Statistical analysis of COMPTEL maximum likelihood-ratio distributions: evidence for a signal from previously undetected AGN

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Abstract.
The maximum likelihood-ratio method is frequently used in COMPTEL analysis to determine the significance of a point source at a given location. In this paper we do not consider whether the likelihood-ratio at a particular location indicates a detection, but rather whether distributions of likelihood-ratios derived from many locations depart from that expected for source free data. We have constructed distributions of likelihood-ratios by reading values from standard COMPTEL maximum-likelihood ratio maps at positions corresponding to the locations of different catagories of AGN. Distributions derived from the locations of Seyfert galaxies are indistinguishable, according to a Kolmogorov-Smirnov test, from those obtained from "random" locations, but differ slightly from those obtained from the locations of flat spectrum radio loud quasars, OVVs, and BL Lac objects. This difference is not due to known COMPTEL sources, since regions near these sources are excluded from the analysis. We suggest that it might arise from a number of sources with fluxes below the COMPTEL detection threshold.

INTRODUCTION

The maximum likelihood-ratio method can be applied to COMPTEL data to determine the significance of a point source at a given location [1]. In this paper we do not consider whether the likelihood-ratio at a particular location indicates a detection, but rather whether distributions of likelihood-ratios derived from many locations depart from that expected for source free data.

Maximum likelihood-ratio distributions were generated by taking positions either from the EGRET AGN search list or from the EGRET source catalogue [2] and reading values at those positions from the standard COMPTEL maximum-likelihood ratio maps. We have divided the EGRET AGN search list into the various sub-catagories shown in Table 1. Data from observation periods up to, and including 523, have been used.

To ensure our distributions are not dominated by known objects, locations within 15^o of the Crab and of the galactic plane have been discarded, together with locations within 6^o of other known MeV sources.

A Kolmogorov-Smirnov (KS) test can be used to compare two measured distributions. It returns the probability that the two distributions are drawn from the same underlying population i.e. a low probability indicates different distributions. In the absence of any sources, the distributions of likelihoods from any class of objects should be compatible so we can use the KS test to search for evidence of a signal in any distribution.

In order to use the KS test to search for distributions containing signal a source-free distribution is required. Such a distribution has been created by taking our total search list of AGN, changing the sign of the galactic latitude and looking up the likelihood at that "mirrored" point.

Generating a source-free distribution by randomly choosing locations on the sky was *not* successful: its use indicated a "signal" from all the catagories of AGN, including e.g. Seyfert galaxies which have not been detected with COMPTEL. This problem may arise as a consequence of the non-isotropic nature of the AGNs in the search list.

Some of the regions studied have (unphysical) "negative" fluxes. The likelihood values from such regions are indicated by multiplying the true value by -1. These "negative" likelihoods are then treated in the same way as positive ones because only the measured distribution is important and not whether an individual measurement represents an upper limit or a detection.

PRELIMINARY RESULTS

Table 1 shows the probabilities obtained by comparing the 3845 flux measurements from the "mirror" distribution with distributions drawn from various classes of sources. The number of measurements in each distribution is shown in square brackets. The first two columns gives results for the entire AGN search-list (i.e. for all catagories of AGN) and the EGRET source catalogue distributions. The strongest evidence (0.004) for a signal is in the 10.0-30.0 MeV band AGN search list distribution - although 8 trials have been performed (which decreases the significance to 0.05).

The AGN search list has been sub-divided into four different catagories of sources. Columns 4-7 in Table 1 show the probabilities obtained using distributions derived from these different AGN classes. We note that the possible

TABLE 1. KS tests of likelihoods: Probability that the "mirror" distribution and distributions from different source catagories arise from the same underlying population.

Energy (MeV)	All AGN classes [4647][1]	EGRET sources [695]	SyG[2] [941]	RLQ[3] [3007]	XBL[7] [452]	RG[8] [222]	FSRQ[4]+ XBL+RBL[5] [3062]	SyG+RG +SSRQ[6] [1424]
0.75-1	0.679	0.668	0.089	0.729	0.744	0.265	0.394	0.308
1-3	0.491	0.541	0.443	0.708	0.072	0.066	0.861	0.351
3-10	0.657	0.038	0.638	0.328	0.480	0.175	0.018	0.543
10-30	0.004	0.297	0.188	0.005	0.121	0.665	0.003	0.142

[1] [#]: number in the sample
[2] SyG: Radio quiet quasars and Seyfert galaxies
[3] RLQ: Radio loud quasars and BL Lacs (i.e. FSRQ, RBL, and SSRQ)
[4] FSRQ: Flat spectrum radio loud quasars
[5] RBL: Radio selected BL Lacs
[6] SSRQ: Steep or intermediate spectrum radio loud quasars
[7] XBL: X-ray selected BL Lacs
[8] RG: Radio galaxies

signal in the 10-30 MeV band, seen in the undivided AGN distribution, is largely contributed by the radio-loud quasars.

