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Time Correlations between Low and High Energy Gamma Rays from Discrete Sources

Final Report; Grant NAG-5-1567

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1 Introduction

During the grant period, the PI's activities related to this grant were in the following areas:

- Continuing analysis of the Cygnus Experiment data on the shadowing of cosmic rays by the moon and sun. This work led to a direct confirmation of the angular resolution of the CYGNUS EAS array, which was published [5].
- Development of analysis methods for the daily search overlapping with EGRET targets. Computer programming and analysis was also done by a graduate student, Alon Koren; his work was supported by this grant.

To date, no steady emission of UHE gamma rays from any source has been detected by the Cygnus Experiment, but some evidence for sporadic emission had been found [1]. Upper limits on steady fluxes from 49 sources in the northern hemisphere have been published [2]. In addition, a daily search of 51 possible sources, over the interval April 1986 to June 1992 found no evidence for emission [3]. From these source lists 4 candidates were selected for comparison with EGRET data. These are shown in the table below.

(NASA-CR-199214) TIME CORRELATIONS BETWEEN LOW AND HIGH ENERGY GAMMA RAYS FROM DISCRETE SOURCES Final Report (George Mason Univ.) 22 p

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Source #	Source	α	δ
1	Cyg X-3	307.7	40.8
2	Her X-1	254.0	35.4
3	Crab	82.9	22.0
4	Cyg X-1	299.1	35.1

The first three sources had been reported by various EAS experiments at various times to be emitters of UHE gamma rays.[4]

2 Overlapping Data Sets

The published GRO target list and the Cygnus Experiment database have been analyzed to find time intervals over which both Cygnus and EGRET will be "looking" at the above 4 sources. The results are displayed in the following table:

GRO Target #	GRO Exposure (Days)	Cyg Expt Source #	Angle to Source (deg)	Cygnus Runs
1	14	3	6.4	3189-3246
2	10	1	6.9	3243-3278
2	10	4	2.0	3243-3278
2.1	6	3	10.4	3275-3308
7.1	7	1	13.0	3506-3533
7.1	7	4	11.4	3506-3533
9.2	7	2	3.0	3628-3656
26	15	3	24.6	

To be included in the above table, a Cygnus source must be within the 25° acceptance aperture of EGRET.

3 Analysis

The Cygnus Experiment data was scanned in the following way. The number of events with arrival angles within $1.58\sigma_{res}$ was determined for each run. Where σ_{res} is the average angular resolution of the EAS detector; this has been measured, using the "shadowing" of the background cosmic rays by the moon and the sun, to be approximately 0.7°[5]. A bin of radius $1.58\sigma_{res}$ maximizes the signal-to-background ratio. The background will be measured over the same run in an annular ring around the source. The ring radii are 1.5 and 2.8 degrees. For each run, the Li-Ma significance was computed.

The method of background determination by annular rings does produce some systematic errors, because the exposure of the annulus is not exactly the same as that of the source bin. To estimate the magnitude of the effect, a numerical calculation was done, assuming a zenith angle distribution of background proportional to $(\cos\theta)^7$, a good, but not exact, approximation to the observed distribution. Figure 1 shows the ratio of background per unit solid angle in the annulus to that in the center of the ring. For our souces, the systematic is less than 1%. This can be very important when a large number of Li-Ma σ's corresponds to a fractional excess which is very small; but this is not the case for few-hour runs for this experiment.

The computer code for performing the above analysis on the Cygnus dataset was written and tested. The code was run on non-source points in the sky to study the distribution of the Li-Ma σ's. These should be distributed on a Gaussian of mean 0 and standard deviation 1. Agreement with expectations was found.

4 Results

The results of this analysis are shown in Table I. No sigificant signals were found from the four sources.

References

[1] B. L. Dingus et al., Phys Rev Lett **61**,1906,(1988).

[2] A Search of the Northern Sky for Ultra-High-Energy Point Sources, D. E. Alexandreas et al., Astrophysical Journal, **383**, L53, (1991).

[3] Daily Search for Emission of Ultra-High Energy Radiation from Point Sources, D. E. Alexandreas et al., Astrophysical Journal, **405** 353 (1992).

[4] Jordan A. Goodman, Proceedings of the Workshop on Physics and Experimental Techniques of High Energy Neutrino and VHE and UHE Gamma-Ray Particle Astrophysics, Little Rock, AR, May 11-13, 1989.

[5] Observation of Shadowing of Ultra High Energy Cosmic Rays by the Moon and the Sun, D. E. Alexandreas et al., Phys Rev D**43**, 1735, (1991).

[6] Li, T. P. and Ma, Y. Q., Ap. J. **272** 317 (1983).

