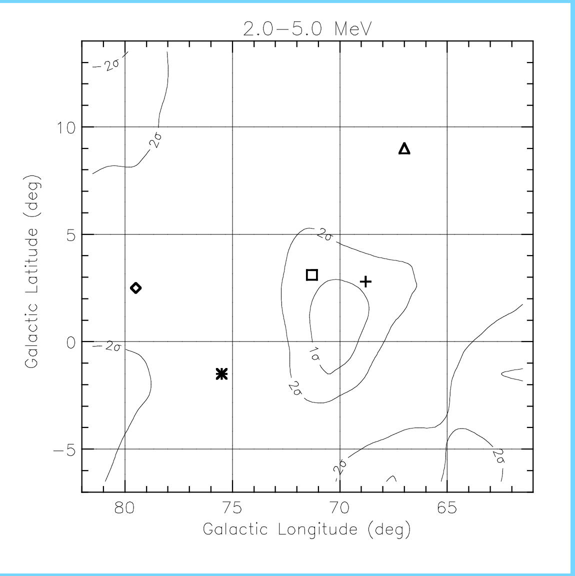
Location Contour Maps





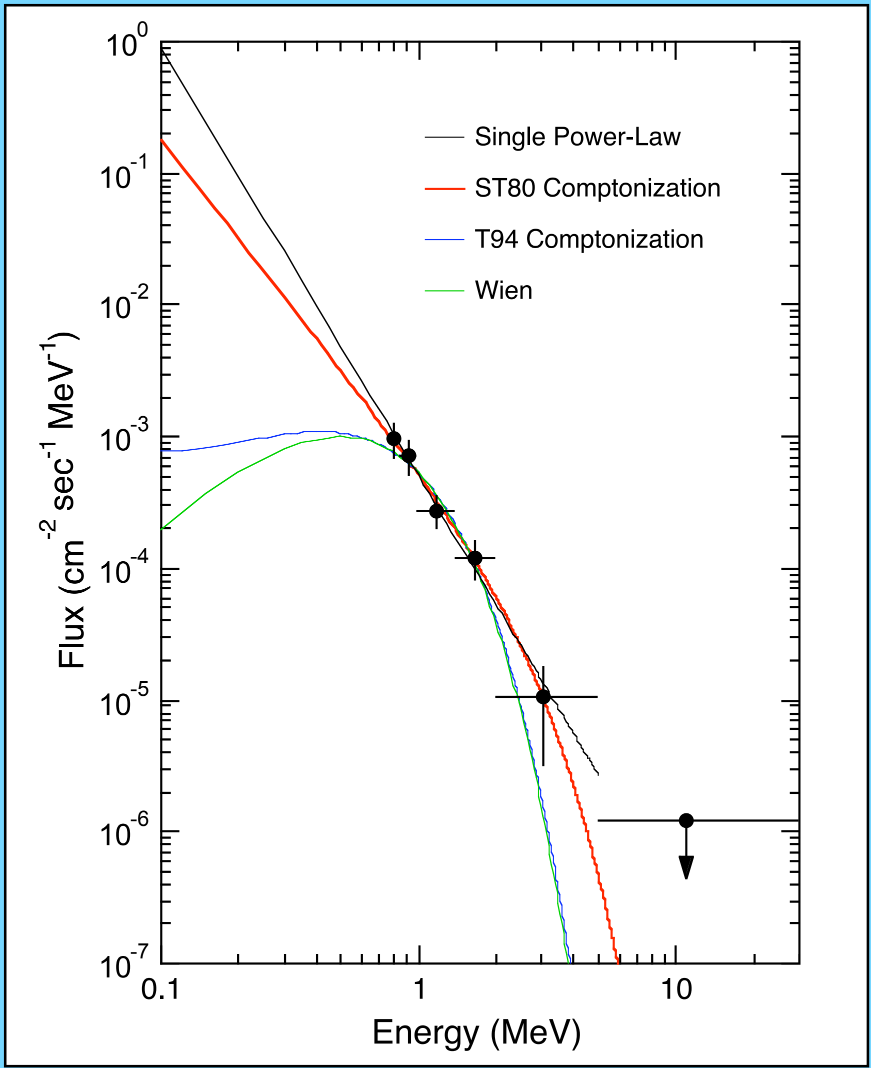
Location contour maps for some of the data points in the final spectrum.





