Document Title Point-Spread-Function Synthesis Using a High-Statistics PSF Library

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1 Introduction

This document discusses the motivation and development of a library of Point-Spread-Functions (PSFs) which can be used to synthesize additional PSFs. This PSF library differs from previous libraries in that each mono-energetic PSF was generated with high counting statistics. It will be shown that the number of photon counts which are used to define PSFs can affect parameter estimation during imaging.

2 Simulation or Synthesis: Creating a PSF

To perform source imaging one must define an instrument response, or PSF, for a potential source. This can be accomplished using one of two methods: (1) Simulation of the assumed source spectrum and conversion to the appropriate COMPTEL dataspace, or (2) synthesizing the COMPTEL instrument response to the assumed source spectrum by weighting existing instrument responses.

The first option involves the use of 3 COMPASS modules in which unbroadened telescope events are generated in a perfect "COMPTEL" with the assumed source energy spectrum (SIMGAM). These events are then broadened with the appropriate COMPTEL instrument resolutions (SIMFIN), and then a PSF is generated by mapping to COMPTEL dataspace (SIMPSF). Any significant variation in the spectrum due, for example to a modified emission model, may require one to regenerate the instrument response.

The second option applies weights, which are determined by the energy spectrum being considered, to a previously defined library of PSFs. The PSFs in the library are defined to be the COMPTEL response to a mono-energetic photon source. Each of these "mono-energetic" PSFs are generated using the procedure described above. The synthesis option has the advantage that the time consuming and computer intensive intrument response monte carlo (SIMGAM) need only be generated once (for each PSF in the library), with the user only supplying the spectral weights used in the synthesis procedure. In addition, spectra which are not easily parameterized (unlike power law or blackbody spectra), can be easily generated again by defining spectral weights.

3 Mono-energetic PSF Generation

The library of mono-energetic PSFs used in synthesizing a PSF must be distributed in energy such that the complete COMPTEL energy range is covered adequately. Clearly one must determine the energy resolution necessary, ie. how far apart should the mono-energetic lines be spaced? In the PSF libraries used to date (COM-RP-UNH-SIM-039), lines were spaced within about one-half of the energy dependent telescope resolution (ie., $\sim 0.5\sigma$). This choice requires many "mono-energetic" PSFs to be created to cover the appropriate instrument energy range. In addition, in the current PSF library each individual PSF has very low statistics; however when combined in a weighted sum the synthesized PSF will have adequate statistics. It is important to note that the primary motivation of this library was to reproduce the instrument response to power-law spectra, and thus high-statistics is not necessary at the high end of the COMPTEL energy range.

Here we have chosen to generate lines with about one FWHM (energy dependent) spacing. With no a priori knowledge of the assumed source spectrum, each line should be able to contribute the statistics necessary to reproduce a mono-energetic source at the appropriate energy. Because of the high-statistics used in each "line", this library can be used to synthesize the instrument response to any *continuous* spectrum, including those that are very hard.

3.1 What is High-Statistics?

In order to faithfully reproduce any source, the PSF used must have adequate statistics. We have generated a number mono-energetic test sources, each with the source strength required to give a minimum detectable flux of 1.6×10^{-4} cm^{-2}s^{-1} (which is the published minimum detectable flux in COMPTEL for the energy range 1-30 MeV). The number of counts required for each line is

$$N_\gamma(E) = 1.6 \times 10^{-4} \cdot T_{eff} \cdot A_{eff} \tag{1}$$

where $T_{eff} = 0.33 \times 14\text{days} = 4 \times 10^5\text{sec}$, and A_{eff} is the energy dependent effective area of COMPTEL. The number of counts used for each test source is summarized in Table 1. For this analysis a uniform background, of magnitude 1×10^{-6}, was assumed to be present.

For each test line 5 PSFs were generated. One expects the quality of source imaging and parameter estimation to improve when the number of counts used to define the PSF used is maximized. Therefore, we measure both the significance of the source detection and the source strength estimate as a function of the number of counts defining each PSF (ie., number of counts in QEV). Figures 1, 2, and 3 show the trends for three of the test lines at energies of 3.1, 8.7, and 30.0 MeV respectively (the other test lines show similar results). Inspection of these figures show that both the detection significance and source strength estimate increase as the number counts used to define of PSF increases, finally plateaus between 40000 to 80000 events.