Table 1

Cygnus Experiment Data For Selected
EGRET Targets, 1991

```
SOURCE 1: CYG X-3

RUNS: 3243-3245   TOTAL EVTS BETWEEN RISE-SET =  288867
START:                 5           30          1991  0.1062483
STARTING JUL DAY, SEC      2448406.5        9179.8530
END:                 5           30          1991  0.8187724
ENDING JUL DAY, SEC        2448406.5        70741.936
SOURCE RA, DEC     307.7000        40.80000
NUMBER OUT THIS RUN              150 SIGNAL          625 BKG
EXCESS =   -1.703705       LI-MA SIGNIFICANCE =  -0.1243719

RUNS: 3246-3249   TOTAL EVTS BETWEEN RISE-SET =  294419
START:                 5           31          1991  0.1034810
STARTING JUL DAY, SEC      2448407.5        8940.7580
END:                 5           31          1991  0.8160403
ENDING JUL DAY, SEC        2448407.5        70505.880
SOURCE RA, DEC     307.7000        40.80000
NUMBER OUT THIS RUN              162 SIGNAL          633 BKG
EXCESS =    8.354492       LI-MA SIGNIFICANCE =   0.5982854

RUNS: 3251-3252   TOTAL EVTS BETWEEN RISE-SET =  136705
START:                 6            1          1991  0.4779480
STARTING JUL DAY, SEC      2448408.5        41294.704
END:                 6            1          1991  0.8133096
ENDING JUL DAY, SEC        2448408.5        70269.944
SOURCE RA, DEC     307.7000        40.80000
NUMBER OUT THIS RUN               58 SIGNAL          261 BKG
EXCESS =   -5.351467       LI-MA SIGNIFICANCE =  -0.6136380

RUNS: 3253-3256   TOTAL EVTS BETWEEN RISE-SET =  287457
START:                 6            2          1991  9.8006941E-02
STARTING JUL DAY, SEC      2448409.5        8467.8000
END:                 6            2          1991  0.8105767
ENDING JUL DAY, SEC        2448409.5        70033.832
SOURCE RA, DEC     307.7000        40.80000
NUMBER OUT THIS RUN              138 SIGNAL          574 BKG
EXCESS =   -1.324677       LI-MA SIGNIFICANCE =  -0.1008404

RUNS: 3257-3261   TOTAL EVTS BETWEEN RISE-SET =  169410
START:                 6            3          1991  9.5262326E-02
STARTING JUL DAY, SEC      2448410.5        8230.6650
END:                 6            3          1991  0.8078468
ENDING JUL DAY, SEC        2448410.5        69797.968
SOURCE RA, DEC     307.7000        40.80000
NUMBER OUT THIS RUN                7 SIGNAL           23 BKG
EXCESS =    1.417304       LI-MA SIGNIFICANCE =   0.5134063

RUNS: 3262-3264   TOTAL EVTS BETWEEN RISE-SET =  278697
START:                 6            4          1991  9.2600234E-02
STARTING JUL DAY, SEC      2448411.5        8000.6600
END:                 6            4          1991  0.8051146
ENDING JUL DAY, SEC        2448411.5        69561.896
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SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN           126 SIGNAL          604 BKG
EXCESS =   -20.60646        LI-MA SIGNIFICANCE =   -1.572119

RUNS: 3265-3267   TOTAL EVTS BETWEEN RISE-SET =  276277
START:               6           5          1991  8.9884765E-02
STARTING JUL DAY, SEC    2448412.5        7766.0440
END:              6           5          1991  0.8023828
ENDING JUL DAY, SEC      2448412.5        69325.872
SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN           146 SIGNAL          562 BKG
EXCESS =    9.588028        LI-MA SIGNIFICANCE =   0.7264319

RUNS: 3268-3270   TOTAL EVTS BETWEEN RISE-SET =  254109
START:               6           6          1991  8.7136529E-02
STARTING JUL DAY, SEC    2448413.5        7528.5960
END:              6           6          1991  0.7996525
ENDING JUL DAY, SEC      2448413.5        69089.976
SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN           136 SIGNAL          602 BKG
EXCESS =   -10.12100        LI-MA SIGNIFICANCE =  -0.7618126

RUNS: 3271-3274   TOTAL EVTS BETWEEN RISE-SET =  114328
START:               6           7          1991  8.4470026E-02
STARTING JUL DAY, SEC    2448414.5        7298.2100
END:              6           7          1991  0.5357088
ENDING JUL DAY, SEC      2448414.5        46285.240
SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN            79 SIGNAL          394 BKG
EXCESS =   -16.63401        LI-MA SIGNIFICANCE =   -1.582941

RUNS: 3275-3277   TOTAL EVTS BETWEEN RISE-SET =  260760
START:               6           8          1991  0.1141745
STARTING JUL DAY, SEC    2448415.5        9864.6770
END:              6           8          1991  0.7942010
ENDING JUL DAY, SEC      2448415.5        68618.960
SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN           148 SIGNAL          614 BKG
EXCESS =   -1.033722        LI-MA SIGNIFICANCE =  -7.6216467E-02

RUNS: 3506-3507   TOTAL EVTS BETWEEN RISE-SET =   96961
START:               8           8          1991  0.3649625
STARTING JUL DAY, SEC    2448476.5        31532.762
END:              8           8          1991  0.6276375
ENDING JUL DAY, SEC      2448476.5        54227.884
SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN            11 SIGNAL           38 BKG
EXCESS =    1.776415        LI-MA SIGNIFICANCE =   0.5060269

RUNS: 3508-3511   TOTAL EVTS BETWEEN RISE-SET =  262332
START:               8           8          1991  0.9123507
STARTING JUL DAY, SEC    2448476.5        78827.104
END:              8           9          1991  0.6249035
ENDING JUL DAY, SEC      2448477.5        53991.664
SOURCE RA, DEC    307.7000        40.80000
NUMBER OUT THIS RUN           143 SIGNAL          587 BKG
EXCESS =   0.5198822        LI-MA SIGNIFICANCE =   3.9421719E-02

RUNS: 3512-3514   TOTAL EVTS BETWEEN RISE-SET =  266849
START:               8           9          1991  0.9096078
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STARTING JUL DAY, SEC     2448477.5         78590.112
END:                 8          10         1991  0.6221724
ENDING JUL DAY, SEC       2448478.5         53755.700
SOURCE RA, DEC     307.7000          40.80000
NUMBER OUT THIS RUN              147 SIGNAL            533 BKG
EXCESS =    17.62708         LI-MA SIGNIFICANCE =    1.354457

RUNS: 3516-3518    TOTAL EVTS BETWEEN RISE-SET =  242129
START:               8          10         1991  0.9759841
STARTING JUL DAY, SEC     2448478.5         84325.024
END:                 8          11         1991  0.6194442
ENDING JUL DAY, SEC       2448479.5         53519.976
SOURCE RA, DEC     307.7000          40.80000
NUMBER OUT THIS RUN              149 SIGNAL            566 BKG
EXCESS =    11.61713         LI-MA SIGNIFICANCE =   0.8746294

RUNS: 3519-3522    TOTAL EVTS BETWEEN RISE-SET =  263532
START:               8          11         1991  0.9042267
STARTING JUL DAY, SEC     2448479.5         78125.184
END:                 8          12         1991  0.6136562
ENDING JUL DAY, SEC       2448480.5         53019.896
SOURCE RA, DEC     307.7000          40.80000
NUMBER OUT THIS RUN              143 SIGNAL            549 BKG
EXCESS =    9.743469         LI-MA SIGNIFICANCE =   0.7464752

RUNS: 3523-3524    TOTAL EVTS BETWEEN RISE-SET =  268374
START:               8          12         1991  0.9014427
STARTING JUL DAY, SEC     2448480.5         77884.648
END:                 8          13         1991  0.6139902
ENDING JUL DAY, SEC       2448481.5         53048.752
SOURCE RA, DEC     307.7000          40.80000