The statistical significance of the 2-5 MeV data point (by itself) is just under 3σ.

The COMPTEL Spectrum



We can characterize the COMPTEL data by fitting selected spectral models to the COMPTEL data alone.

The COMPTEL data can be characterized as very soft, with a power-law index of -3.7.

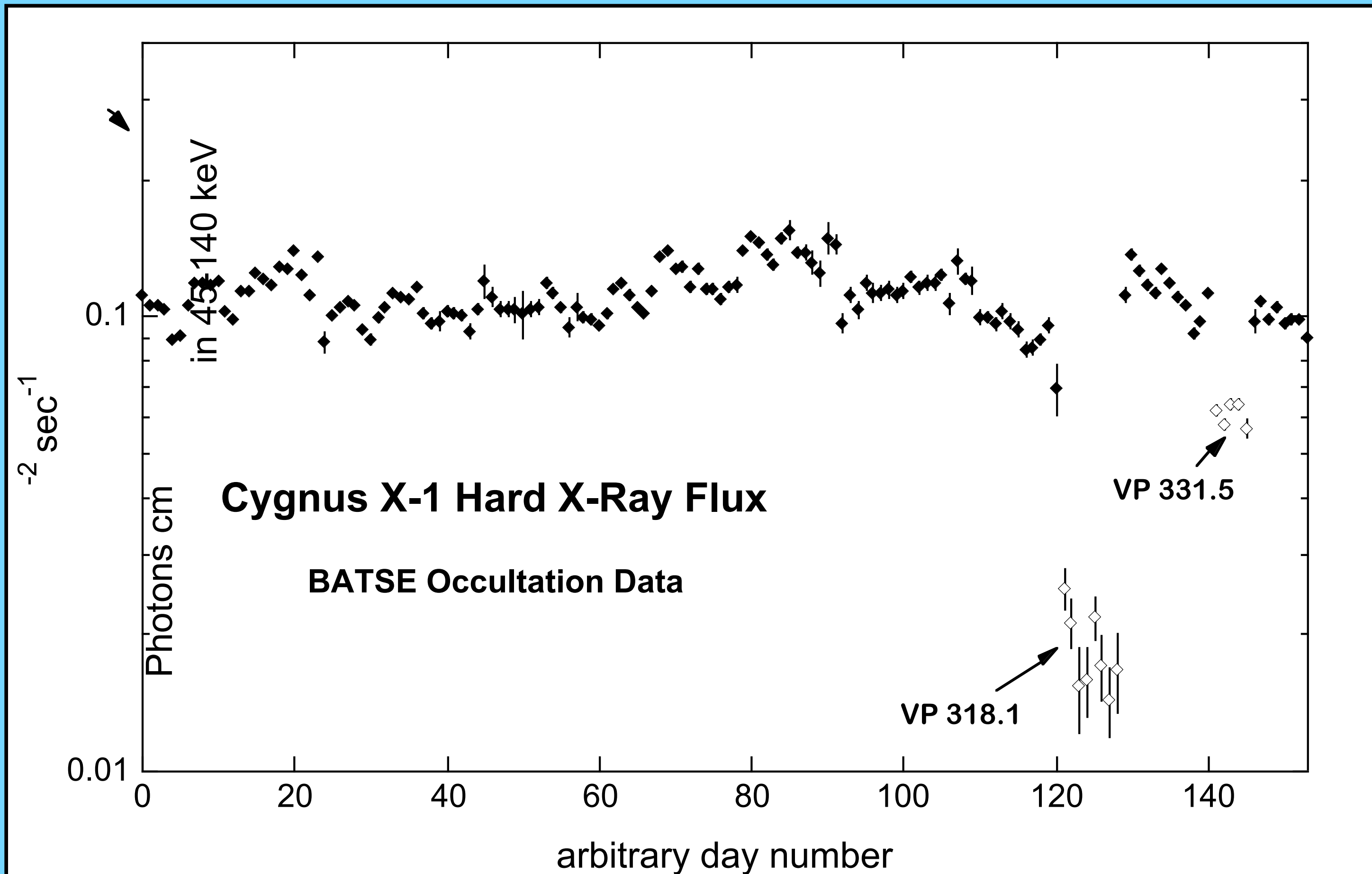
Fits using Comptonization models suggest a very hot plasma with a very small optical depth. But the extrapolation of these fits to lower energies does not agree well with observations.