Finally, column 8-9 shows the AGN search list divided into two catagories: the first consisting of objects from classes which have shown emission in the γ-ray region (flat spectrum radio quasars and x-ray or radio selected BL Lac objects) and the other of objects from classes which have not shown emission in the γ-ray region (Seyfert galaxies, steep spectrum radio quasars and radio galaxies). We see not only evidence for a signal in the 10.0-30.0 MeV band for the known γ-ray emitting classes, but also marginal evidence in the 3-10 MeV band. Care must be taken when interpreting these probabilities since we are performing extra trials on the data, however we do have an *a priori* knowledge which leads us to divide the sources into these catagories.

LIKELIHOOD DISTRIBUTIONS

The results section shows a possible "signal" in the 3-10 MeV and 10-30 MeV from classes of AGN known to emit γ-rays. Fig. 1 shows the observed and predicted likelihood distributions in the 10-30 MeV band for the radio loud quasar and "mirror" distributions. The observed values are in reasonable agreement with the predicted values, but there is no obvious sign of any signal, i.e. the observed values for the radio loud quasars do not exceed those for the "mirror" distributions.

Fig. 1 shows that the observed "signal" does not arise from a few sources with a relatively high likelihood, since such sources would produce a visible excess. It must therefore arise from a larger number of sources with low

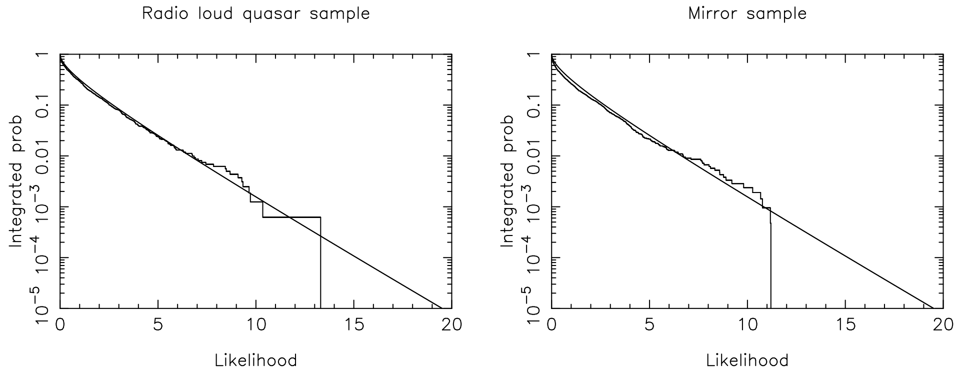

FIGURE 1. Observed and predicted distributions in the 10.0-30.0 MeV band for the radio loud quasar and "mirror" samples.

likelihoods. Fig. 2 shows the *difference* in all four energy bands between the integrated likelihood distributions of the combined blazar plus flat spectrum radio quasar sample and the "mirror" sample, after scaling to correct for the different number of observations. The numerical difference is shown in the plots on the left and the significance of that difference is shown in the plots on right. There is an excess of ~100 events at likelihoods between 1 and 5 in the 10-30 MeV band and a smaller effect in the 3-10 MeV bands.

CONCLUSIONS

The analysis presented here demonstrates the potential of this method for studying likelihood distributions from classes of AGN with COMPTEL rather than clearly detected sources. The "mirror" method of generating a "source-free" distribution provides consistent results but is limited by statistics, however generating a "source-free" background by selecting random locations on the sky gives unsatisfactory results.

Preliminary results from the KS analysis shows some evidence for a "signal" in the 10-30 MeV band, and perhaps also the 3-10 MeV band, related to radio loud AGN. The "signal" does not arise from known COMPTEL sources. The data is consistent with ~100 source observations having measured likelihoods of between 1 and 6, although the uncertainties are large. The number of individual sources implied by these results could be factor of 10 or more less than this, since all locations on the sky have been repeatedly viewed by COMPTEL.