NUMBER OUT THIS RUN              144 SIGNAL            601 BKG
EXCESS =   -1.878281         LI-MA SIGNIFICANCE =  -0.1402719

RUNS: 3525-3528    TOTAL EVTS BETWEEN RISE-SET =  263550
START:               8          13         1991  0.8987715
STARTING JUL DAY, SEC     2448481.5         77653.856
END:                 8          14         1991  0.6112589
ENDING JUL DAY, SEC       2448482.5         52812.772
SOURCE RA, DEC     307.7000          40.80000
NUMBER OUT THIS RUN              139 SIGNAL            573 BKG
EXCESS =  -8.1954956E-02   LI-MA SIGNIFICANCE =  -9.9222967E-03

RUNS: 3530-3532    TOTAL EVTS BETWEEN RISE-SET =  246173
START:               8          14         1991  0.9624151
STARTING JUL DAY, SEC     2448482.5         83152.664
END:                 8          15         1991  0.6085267
ENDING JUL DAY, SEC       2448483.5         52576.708
SOURCE RA, DEC     307.7000          40.80000
NUMBER OUT THIS RUN              129 SIGNAL            626 BKG
EXCESS =   -22.94643         LI-MA SIGNIFICANCE =   -1.723565


SOURCE 2: HER X-1

RUNS: 3630-3633    TOTAL EVTS BETWEEN RISE-SET =  227540
START:               9          12         1991  0.7124211
STARTING JUL DAY, SEC     2448511.5         61553.184
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END: 9 13 1991 0.3592569
ENDING JUL DAY, SEC 2448512.5 31039.792
SOURCE RA, DEC 254.0000 35.40000
NUMBER OUT THIS RUN 104 SIGNAL 482 BKG
EXCESS = -12.99390 LI-MA SIGNIFICANCE = -1.102705

RUNS: 3634-3637 TOTAL EVTS BETWEEN RISE-SET = 258911
START: 9 13 1991 0.6865874
STARTING JUL DAY, SEC 2448512.5 59321.152
END: 9 14 1991 0.3565269
ENDING JUL DAY, SEC 2448513.5 30803.928
SOURCE RA, DEC 254.0000 35.40000
NUMBER OUT THIS RUN 141 SIGNAL 585 BKG
EXCESS = -0.9946594 LI-MA SIGNIFICANCE = -7.5141393E-02

RUNS: 3638-3640 TOTAL EVTS BETWEEN RISE-SET = 259438
START: 9 14 1991 0.6838804
STARTING JUL DAY, SEC 2448513.5 59087.264
END: 9 15 1991 0.3537946
ENDING JUL DAY, SEC 2448514.5 30567.852
SOURCE RA, DEC 254.0000 35.40000
NUMBER OUT THIS RUN 128 SIGNAL 583 BKG
EXCESS = -13.50922 LI-MA SIGNIFICANCE = -1.038889

RUNS: 3641-3643 TOTAL EVTS BETWEEN RISE-SET = 252029
START: 9 15 1991 0.6812382
STARTING JUL DAY, SEC 2448514.5 58858.976
END: 9 16 1991 0.3510724
ENDING JUL DAY, SEC 2448515.5 30332.652
SOURCE RA, DEC 254.0000 35.40000
NUMBER OUT THIS RUN 131 SIGNAL 557 BKG
EXCESS = -4.198334 LI-MA SIGNIFICANCE = -0.3260629

RUNS: 3644-3646 TOTAL EVTS BETWEEN RISE-SET = 72810
START: 9 16 1991 0.6784033
STARTING JUL DAY, SEC 2448515.5 58614.044
END: 9 16 1991 0.8768926
ENDING JUL DAY, SEC 2448515.5 75763.512
SOURCE RA, DEC 254.0000 35.40000
NUMBER OUT THIS RUN 5 SIGNAL 9 BKG
EXCESS = 2.815467 LI-MA SIGNIFICANCE = 1.411965

RUNS: 3647-3648 TOTAL EVTS BETWEEN RISE-SET = 176546
START: 9 17 1991 0.8781734
STARTING JUL DAY, SEC 2448516.5 75874.176
END: 9 18 1991 0.3456107
ENDING JUL DAY, SEC 2448517.5 29860.768
SOURCE RA, DEC 254.0000 35.40000
NUMBER OUT THIS RUN 139 SIGNAL 564 BKG
EXCESS = 2.102585 LI-MA SIGNIFICANCE = 0.1607617

SOURCE 3: CRAB

RUNS: 3128-3128 TOTAL EVTS BETWEEN RISE-SET = 80992
START: 4 30 1991 1.7729074E-02
STARTING JUL DAY, SEC 2448376.5 1531.7920
END: 4 30 1991 0.2180571
ENDING JUL DAY, SEC 2448376.5 18840.132
SOURCE RA, DEC 82.90000 22.00000

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NUMBER OUT THIS RUN              8 SIGNAL          27 BKG
EXCESS =     1.446400       LI-MA SIGNIFICANCE =    0.4863757

RUNS: 3129-3132   TOTAL EVTS BETWEEN RISE-SET =  223641
START:                  4          30          1991  0.6225634
STARTING JUL DAY, SEC     2448376.5          53789.480
END:                 5          1          1991  0.2156128
ENDING JUL DAY, SEC       2448377.5          18628.942
SOURCE RA, DEC     82.90000         22.00000
NUMBER OUT THIS RUN              98 SIGNAL          440 BKG
EXCESS =    -8.799408       LI-MA SIGNIFICANCE =   -0.7767792

RUNS: 3133-3135   TOTAL EVTS BETWEEN RISE-SET =  204701
START:                  5          1           1991  0.6198362
STARTING JUL DAY, SEC     2448377.5          53553.844
END:                 5          2          1991  0.2128818
ENDING JUL DAY, SEC       2448378.5          18392.984
SOURCE RA, DEC     82.90000         22.00000
NUMBER OUT THIS RUN              85 SIGNAL          449 BKG
EXCESS =    -23.98394       LI-MA SIGNIFICANCE =    -2.160676

RUNS: 3136-3139   TOTAL EVTS BETWEEN RISE-SET =  175551
START:                  5          2           1991  0.6171614
STARTING JUL DAY, SEC     2448378.5          53322.748
END:                 5          3          1991  0.2101480
ENDING JUL DAY, SEC       2448379.5          18156.788
SOURCE RA, DEC     82.90000         22.00000
NUMBER OUT THIS RUN             107 SIGNAL          455 BKG
EXCESS =    -3.440292       LI-MA SIGNIFICANCE =   -0.2955106

RUNS: 3140-3143   TOTAL EVTS BETWEEN RISE-SET =  227998
START:                  5          3           1991  0.6144451
STARTING JUL DAY, SEC     2448379.5          53088.060
END:                 5          4          1991  0.2074148
ENDING JUL DAY, SEC       2448380.5          17920.634
SOURCE RA, DEC     82.90000         22.00000
NUMBER OUT THIS RUN             132 SIGNAL          458 BKG
EXCESS =     20.83153       LI-MA SIGNIFICANCE =     1.710852

RUNS: 3144-3146   TOTAL EVTS BETWEEN RISE-SET =  227819
START:                  5          4           1991  0.6116328
STARTING JUL DAY, SEC     2448380.5          52845.072
END:                 5          5          1991  0.2046953
ENDING JUL DAY, SEC       2448381.5          17685.670
SOURCE RA, DEC     82.90000         22.00000
NUMBER OUT THIS RUN             115 SIGNAL          449 BKG
EXCESS =     6.016060       LI-MA SIGNIFICANCE =    0.5114335

RUNS: 3147-3150   TOTAL EVTS BETWEEN RISE-SET =  216677
START:                  5          5           1991  0.6090060
STARTING JUL DAY, SEC     2448381.5          52618.116
END:                 5          6          1991  0.2019632
ENDING JUL DAY, SEC       2448382.5          17449.620
SOURCE RA, DEC     82.90000         22.00000
NUMBER OUT THIS RUN             122 SIGNAL          423 BKG
EXCESS =     19.32693       LI-MA SIGNIFICANCE =     1.651391

RUNS: 3151-3153   TOTAL EVTS BETWEEN RISE-SET =  215724
START:                  5          6           1991  0.6062670
STARTING JUL DAY, SEC     2448382.5          52381.472
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END:                5           7          1991  0.1992262
ENDING JUL DAY, SEC       2448383.5          17213.146
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN             103 SIGNAL           395 BKG
EXCESS =    7.123260        LI-MA SIGNIFICANCE =    0.6432390

RUNS: 3154-3157   TOTAL EVTS BETWEEN RISE-SET =  207972
START:                5           7          1991  0.6035081
STARTING JUL DAY, SEC     2448383.5          52143.100
END:                5           8          1991  0.1965024
ENDING JUL DAY, SEC       2448384.5          16977.804
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN             102 SIGNAL           413 BKG
EXCESS =    1.754196        LI-MA SIGNIFICANCE =    0.1566881

RUNS: 3158-3160   TOTAL EVTS BETWEEN RISE-SET =  216877
START:                5           8          1991  0.6007581