Table 1: Source Strengths

Line Energy (MeV)	N_γ
1.8	3177
3.1	3383
5.2	3182
8.7	2787
14.7	2315
24.6	1862
30.0	1700

4 The PSF Library

A complete high-statistics PSF library has been generated. The PSFs in the library include line energies which may contribute to the energy interval 1-30 MeV and were required to include 80000 events *before* event broadening and mapping to dataspace (ie., number of events in QEV). There are a total of 43 lines which are spaced by 1 FWHM (energy dependent) energy resolution. Table 2 lists the "mono-energetic" PSFs included in this library. All PSFs used here were generated for a source 10^o off-axis (0^o azimuth angle), $2^o\overline{\phi}$ binning and telescope events in the energy interval 1.0-30.0 MeV. Also given is the number of events included in the final PSF.

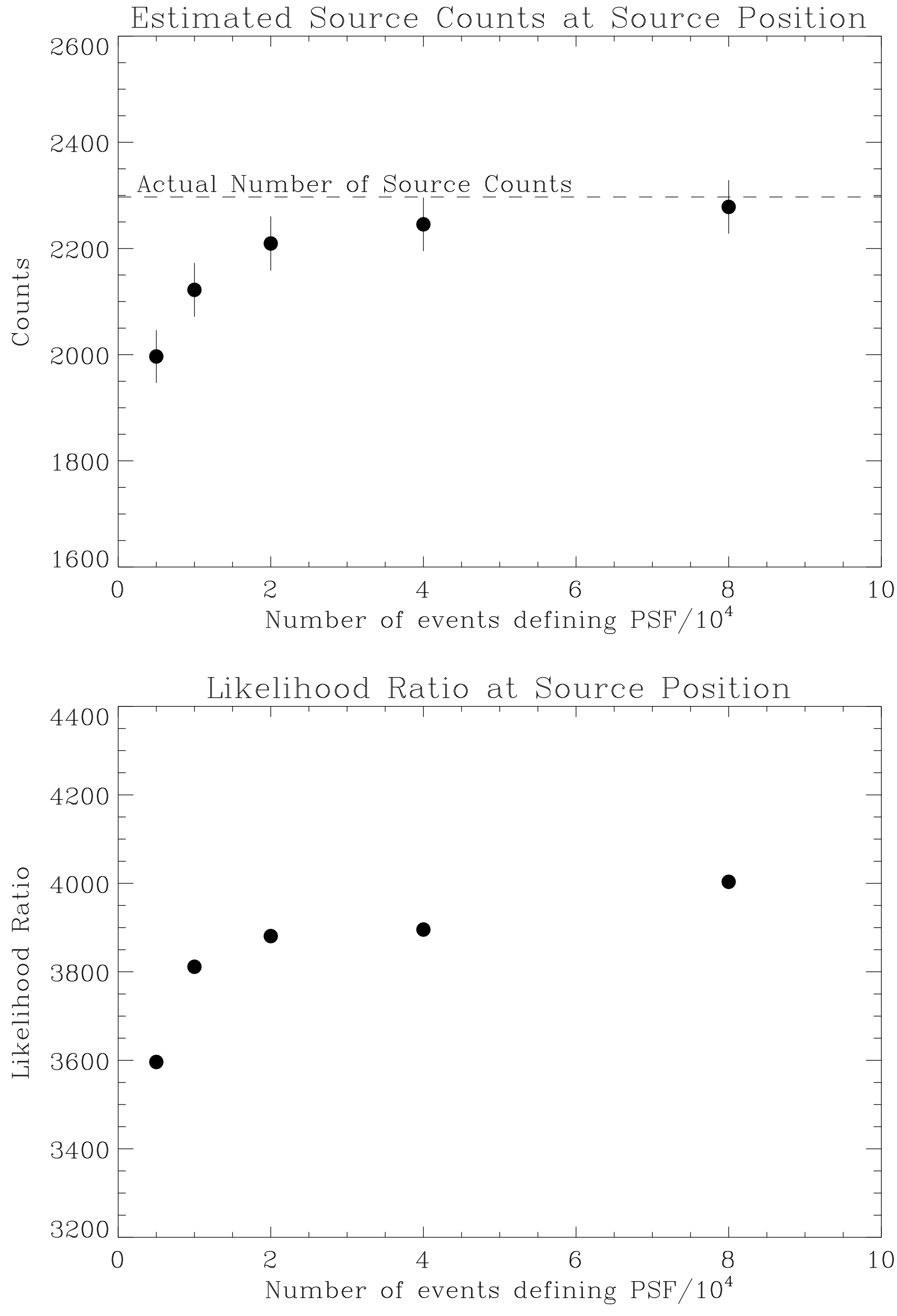
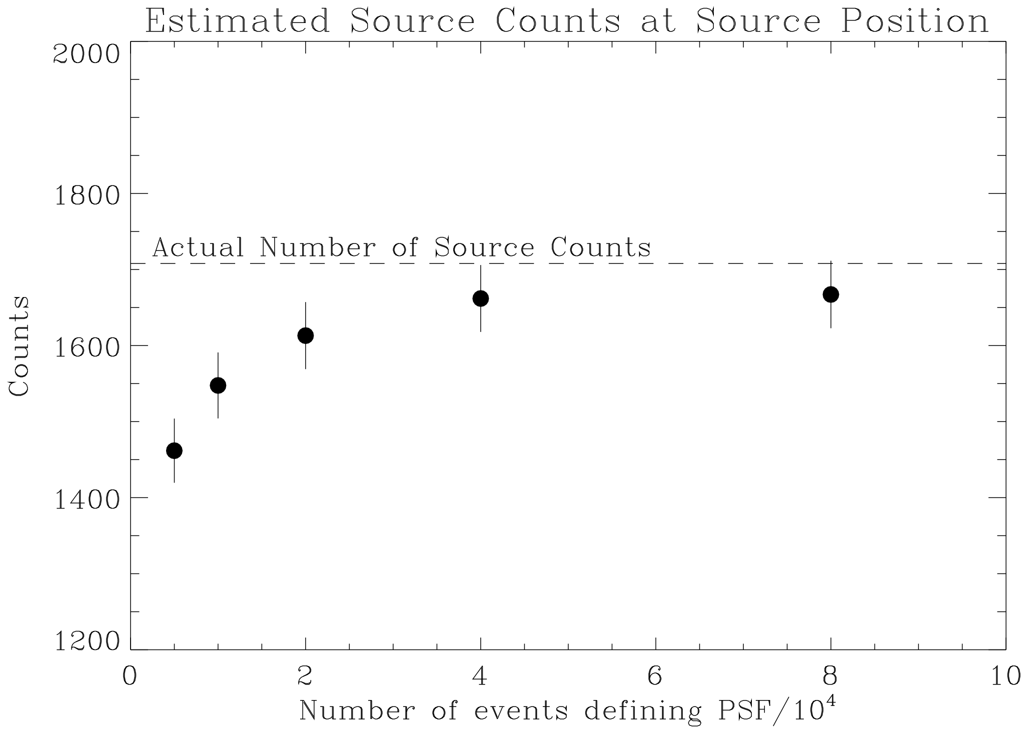