ST80 =>	**Comptonization Model of Sunyaev and Titarchuk (1980).**
T94 =>	**Generalized Comptonization Model of Titarchuk (1994).**

Combined Spectral Analysis

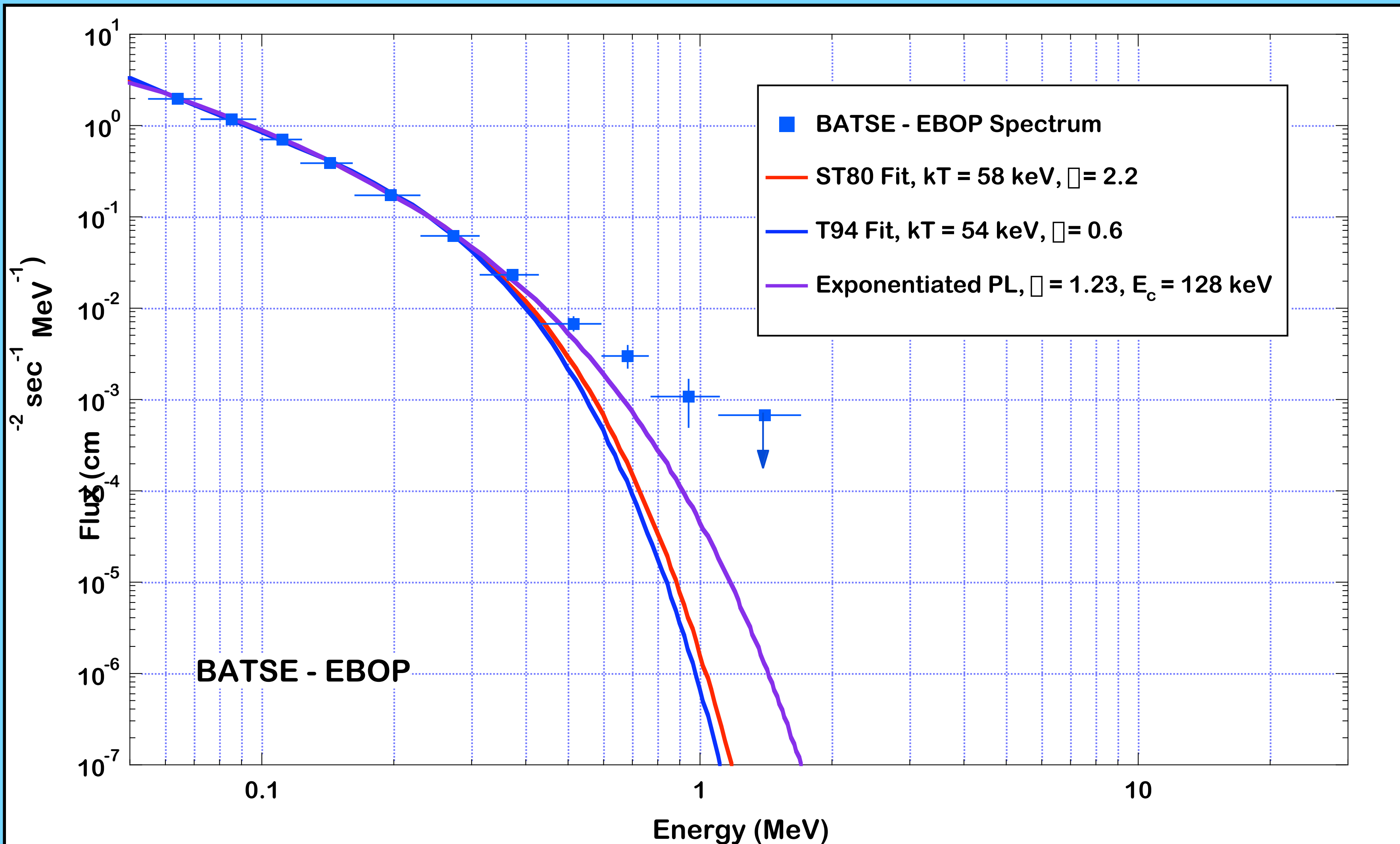
- ☞ Using the COMPTEL data alone, it is difficult to assemble a broad picture of the high energy emission.
- ☞ We have completed a more complete analysis using contemporaneous data from both BATSE and OSSE.
- ☞ Data selection was driven by those periods in which both OSSE and COMPTEL were viewing Cyg X-1.
- ☞ Only those data selected from phases 1-3 have been used so far.
- ☞ The selected viewing periods are indicated in the above COMPTEL observation summary.