STARTING JUL DAY, SEC     2448384.5          51905.500
END:                5           9          1991  0.1937716
ENDING JUL DAY, SEC       2448385.5          16741.870
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN             104 SIGNAL           399 BKG
EXCESS =    7.152359        LI-MA SIGNIFICANCE =    0.6426724

RUNS: 3161-3164   TOTAL EVTS BETWEEN RISE-SET =  222685
START:                5           9          1991  0.5980226
STARTING JUL DAY, SEC     2448385.5          51669.156
END:                5          10          1991  0.1910331
ENDING JUL DAY, SEC       2448386.5          16505.263
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN             139 SIGNAL           440 BKG
EXCESS =    32.20059        LI-MA SIGNIFICANCE =     2.645323

RUNS: 3165-3167   TOTAL EVTS BETWEEN RISE-SET =  221591
START:                5          10          1991  0.5952761
STARTING JUL DAY, SEC     2448386.5          51431.852
END:                5          11          1991  0.1883089
ENDING JUL DAY, SEC       2448387.5          16269.890
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN             110 SIGNAL           437 BKG
EXCESS =    3.928772        LI-MA SIGNIFICANCE =    0.3397673

RUNS: 3168-3171   TOTAL EVTS BETWEEN RISE-SET =  214814
START:                5          11          1991  0.5925326
STARTING JUL DAY, SEC     2448387.5          51194.816
END:                5          12          1991  0.1855769
ENDING JUL DAY, SEC       2448388.5          16033.848
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN             104 SIGNAL           417 BKG
EXCESS =    2.783287        LI-MA SIGNIFICANCE =    0.2468261

RUNS: 3172-3174   TOTAL EVTS BETWEEN RISE-SET =   91776
START:                5          12          1991  0.5898861
STARTING JUL DAY, SEC     2448388.5          50966.164
END:                5          13          1991  0.1828470
ENDING JUL DAY, SEC       2448389.5          15797.980
SOURCE RA, DEC     82.90000          22.00000
NUMBER OUT THIS RUN              15 SIGNAL            55 BKG
EXCESS =    1.650074        LI-MA SIGNIFICANCE =    0.3956241
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RUNS: 3175-3178   TOTAL EVTS BETWEEN RISE-SET =  155755
START:                5          13          1991  0.5870709
STARTING JUL DAY, SEC    2448389.5       50722.924
END:                5          14          1991  0.1801089
ENDING JUL DAY, SEC      2448390.5       15561.406
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN              65 SIGNAL          264 BKG
EXCESS =   0.9203568        LI-MA SIGNIFICANCE =   0.1028420

RUNS: 3190-3194   TOTAL EVTS BETWEEN RISE-SET =  201260
START:                5          16          1991  0.5792501
STARTING JUL DAY, SEC    2448392.5       50047.212
END:                5          17          1991  0.1722558
ENDING JUL DAY, SEC      2448393.5       14882.905
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN              83 SIGNAL          356 BKG
EXCESS =   -3.410431        LI-MA SIGNIFICANCE =  -0.3317360

RUNS: 3195-3196   TOTAL EVTS BETWEEN RISE-SET =  221917
START:                5          17          1991  0.5919200
STARTING JUL DAY, SEC    2448393.5       51141.892
END:                5          18          1991  0.1694970
ENDING JUL DAY, SEC      2448394.5       14644.543
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN             105 SIGNAL          426 BKG
EXCESS =    1.598755        LI-MA SIGNIFICANCE =   0.1406420

RUNS: 3197-3199   TOTAL EVTS BETWEEN RISE-SET =  222835
START:                5          18          1991  0.5737408
STARTING JUL DAY, SEC    2448394.5       49571.208
END:                5          19          1991  0.1667426
ENDING JUL DAY, SEC      2448395.5       14406.559
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN             118 SIGNAL          437 BKG
EXCESS =    11.92877        LI-MA SIGNIFICANCE =    1.016748

RUNS: 3213-3216   TOTAL EVTS BETWEEN RISE-SET =   85795
START:                5          22          1991  0.6279956
STARTING JUL DAY, SEC    2448398.5       54258.820
END:                5          23          1991  0.1557291
ENDING JUL DAY, SEC      2448399.5       13454.994
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN               5 SIGNAL           23 BKG
EXCESS =  -0.5826964        LI-MA SIGNIFICANCE =  -0.2260393

RUNS: 3217-3221   TOTAL EVTS BETWEEN RISE-SET =  114453
START:                5          23          1991  0.5600244
STARTING JUL DAY, SEC    2448399.5       48386.112
END:                5          24          1991  0.1529697
ENDING JUL DAY, SEC      2448400.5       13216.580
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN               6 SIGNAL           20 BKG
EXCESS =    1.145482        LI-MA SIGNIFICANCE =   0.4463552

RUNS: 3222-3225   TOTAL EVTS BETWEEN RISE-SET =  229649
START:                5          24          1991  0.5572373
STARTING JUL DAY, SEC    2448400.5       48145.304
END:                5          25          1991  0.1502192
ENDING JUL DAY, SEC      2448401.5       12978.942
SOURCE RA, DEC    82.90000       22.00000
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NUMBER OUT THIS RUN              93 SIGNAL          440 BKG
EXCESS =   -13.79941       LI-MA SIGNIFICANCE =   -1.230448

RUNS: 3226-3228   TOTAL EVTS BETWEEN RISE-SET =  230742
START:                 5          25          1991  0.5544236
STARTING JUL DAY, SEC    2448401.5         47902.204
END:                5          26          1991  0.1474586
ENDING JUL DAY, SEC      2448402.5         12740.427
SOURCE RA, DEC    82.90000         22.00000
NUMBER OUT THIS RUN              93 SIGNAL          453 BKG
EXCESS =   -16.95484       LI-MA SIGNIFICANCE =   -1.498125

RUNS: 3229-3231   TOTAL EVTS BETWEEN RISE-SET =  231305
START:                 5          26          1991  0.5517312
STARTING JUL DAY, SEC    2448402.5         47669.576
END:                5          27          1991  0.1447044
ENDING JUL DAY, SEC      2448403.5         12502.462
SOURCE RA, DEC    82.90000         22.00000
NUMBER OUT THIS RUN             107 SIGNAL          456 BKG
EXCESS =   -3.683022       LI-MA SIGNIFICANCE =  -0.3162389

RUNS: 3232-3235   TOTAL EVTS BETWEEN RISE-SET =  225914
START:                 5          27          1991  0.5490213
STARTING JUL DAY, SEC    2448403.5         47435.440
END:                5          28          1991  0.1419554
ENDING JUL DAY, SEC      2448404.5         12264.946
SOURCE RA, DEC    82.90000         22.00000
NUMBER OUT THIS RUN             116 SIGNAL          416 BKG
EXCESS =    15.02602       LI-MA SIGNIFICANCE =    1.303895

RUNS: 3236-3239   TOTAL EVTS BETWEEN RISE-SET =  227321
START:                 5          28          1991  0.5461959
STARTING JUL DAY, SEC    2448404.5         47191.320
END:                5          29          1991  0.1391957
ENDING JUL DAY, SEC      2448405.5         12026.509
SOURCE RA, DEC    82.90000         22.00000
NUMBER OUT THIS RUN             117 SIGNAL          433 BKG
EXCESS =    11.89967       LI-MA SIGNIFICANCE =    1.018807

RUNS: 3240-3243   TOTAL EVTS BETWEEN RISE-SET =  145188
START:                 5          29          1991  0.5435073
STARTING JUL DAY, SEC    2448405.5         46959.032