Figure 1: Source Detection Significance $(-2\ln(Lik))$ and source strength as a function of the number of counts defining the instrument response (PSF). Source energy 3.1 MeV. One sigma error bars are shown.



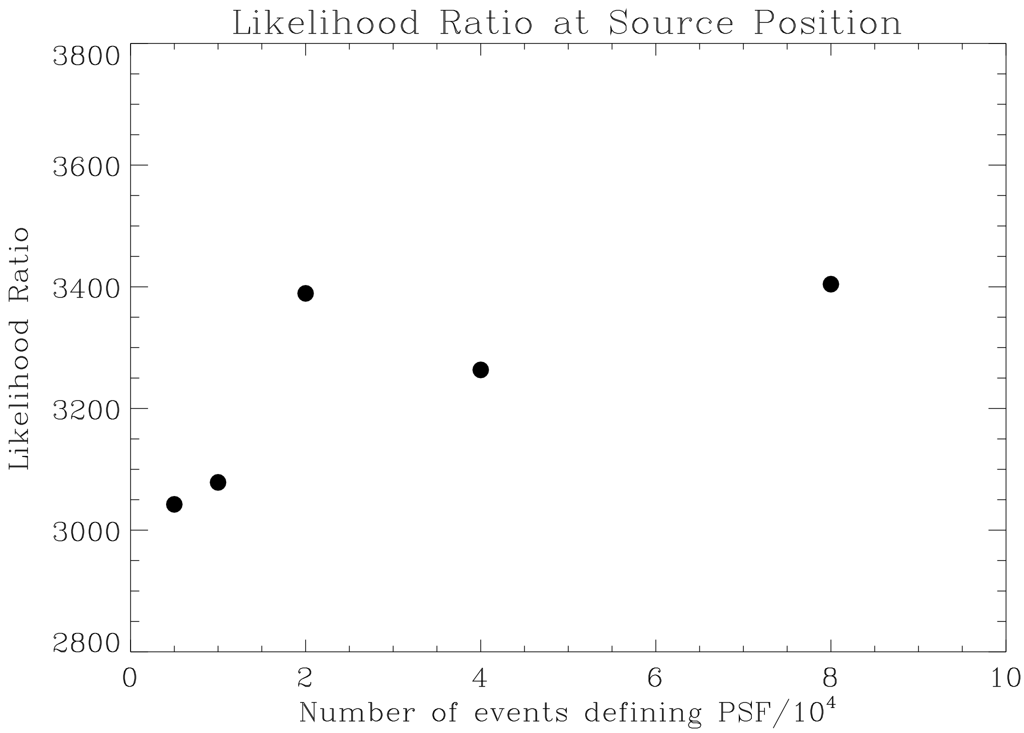
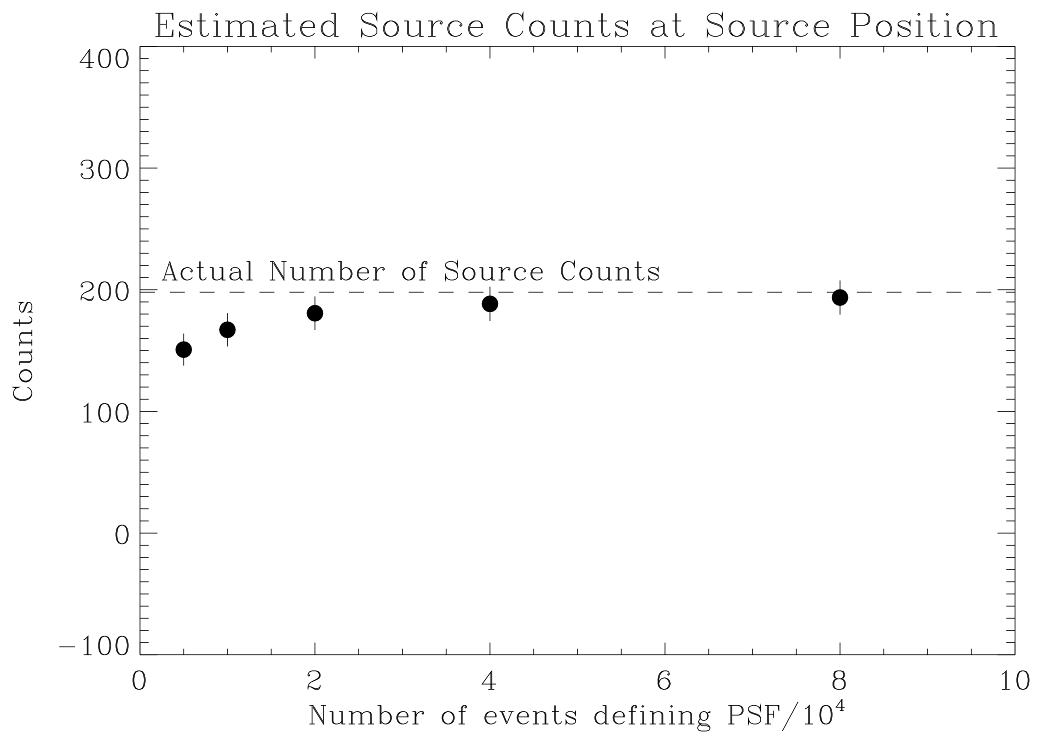


Figure 2: Source Detection Significance $(-2\ln(Lik))$ and source strength as a function of the number of counts defining the instrument response (PSF). Source energy 8.7 MeV. One sigma error bars are shown.