Hard X-Ray Flux Level

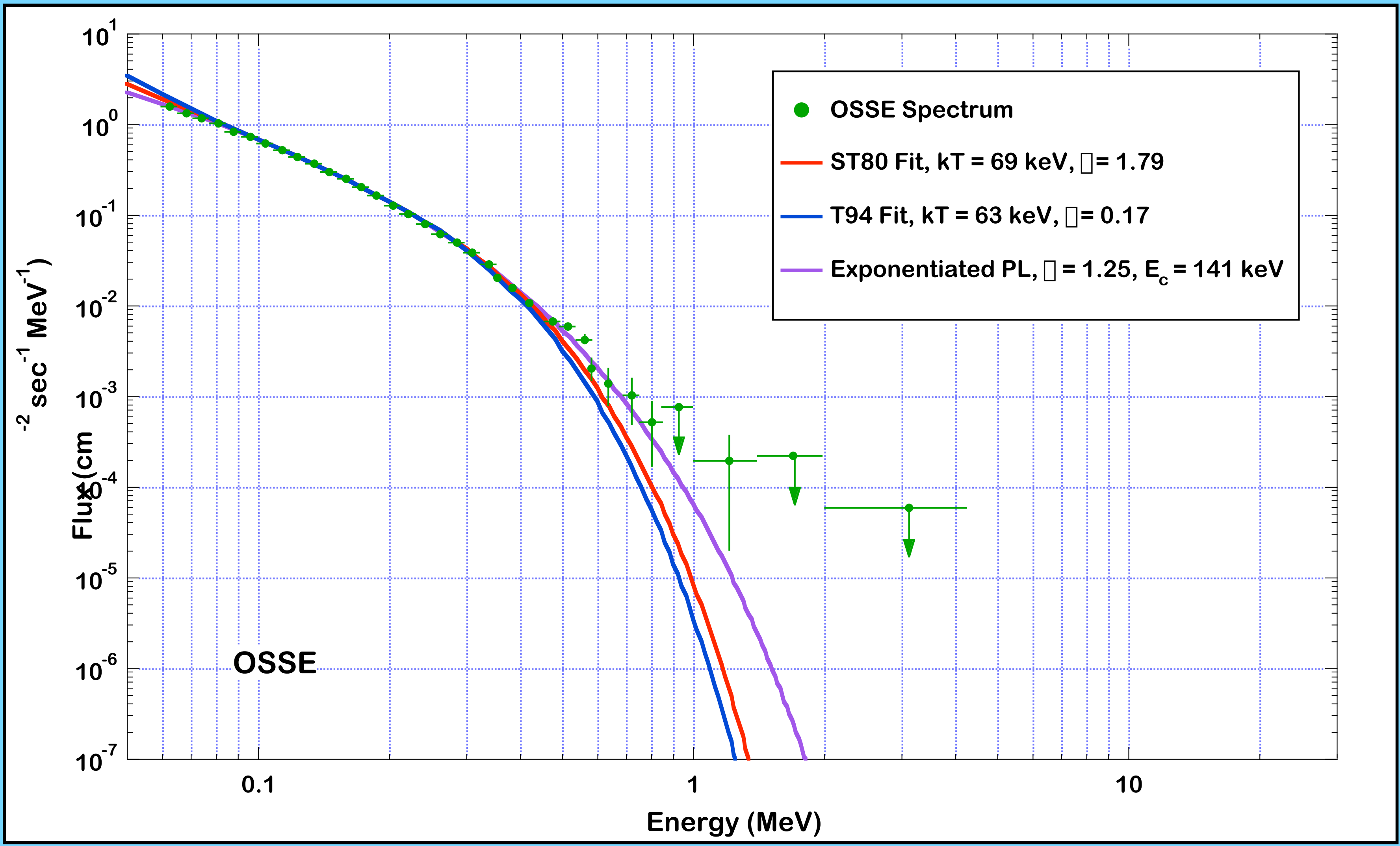


BATSE Occultation data for the selected viewing periods. The hard X-ray flux is largely constant within these data, except for VPs 318.1 and 331.5, which were excluded from the final aanalysis.