END:                5          30          1991  0.1364448
ENDING JUL DAY, SEC      2448406.5         11788.831
SOURCE RA, DEC    82.90000         22.00000
NUMBER OUT THIS RUN              96 SIGNAL          369 BKG
EXCESS =    6.434135       LI-MA SIGNIFICANCE =   0.6014056

RUNS: 3276-3278   TOTAL EVTS BETWEEN RISE-SET =  219192
START:                 6           8          1991  0.5310876
STARTING JUL DAY, SEC    2448415.5         45885.968
END:                6           9          1991  0.1091265
ENDING JUL DAY, SEC      2448416.5         9428.5290
SOURCE RA, DEC    82.90000         22.00000
NUMBER OUT THIS RUN              93 SIGNAL          460 BKG
EXCESS =   -18.65392       LI-MA SIGNIFICANCE =   -1.640368

RUNS: 3279-3282   TOTAL EVTS BETWEEN RISE-SET =  223264
START:                 6           9          1991  0.5134203
STARTING JUL DAY, SEC    2448416.5         44359.520
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END:                6           10         1991  0.1064004
ENDING JUL DAY, SEC       2448417.5        9192.9970
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN             105 SIGNAL          478 BKG
EXCESS =   -11.02299       LI-MA SIGNIFICANCE =  -0.9360666

RUNS: 3283-3286   TOTAL EVTS BETWEEN RISE-SET =  223441
START:                6           10         1991  0.5106120
STARTING JUL DAY, SEC     2448417.5        44116.876
END:                6           11         1991  0.1036629
ENDING JUL DAY, SEC       2448418.5        8956.4790
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN              90 SIGNAL          465 BKG
EXCESS =   -22.86755       LI-MA SIGNIFICANCE =   -2.016189

RUNS: 3287-3289   TOTAL EVTS BETWEEN RISE-SET =   91650
START:                6           11         1991  0.5079527
STARTING JUL DAY, SEC     2448418.5        43887.116
END:                6           12         1991  0.1009353
ENDING JUL DAY, SEC       2448419.5        8720.8110
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN              10 SIGNAL           35 BKG
EXCESS =    1.504593       LI-MA SIGNIFICANCE =   0.4478266

RUNS: 3298-3304   TOTAL EVTS BETWEEN RISE-SET =  128195
START:                6           13         1991  0.5165891
STARTING JUL DAY, SEC     2448420.5        44633.296
END:                6           13         1991  0.8407539
ENDING JUL DAY, SEC       2448420.5        72641.144
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN              75 SIGNAL          333 BKG
EXCESS =   -5.827736       LI-MA SIGNIFICANCE =  -0.5900838

RUNS: 3305-3305   TOTAL EVTS BETWEEN RISE-SET =   79263
START:                6           14         1991  0.8941288
STARTING JUL DAY, SEC     2448421.5        77252.728
END:                6           15         1991  9.2742339E-02
ENDING JUL DAY, SEC       2448422.5        8012.9380
SOURCE RA, DEC    82.90000       22.00000
NUMBER OUT THIS RUN              11 SIGNAL           25 BKG
EXCESS =    4.931852       LI-MA SIGNIFICANCE =    1.574274


SOURCE 4: CYG X-1

RUNS: 3243-3245   TOTAL EVTS BETWEEN RISE-SET =  270846
START:                5           30         1991  0.1047959
STARTING JUL DAY, SEC     2448406.5        9054.3660
END:                5           30         1991  0.7728004
ENDING JUL DAY, SEC       2448406.5        66769.960
SOURCE RA, DEC    299.1000       35.10000
NUMBER OUT THIS RUN             153 SIGNAL          652 BKG
EXCESS =   -5.257309       LI-MA SIGNIFICANCE =  -0.3775080

RUNS: 3246-3249   TOTAL EVTS BETWEEN RISE-SET =  275777
START:                5           31         1991  0.1020332
STARTING JUL DAY, SEC     2448407.5        8815.6650
END:                5           31         1991  0.7700691
ENDING JUL DAY, SEC       2448407.5        66533.968
SOURCE RA, DEC    299.1000       35.10000
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NUMBER OUT THIS RUN          153 SIGNAL          610 BKG
EXCESS =    4.937180       LI-MA SIGNIFICANCE =    0.3615986

RUNS: 3251-3252   TOTAL EVTS BETWEEN RISE-SET =  117767
START:              6           1          1991  0.4779480
STARTING JUL DAY, SEC    2448408.5        41294.704
END:              6           1          1991  0.7673369
ENDING JUL DAY, SEC      2448408.5        66297.908
SOURCE RA, DEC    299.1000        35.10000
NUMBER OUT THIS RUN           29 SIGNAL          157 BKG
EXCESS =   -9.107971       LI-MA SIGNIFICANCE =   -1.393770

RUNS: 3253-3256   TOTAL EVTS BETWEEN RISE-SET =  269581
START:              6           2          1991  9.6544065E-02
STARTING JUL DAY, SEC    2448409.5        8341.4070
END:              6           2          1991  0.7646054
ENDING JUL DAY, SEC      2448409.5        66061.908
SOURCE RA, DEC    299.1000        35.10000
NUMBER OUT THIS RUN          169 SIGNAL          629 BKG
EXCESS =    16.32539       LI-MA SIGNIFICANCE =    1.161021

RUNS: 3257-3261   TOTAL EVTS BETWEEN RISE-SET =  151760
START:              6           3          1991  9.3867071E-02
STARTING JUL DAY, SEC    2448410.5        8110.1150
END:              6           3          1991  0.7618673
ENDING JUL DAY, SEC      2448410.5        65825.336
SOURCE RA, DEC    299.1000        35.10000
NUMBER OUT THIS RUN            5 SIGNAL            9 BKG
EXCESS =    2.815467       LI-MA SIGNIFICANCE =    1.411965

RUNS: 3262-3264   TOTAL EVTS BETWEEN RISE-SET =  261377
START:              6           4          1991  9.1171905E-02
STARTING JUL DAY, SEC    2448411.5        7877.2530
END:              6           4          1991  0.7591425
ENDING JUL DAY, SEC      2448411.5        65589.916
SOURCE RA, DEC    299.1000        35.10000
NUMBER OUT THIS RUN          144 SIGNAL          639 BKG
EXCESS =   -11.10187       LI-MA SIGNIFICANCE =  -0.8114077

RUNS: 3265-3267   TOTAL EVTS BETWEEN RISE-SET =  259133
START:              6           5          1991  8.8460229E-02
STARTING JUL DAY, SEC    2448412.5        7642.9640
END:              6           5          1991  0.7564093
ENDING JUL DAY, SEC      2448412.5        65353.760
SOURCE RA, DEC    299.1000        35.10000
NUMBER OUT THIS RUN          131 SIGNAL          620 BKG
EXCESS =   -19.49007       LI-MA SIGNIFICANCE =   -1.464115

RUNS: 3268-3270   TOTAL EVTS BETWEEN RISE-SET =  243287
START:              6           6          1991  8.5684054E-02
STARTING JUL DAY, SEC    2448413.5        7403.1020
END:              6           6          1991  0.7536801
ENDING JUL DAY, SEC      2448413.5        65117.956
SOURCE RA, DEC    299.1000        35.10000
NUMBER OUT THIS RUN          146 SIGNAL          575 BKG
EXCESS =    6.432587       LI-MA SIGNIFICANCE =    0.4840550

RUNS: 3271-3274   TOTAL EVTS BETWEEN RISE-SET =  114678
START:              6           7          1991  8.3063044E-02
STARTING JUL DAY, SEC    2448414.5        7176.6470
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END:                6           7          1991  0.5357088
ENDING JUL DAY, SEC        2448414.5         46285.240
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                 97 SIGNAL            369 BKG
EXCESS =     7.434135        LI-MA SIGNIFICANCE =    0.6934137

RUNS: 3275-3277   TOTAL EVTS BETWEEN RISE-SET =  243209
START:                6           8          1991  0.1141745
STARTING JUL DAY, SEC      2448415.5         9864.6770