REFERENCES

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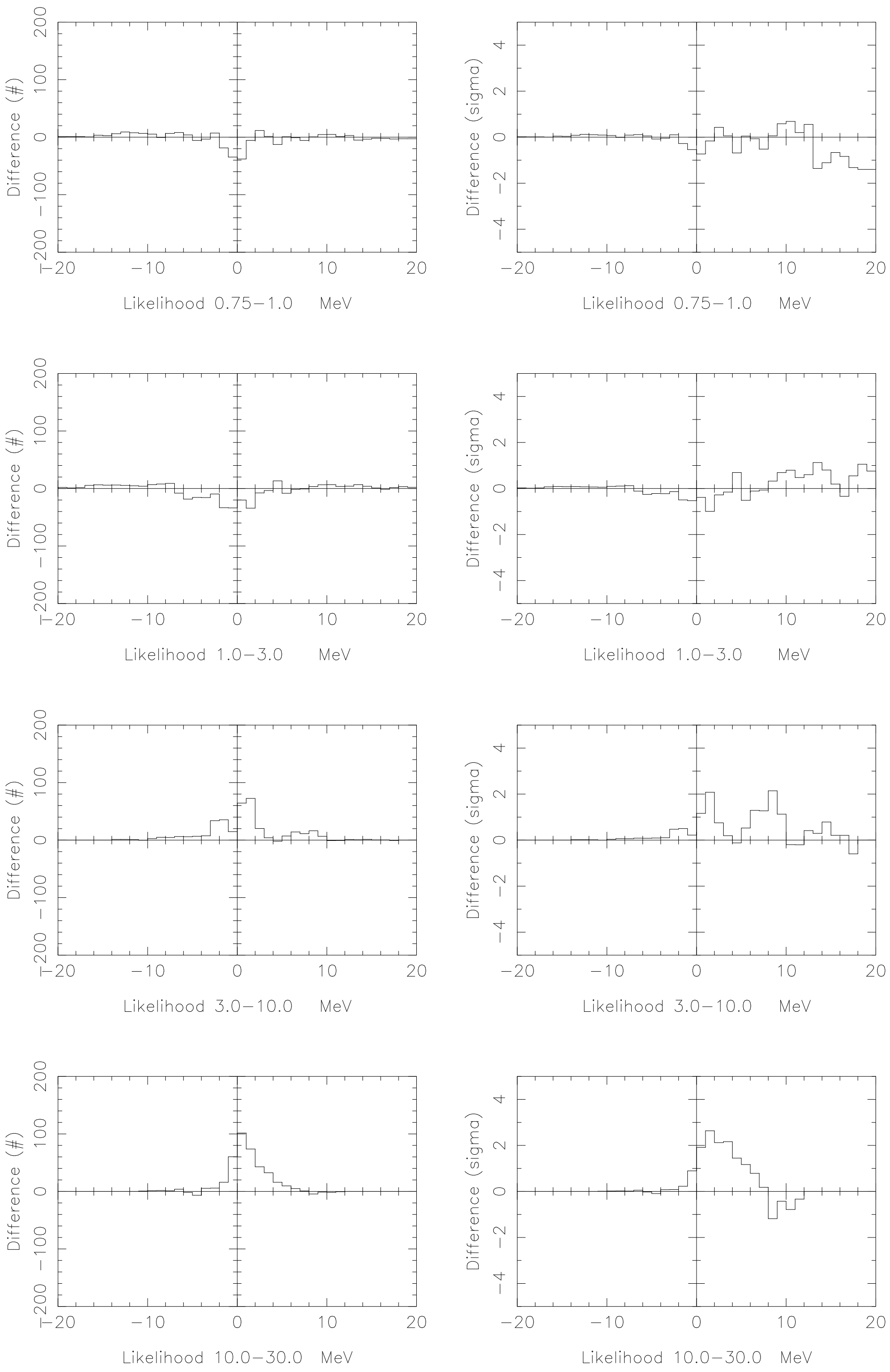

FIGURE 2. Differences between the integrated likelihood distributions of the FSRQ+XBL+RBL and “mirror” samples. The plots on the left show the numerical difference and those on the right show the difference in σ