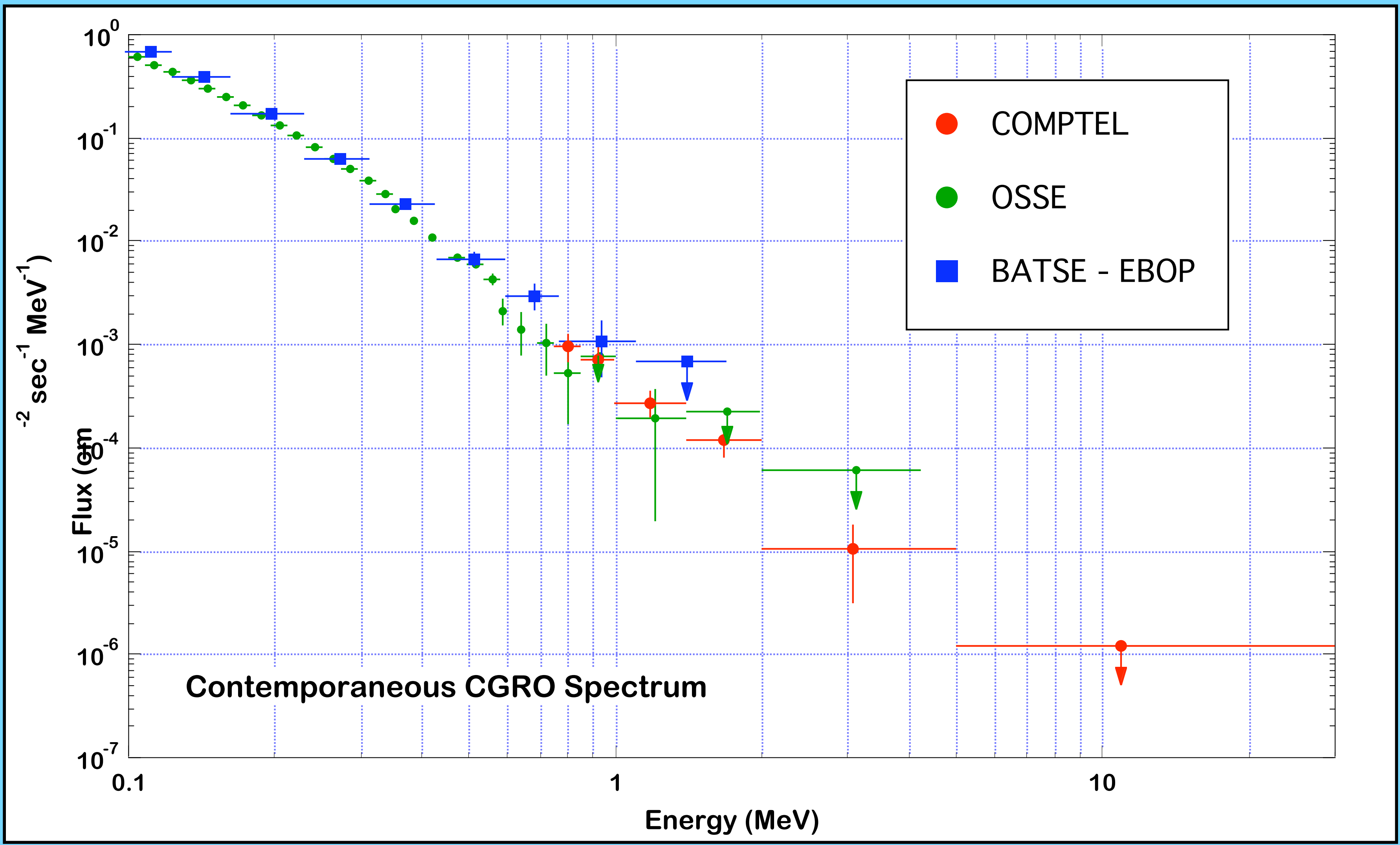
The BATSE Spectrum



The OSSE Spectrum



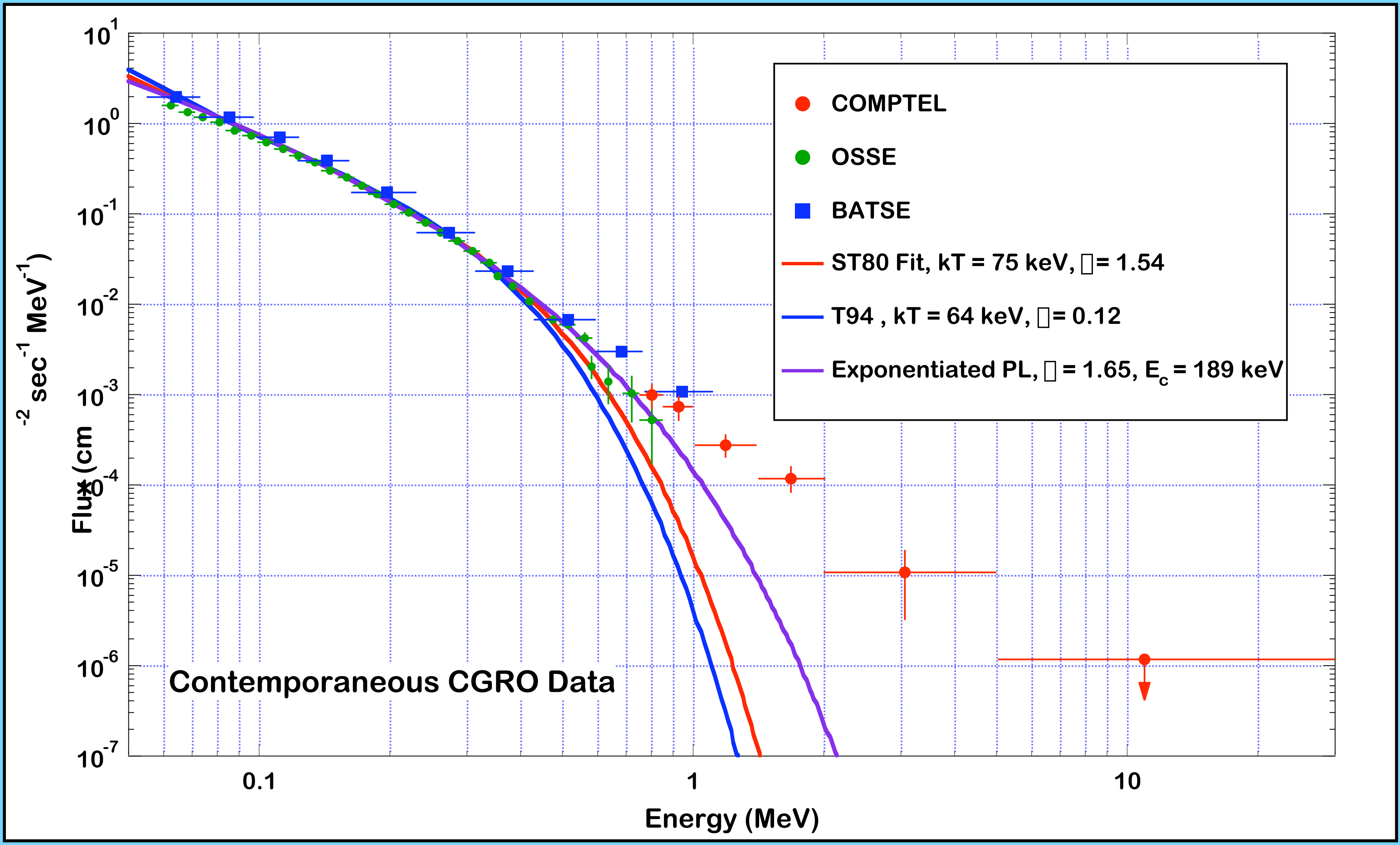
The Combined CGRO Spectrum



CGRO Spectrum Comparison

- ☞ A visual inspection of the three spectra shows some potentially significant differences between the OSSE and BATSE-EBOP spectra at all energies.
- ☞ The nature of the connection of the COMPTEL spectrum to lower energies may depend somewhat on whether the OSSE or BATSE-EBOP spectrum is used for comparison.
- ☞ In the following panels, we show the results of joint spectral fits using both the OSSE and BATSE-EBOP spectra separately.
- ☞ In each case, we show the fits as derived over both the entire energy range and over an energy range restricted to energies above 300 keV. If there exists a component of the spectrum due to reflection off an optically thick disk, then the fits above 300 keV may be more representative of the Comptonization component.

Fits to Combined Spectrum
(fit to full range of data)



Fits to Combined Spectrum

(fit to data > 300 keV only)

Summary of the Data