END:                6           8          1991  0.7482131
ENDING JUL DAY, SEC        2448415.5         64645.608
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                167 SIGNAL            600 BKG
EXCESS =     21.36444        LI-MA SIGNIFICANCE =     1.544302

RUNS: 3506-3507   TOTAL EVTS BETWEEN RISE-SET =   79939
START:                8           8          1991  0.3649625
STARTING JUL DAY, SEC      2448476.5         31532.762
END:                8           8          1991  0.5814450
ENDING JUL DAY, SEC        2448476.5         50236.852
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                  7 SIGNAL             18 BKG
EXCESS =     2.630933        LI-MA SIGNIFICANCE =     1.019419

RUNS: 3508-3511   TOTAL EVTS BETWEEN RISE-SET =  245579
START:                8           8          1991  0.9109614
STARTING JUL DAY, SEC      2448476.5         78707.072
END:                8           9          1991  0.5789334
ENDING JUL DAY, SEC        2448477.5         50019.848
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                138 SIGNAL            596 BKG
EXCESS =    -6.664658        LI-MA SIGNIFICANCE =  -0.5017450

RUNS: 3512-3514   TOTAL EVTS BETWEEN RISE-SET =  249733
START:                8           9          1991  0.9082220
STARTING JUL DAY, SEC      2448477.5         78470.384
END:                8          10          1991  0.5761969
ENDING JUL DAY, SEC        2448478.5         49783.416
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                140 SIGNAL            563 BKG
EXCESS =     3.345306        LI-MA SIGNIFICANCE =    0.2554602

RUNS: 3516-3518   TOTAL EVTS BETWEEN RISE-SET =  224997
START:                8          10          1991  0.9759841
STARTING JUL DAY, SEC      2448478.5         84325.024
END:                8          11          1991  0.5734699
ENDING JUL DAY, SEC        2448479.5         49547.804
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                126 SIGNAL            553 BKG
EXCESS =    -8.227432        LI-MA SIGNIFICANCE =  -0.6450334

RUNS: 3519-3521   TOTAL EVTS BETWEEN RISE-SET =  248182
START:                8          11          1991  0.9027219
STARTING JUL DAY, SEC      2448479.5         77995.168
END:                8          12          1991  0.5707400
ENDING JUL DAY, SEC        2448480.5         49311.940
SOURCE RA, DEC     299.1000          35.10000
NUMBER OUT THIS RUN                128 SIGNAL            541 BKG
EXCESS =    -3.314728        LI-MA SIGNIFICANCE =  -0.2606946
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RUNS: 3523-3524   TOTAL EVTS BETWEEN RISE-SET =  251215
START:                8           12          1991  0.9000806
STARTING JUL DAY, SEC     2448480.5         77766.960
END:                8           13          1991  0.5680078
ENDING JUL DAY, SEC      2448481.5         49075.872
SOURCE RA, DEC     299.1000        35.10000
NUMBER OUT THIS RUN              142 SIGNAL          594 BKG
EXCESS =    -2.179199        LI-MA SIGNIFICANCE =  -0.1634955

RUNS: 3525-3528   TOTAL EVTS BETWEEN RISE-SET =  247295
START:                8           13          1991  0.8972313
STARTING JUL DAY, SEC     2448481.5         77520.784
END:                8           14          1991  0.5652707
ENDING JUL DAY, SEC      2448482.5         48839.388
SOURCE RA, DEC     299.1000        35.10000
NUMBER OUT THIS RUN              154 SIGNAL          597 BKG
EXCESS =     9.092621        LI-MA SIGNIFICANCE =   0.6692966

RUNS: 3530-3532   TOTAL EVTS BETWEEN RISE-SET =  228935
START:                8           14          1991  0.9624151
STARTING JUL DAY, SEC     2448482.5         83152.664
END:                8           15          1991  0.5625567
ENDING JUL DAY, SEC      2448483.5         48604.904
SOURCE RA, DEC     299.1000        35.10000
NUMBER OUT THIS RUN              144 SIGNAL          625 BKG
EXCESS =    -7.703705        LI-MA SIGNIFICANCE =  -0.5669179
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DAILY SEARCH FOR EMISSION OF ULTRA–HIGH-ENERGY RADIATION FROM POINT SOURCES

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ABSTRACT

A daily search for emission of ultra–high-energy radiation from astrophysical point sources using the CYGNUS extensive air shower array is described. The data set spans the period from 1986 April 4 to 1992 June 22. Fifty-one astrophysical objects have been examined, including Cyg X-3, Her X-1, the Crab, a number of gamma-ray and X-ray sources from the *COS B* and the fourth *Uhuru* catalogs, and several cataclysmic variables, nearby galaxies, and radio pulsars. The observed daily number of events from the source directions are consistent with expected statistical fluctuations of the number of events from background cosmic rays.

Subject heading: gamma rays: observations

1. INTRODUCTION

The first reported observation of ultra–high-energy (UHE) gamma rays from the direction of Cyg X-3 (Samorski & Stamm 1983), covering the period from 1976 through 1980, was confirmed by Lloyd-Evans et al. (1983). Subsequent air shower experiments with better angular resolution, larger effective area, and lower energy threshold have not observed any significant long-term excess in the UHE range from Cyg X-3 or any other source (Alexandreas et al. 1991a; Cronin et al. 1992). On the other hand, there have been many reports of episodic emission from several possible sources. These episodes, lasting from minutes to several weeks, are too numerous to be quoted here; the subject is thoroughly covered in several recent reviews (see, e.g., Weeks 1992). In this paper we report a search for emission from astrophysical point sources on the time scale of a day using the data from the CYGNUS air shower array, which covers the period from 1986 April 4 through 1992 June 22.

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2. EXPERIMENT

The CYGNUS extensive air shower experiment began operation in 1986 April with 50 scintillation counters, located around the Los Alamos Meson Physics Facility beam stop (106°3 W, 35°9 N). The array has been expanded since that time. This paper describes the analysis of data taken with the CYGNUS-I array, which presently has 108 counters covering an area of 22,000 m^2. The spacing of the counters of the array ranges from ~ 7 m near the center to ~ 20 m near the edges. A more detailed description of the CYGNUS experiment can be found elsewhere (Alexandreas et al. 1991b).

The sensitivity of the experiment to point-source emission has improved substantially since data taking began. A layer of lead, approximately one radiation-length thick, was placed above each counter in 1989 June to improve the angular resolution and lower the energy threshold of the array. The data can be divided into two periods. The array was augmented during Period 1 from 50 to 108 counters, none of which had lead. This growth primarily changed the collection area, with little effect on the energy reponse or relative efficiency for photon-initiated and proton-intiated showers. Period 2 data were taken with 108 counters, each having a layer of lead, and a significantly looser trigger condition.