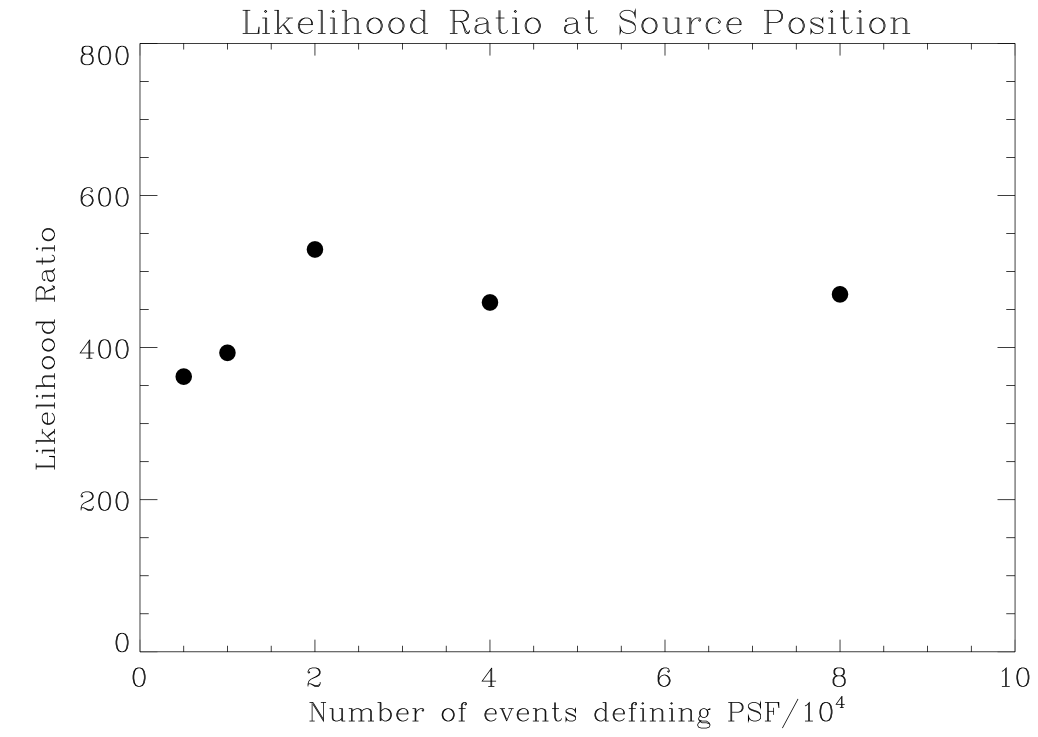


Figure 3: Source Detection Significance $(-2\ln(Lik))$ and source strength as a function of the number of counts defining the instrument response (PSF). Source energy 30 MeV. One sigma error bars are shown.

Table 2: High-Statistics PSF Library

Line Energy (MeV)	IAQ (Uxxx.IAQ)	N_{evnts}
0.5	5641	0
0.6	5642	0
0.7	5643	0
0.8	5644	0
0.9	5645	141
1.0	5646	12567
1.2	5647	30861
1.3	5648	35204
1.4	5649	38088
1.6	5650	42929
1.8	5651	46066
2.0	5652	48927
2.2	5653	50284
2.5	5654	51910
2.8	5655	53000
3.1	5656	53462
3.4	5657	53915
3.8	5658	54009
4.2	5659	53771
4.7	5660	53347
5.2	5661	52979
5.8	5662	52484
6.4	5663	51962
7.1	5664	50974
7.9	5665	49598
8.7	5666	48240
9.7	5667	46501
10.8	5668	44661
11.9	5669	43077
13.2	5670	40838
14.7	5671	37378
16.3	5672	33506
18.0	5673	29686
20.0	5674	25240
22.2	5675	25254
24.6	5676	16624
27.3	5677	12598
30.0	5678	9904
33.4	5679	5888
37.0	5680	3791
41.0	5681	2446
45.5	5682	1687
50.0	5683	1181

5 Comparison of Simulated vs Synthesized PSF

The PSFs synthesized by using the high-statistics library have been compared to both the PSFs generated by direct source simulation and those synthesized with the current library. As an example the comparison using a power-law source spectrum with index -2 is presented. The PSF comparisons are presented as different slices through the dataspace.

By inspection it is apparent that the PSF synthesized with the high-statistics library reproduces the directly simulated PSF quite well. In fact because of its higher overall statistics, the synthesized PSF appears to have covered the dataspace more completely. The same conclusions hold for the comparison with the PSF synthesized with the current library.