- ☞ The COMPTEL data provides information on the spectrum of Cygnus X-1 to energies above 2 MeV.
- ☞ No strong evidence for detectable emission above 5 MeV.
- ☞ The COMPTEL spectrum can be described as smooth power-law continuum with a spectral index of -3.7.
- ☞ Combining COMPTEL data with lower energy data is needed in order to extract the most useful science from the COMPTEL data.
- ☞ Comtemporaneous data at lower energies is available from both BATSE-EBOP and OSSE, but there appears to be some differences between these two spectra. The BATSE-EBOP flux levels are consistently higher than the OSSE flux levels.
- ☞ Interpretation of the COMPTEL data depends somewhat on whether a comparison is made with BATSE-EBOP or OSSE.

Summary / OSSE-COMPTEL

☞ **For the broad-band fits:**

- **The ST80 model provides a good fit up to ~200-300 keV.**
- **The T94 model provides a somewhat better fit up to ~400 keV.**
- **Both models fall well below the observed flux at energies near 1 MeV.**
- **Best-fit plasma parameters are kT ≈ 60 keV, ≈ 2.5**

☞ **For the fits restricted to data > 300 KeV:**

- **Both models do reasonably well up to ~1 MeV.**
- **Both models fall far below the data at energies > 1 MeV.**
- **Best-fit plasma parameters are kT ≈ 125 keV, ≈ 0.6.**

☞ **The nature of the connection between the OSSE and COMPTEL spectra is perhaps unclear, although the statistical significance of any structure is quite low. Certainly, this composite spectrum deviates much more from the thermal Comptonization models.**

Conclusions

- ☞ The COMPTEL data show evidence for emission from Cygnus X-1 to energies above 2 MeV.
- ☞ Standard single-temperature thermal Comptonization models do not adequately fit the broad-band spectrum.
- ☞ The broad band spectra are qualitatively consistent with several proposed scenarios:
  - Models which incorporate a Compton reflection component (e.g., Haardt et al. (1993), Wilms et al. (1996)).
  - Models which invoke some type of stochastic acceleration process (e.g., Li et al. (1996)).
  - Models involving thermal stratification (e.g., Skibo and Dermer (1995), Ling et al. (1997)).