The energy of the primary cosmic rays initiating the air showers detected by the CYGNUS array is determined with the help of detailed Monte Carlo simulations (Alexandreas et al. 1991c). For showers initiated by protons, the most probable primary energy and median primary energy detected by the CYGNUS array in its present configuration are approximately 50 and 100 TeV, respectively (Alexandreas et al. 1991b). The median primary energy for gamma-ray-initiated events is ~ 80 TeV, assuming that the gamma rays and cosmic rays have similar energy spectra. The CYGNUS-I event rate is presently ~ 3.5 events s^{-1}.

Figure 1 shows the results of simulations of the response of

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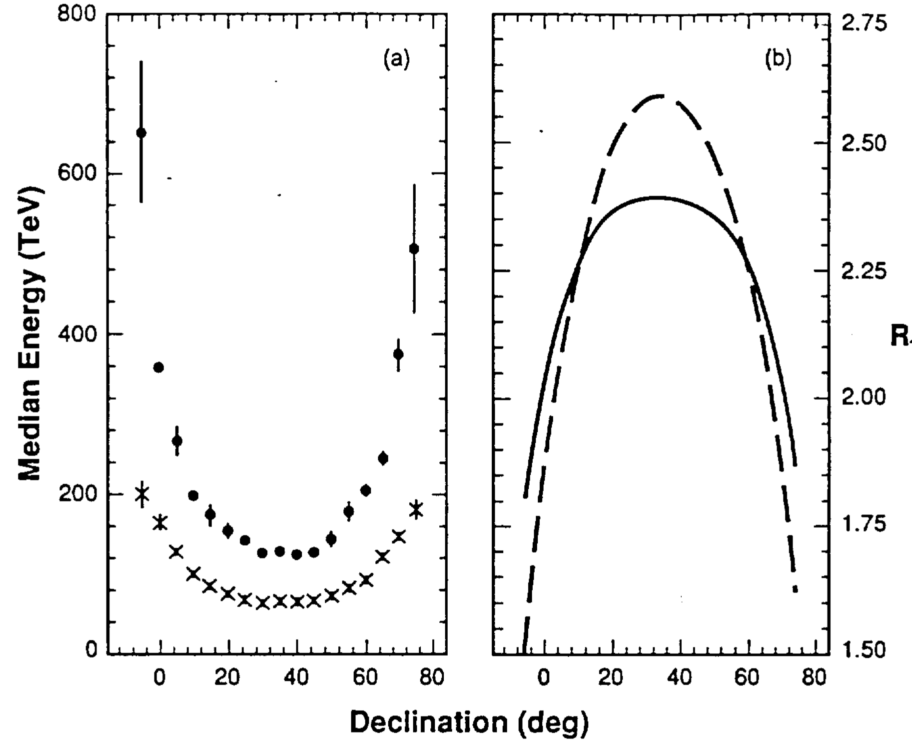

FIG. 1.—(*a*) Median detected energy of showers from a simulated photon source as a function of the source declination. The dots are for Period 1, and the crosses are for Period 2. (*b*) Ratio of the detection efficiency for photons to the detection efficiency for cosmic rays, R_γ, determined from simulations as a function of declinations. The dotted curves are for the Period 1 configuration, and the solid curves are for Period 2.

the array for the two periods. Figure 1*a* shows the median of the primary energy distribution, E_m, for detected photons from a hypothetical point source as a function of the declination of the source, assuming the photon energy spectrum has the same shape as the cosmic-ray energy spectrum. Figure 1*b* shows the ratio of the detection efficiency for photon-initiated showers to the efficiency for cosmic-ray-initiated showers, R_γ, assuming that they have the same spectral shape. Cosmic rays are assumed to consist of four parts protons, four parts He, two parts N, two parts Mg, one part Cl, and one part Fe. This composition is consistent with direct measurements (Burnett et al. 1990). Figure 2 shows the daily expected number of background events in a source bin spanning 2°.0 in declination and 2°.0/cos δ in right ascension, from several candidate sources. This figure shows the growth in sensitivity with time resulting from the upgrades described above. The higher trigger rate in Period 2 is predominantly due to the looser trigger conditions.

A few runs with hardware problems, comprising about 5% of the data sample, have been excluded from the analysis. Most of these runs have either malfunctions in the data acquisition system or noisy counters. After removal of the bad runs, the data set used for this search contains a total of about 3.04×10^8 air showers.

Studies of the solar and lunar shadows of the cosmic rays (Alexandreas et al. 1991d) have shown that the CYGNUS array has a projected rms angular resolution of $0°.75^{+0.13}_{-0.09}$, with a systematic pointing error less than 0°.6. A more recent analysis with additional data indicates an angular resolution of 0°.66 ± 0°.07.

3. SEARCH METHOD

For each air shower, the local coordinates and time of detection are transformed into celestial coordinates (α, δ); events

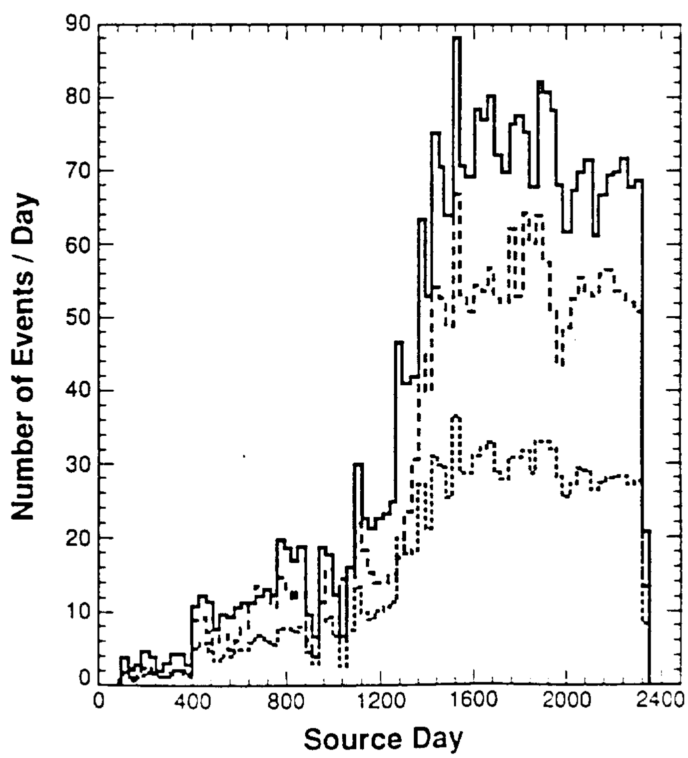

FIG. 2.—Calculated daily background counts for three sources at different declinations. *Solid curve:* Her X-1 (δ = 35°.4); *top dashed curve:* the Crab (δ = 22°.0); *bottom dashed curve:* PSR 1929+10 (δ = 10°.9). The rise in the number of background events per day is due to changes in the experimental configurations, as described in the text. The counts have been averaged over 30 day intervals to make this plot.

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TABLE 1

CYGNUS SOURCE LIST[a]

Source	1989 Feb 1 N_S	N_B	f_{90}	ϕ_γ	E_m	1992 Apr 1 N_S	N_B	f_{90}	ϕ_γ	E_m
Cyg X-3	28	24.8	0.50	1.1	130	58	68.1	0.15	1.1	70
Her X-1	31	21.3	0.86	1.9	130	71	71.8	0.21	1.5	70
Crab	22	20.4	0.50	0.9	150	50	53.1	0.22	1.6	70
Cyg X-1	27	24.6	0.47	1.0	130	83	68.7	0.41	2.9	70
M31	20	20.4	0.43	1.0	130	60	65.5	0.18	1.3	70
Virgo A	7	13.1	0.31	0.4	190	35	32.8	0.39	1.9	90
AM Herc	22	23.9	0.35	0.6	150	58	65.2	0.17	1.2	70
DQ Herc	23	24.1	0.37	0.8	130	74	65.1	0.34	2.4	70
U Gem	20	19.9	0.45	0.8	150	66	52.6	0.49	3.5	70
SS Cygni	23	25.2	0.33	0.7	130	74	75.3	0.20	1.6	70
HZ 43	22	25.7	0.30	0.7	130	44	59.1	0.13	0.9	70
GK Per	26	21.1	0.63	1.4	130	68	59.4	0.36	2.6	70
V404 Cygni	28	24.6	0.51	1.1	130	73	65.8	0.31	2.2	70
Geminga	17	16.4	0.53	0.8	170	38	41.5	0.24	1.4	80
1E 2259+58	22	13.6	1.16	1.3	200	54	46.7	0.41	2.0	90
SS 433	11	6.0	1.77	1.4	270	28	17.7	1.05	2.8	130
4U 0042+32	24	18.4	0.74	1.6	130	51	65.5	0.13	0.9	70
4U 0115+63	9	12.4	0.42	0.4	230	32	31.4	0.36	1.1	120
4U 0316+41	19	18.8	0.47	1.0	130	70	65.6	0.28	2.0	70
4U 0352+30	25	23.7	0.45	1.0	130	66	61.8	0.29	2.1	70
4U 0614+09	5	10.3	0.36	0.4	210	24	24.9	0.37	1.3	110
4U 1257+28	24	25.3	0.36	0.8	130	50	60.1	0.15	1.1	70
4U 1651+39	26	24.0	0.47	1.0	130	71	72.2	0.21	1.5	70
4U 1837+04	8	8.1	0.76	0.6	270	19	17.9	0.53	1.4	130
4U 1901+03	6	6.5	0.82	0.5	300	17	14.9	0.65	1.6	140
4U 1907+09	8	8.4	0.71	0.9	200	26	26.9	0.36	1.5	100
4U 1918+15	10	13.2	0.41	0.6	180	44	33.2	0.63	3.0	90
4U 1957+40	33	24.9	0.69	1.5	130	66	69.5	0.19	1.3	70
4U 1954+31	18	25.2	0.23	0.5	130	74	63.8	0.37	2.6	70
4U 2142+38	18	23.3	0.28	0.6	130	76	60.7	0.47	3.3	70
4U 2321+58	18	12.2	1.04	1.2	200	44	43.9	0.29	1.4	90
4U 2358+21	17	12.8	0.88	1.6	150	44	45.7	0.26	1.5	80
2CG 065+00	23	24.6	0.35	0.8	130	71	66.3	0.28	2.0	70
2CG 075+00	23	23.0	0.41	0.9	130	80	68.9	0.36	2.6	70
2CG 078+01	14	25.1	0.18	0.4	130	66	66.6	0.22	1.6	70
2CG 095+04	17	19.6	0.37	0.5	180	54	52.0	0.29	1.7	80
2CG 135+01	11	13.1	0.46	0.5	220	31	33.9	0.28	1.1	100
2CG 121+04	8	9.7	0.56	0.4	290	22	25.4	0.31	0.8	130
PSR 0355+54	15	22.3	0.24	0.4	170	41	50.1	0.17	1.0	80
PSR 0950+08	4	10.5	0.32	0.3	220	17	22.3	0.28	1.0	110
PSR 1929+10	10	11.5	0.53	0.6	200	23	27.7	0.27	1.1	100
PSR 1937+21	16	20.4	0.31	0.6	150	42	47.8	0.20	1.1	80
PSR 1951+32	24	25.9	0.34	0.8	130	70	66.3	0.27	1.9	70
PSR 1953+29	19	23.5	0.29	0.6	130	67	68.2	0.22	1.6	70
PSR 1957+20	19	19.8	0.42	0.7	160	45	46.6	0.26	1.5	80
3C 279	1	2.9	0.99	0.2	680	4	3.1	1.71	2.6	200
K1	19	19.1	0.46	1.0	130	56	63.8	0.17	1.2	70
K3	24	26.0	0.33	0.7	130	77	67.8	0.34	2.4	70
K4	11	12.7	0.49	0.5	220	30	33.6	0.27	1.1	100
K5	4	7.4	0.51	0.3	310	33	27.2	0.56	1.3	140
K6	22	16.8	0.77	1.5	140	53	52.9	0.26	1.9	70

[a] Together with data for each of the sources on two typical days, 1989 February 1 and 1992 April 1. The data given are N_S, the number of events in the source bin, N_B, the number of expected background events, f_{90}, the 90% confidence level upper limit for the number of excess source events relative to the number of detected cosmic-ray events in the source bin, and ϕ_γ, the 90% confidence level upper limit for the gamma-ray flux above E_m, the median gamma-ray energy for the source bin. The units for E_m are TeV and for the flux are $(\mathrm{cm}^{-2}\,\mathrm{s}^{-1}) \times 10^{-12}$.

that fall within a source bin are counted as on-source. The 2°0 bin size, which is somewhat smaller than was used in previous analyses (Alexandreas et al. 1991a), is more appropriate for the angular resolution determined from the solar and lunar shadows.

For each source, the data are segmented into source days; a source day consists of 24 sidereal hours centered at the source meridian transit. The expected number of background events for each source day is compared to the corresponding number of on-source events. The background is calculated as described below.