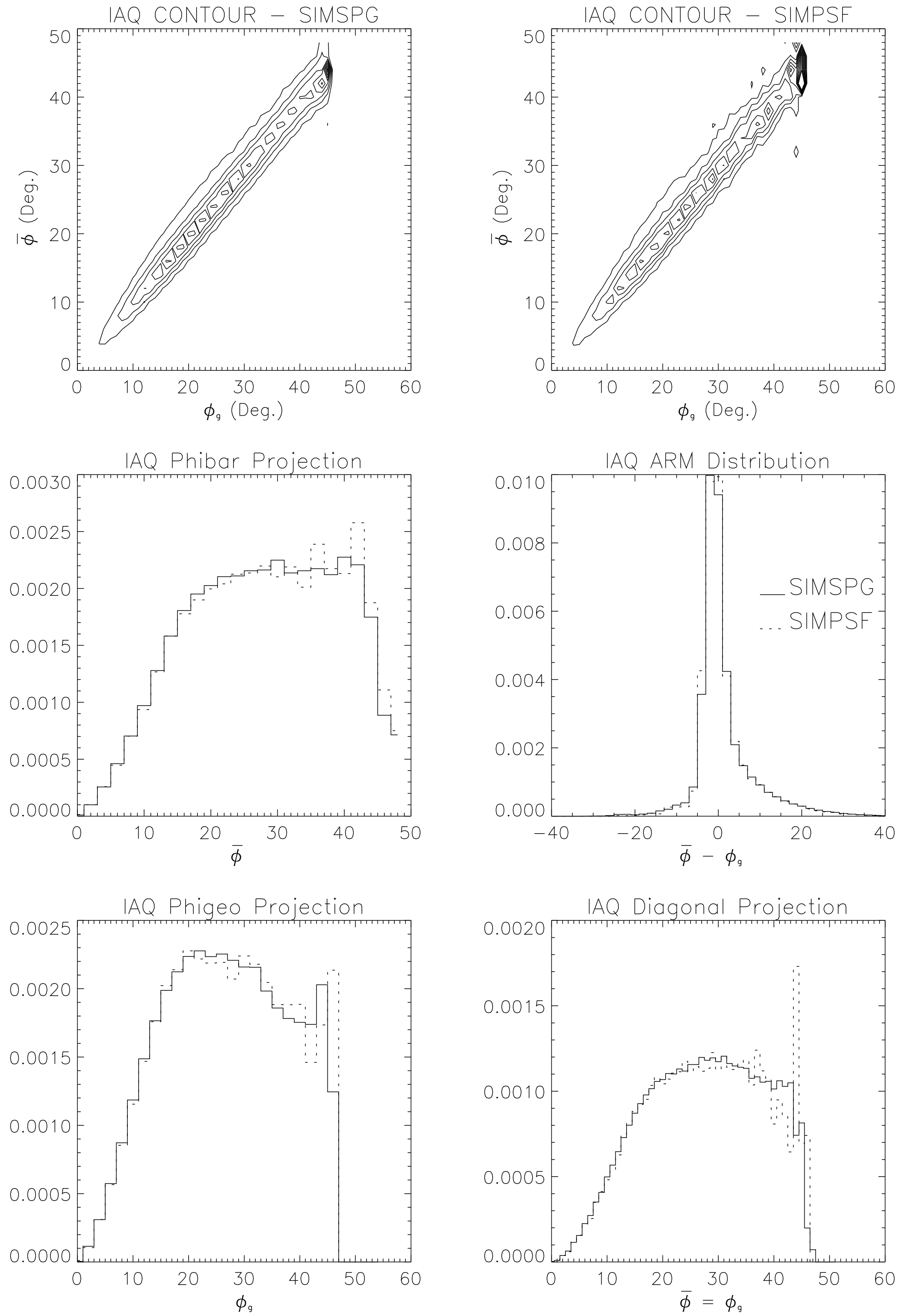


Figure 4: Comparison of synthesized PSF (SIMSPG), solid, and directly simulated PSF (SIMPSF), dashed, for power law spectrum with index=-2.

6 Conclusions

A library of mono-energetic instrument responses with high counting statistics, whose lines are spaced sparsely throughout the applicable energy range has been shown to produce synthesized PSFs at least as well as the techniques currently used. The advantage of using such a library is that the computer intensive simulations need only be performed once; variations in energy intervals of interest, spectral shapes, etc. can be applied as needed by the user. This library could be used to produce the instrument response (PSF) for any continuous spectrum, including those that are hard.