For each recorded event, 10 fake events are generated by associating the hour angle of the event with the times of 10 other events, randomly chosen from a buffer that typically spans about 5 hr of data and brackets in time the event being processed. The fake events that fall within a source bin are counted as background events for that source.

The advantage of this method is that it automatically compensates for all event rate variations, because the background events have the same time distribution as the real ones. It also compensates for changes in sensitivity that would alter the local-angle distribution of showers, because the background events are generated from the observed distribution of local coordinates.

Potential systematic effects are closely monitored. For each source and each day, events are counted in 54 control bins surrounding the source bin (5 bins in declination × 11 bins in right ascension, excluding the source bin), and backgrounds for these bins are calculated in the same way as for the source bin. Systematic errors in the background estimate have been studied by comparing the distribution of the daily excess number of events in each of the 54 bins with expectations based on Poisson fluctuations of the calculated background event rate. After removing data with detector malfunctions, no systematic effects have been found.

4. SEARCH RESULTS

The method described above has been applied to the entire CYGNUS data set. The objects examined are listed in Table 1. Cyg X-3, Her X-1, and the Crab, three of the most studied objects in the UHE range, head the list. In addition, the list includes six *COS B* sources (Swanenburg et al. 1981), seven radio pulsars, 16 *Uhuru* X-ray sources (Forman et al. 1978), six cataclysmic variables, a few nearby galaxies, and other unusual objects. The six spots in the sky (K1, K3, K4, K5, and K6, with K2 being Cyg X-3) that had the largest excesses in the air shower data of the Kiel group (Stamm & Samorski 1983) have also been examined.

Searching for a signal in a large candidate source population poses the difficulty that a signal from a particular source, that may appear significant in isolation, may not be so when considering the statistics from all candidates. This difficulty is handled in the following manner. The potential sources are separated into a primary list, comprised of Cyg X-3, Her X-1, and the Crab, and a secondary list, consisting of the 48 remaining objects. A separate hypothesis is tested for each object on the primary list (namely, that the object emitted UHE radiation on 1 day), while a fourth hypothesis is tested for the set of 48 other objects (i.e., that any of the other objects emitted UHE radiation on 1 day).

For each source day, the deviation from background is expressed as the number of standard deviations (positive or negative) calculated according to the Li and Ma prescription (Li & Ma 1983). The distribution of daily deviations is histogrammed in Figure 3 for each of the three primary candidates and for the ensemble of 48 remaining candidates; the curves are best fits to a Gaussian with the parameters shown in the figure.

No significant single-day excess is observed from Cyg X-3, Her X-1, or the Crab; note that the burst of UHE emission from Her X-1 previously observed by this experiment in 1986 (Dingus et al. 1988) is significant primarily because of the combination of periodicity and excess on the day of the burst. The largest excess from any of these three objects is 4.09 σ. Considering the ~ 1950 days observed for each source and the four hypotheses tested, the probability of observing an excess as large or larger than 4.09 σ is about 20%. The remaining 48 objects, with a total of 93,436 source days, also do not show any significant single-day excess, as can be seen by the excellent fit to a Gaussian. We note here that the small but significant negative deviation of the centroid of the Gaussian from zero is intrinsic to the Li & Ma prescription (Alexandreas et al. 1992). A simulated exposure with our source bin statistics and backgrounds produces precisely the observed deviation of the centroid from zero. We conclude that there is no statistically significant excess observed from any of the candidate sources in the primary or secondary list, on any day from 1986 April 4 to 1992 June 22.

The observed number of on-source events and the expected number of background events can be used to derive an upper limit for the number of signal events (Helene 1983; Protheroe 1984). The calculation of the upper limit must include effects due to the uncertain knowledge of the background. To illustrate the sensitivity to point-source emission, Table 1 shows the 90% confidence level limit for f_{90}, the number of excess source events relative to the number of detected cosmic-ray events in the source bin, for each source for a representative day in each data-taking period.

5. FLUX LIMITS

The all-particle cosmic-ray flux, ϕ_{CR}, is used to convert f_{90} into ϕ_γ, the flux of UHE emission:

$$\phi_\gamma = \frac{f_{90}\,\phi_{CR}\,\Omega}{0.72 R_\gamma}\,, \qquad (1)$$

where Ω ($= 1.2 \times 10^{-3}$ sr) is the solid angle of the source bin and the factor of 0.72 accounts for the fraction of the signal that is expected to be contained in the source bin. R_γ is the ratio of the detection efficiency for photons to the detection efficiency for cosmic rays. R_γ has been determined from simulations for various source declinations (Fig. 1*b*). The flux limit for any particular source on a given day will depend on the exposure to the source on that day and the declination of the source. The exposure is reflected in the number of expected background events calculated for the source on the given day. The flux limit for a source is given as the upper limit on the integral flux above the median gamma-ray energy in the source bin, E_m, to minimize the dependence of the limit on the unknown spectral index for emission from the source (Gaisser et al. 1989).

The cosmic-ray proton flux above energy E in TeV, measured by Burnett et al. (1990), is

$$\phi_p = (5.1 \pm 1.4) \times 10^{-6} E^{-1.76 \pm 0.09}\ \mathrm{cm^{-2}\ s^{-1}\ sr^{-1}}\,. \qquad (2)$$

Using the measured ratio of the all-particle flux to the proton flux of ~ 3.5, from Figure 4 in their paper, the all-particle flux is

$$\phi_{CR} = (1.8 \pm 0.5) \times 10^{-5} E^{-1.76 \pm 0.09}\ \mathrm{cm^{-2}\ s^{-1}\ sr^{-1}}\,. \qquad (3)$$

Another estimate of the total cosmic-ray flux can be obtained from the parameterization given in Nagle et al. (1988), which is

$$\phi_{CR} = 1.3 \times 10^{-5} E^{-1.55}\ \mathrm{cm^{-2}\ s^{-1}\ sr^{-1}}\,. \qquad (4)$$

We use equation (3) to obtain flux limits from our data, because this is the most accurate direct measure of the cosmic-ray flux in this energy range. Note that the fluxes in equations (3) and (4) differ by nearly a factor of 2 for $E = 100$ TeV.

Table 1 also shows the 90% confidence level upper limit on the flux above the median gamma-ray energy in the source bin emitted by each of the examined sources on 1989 February 1

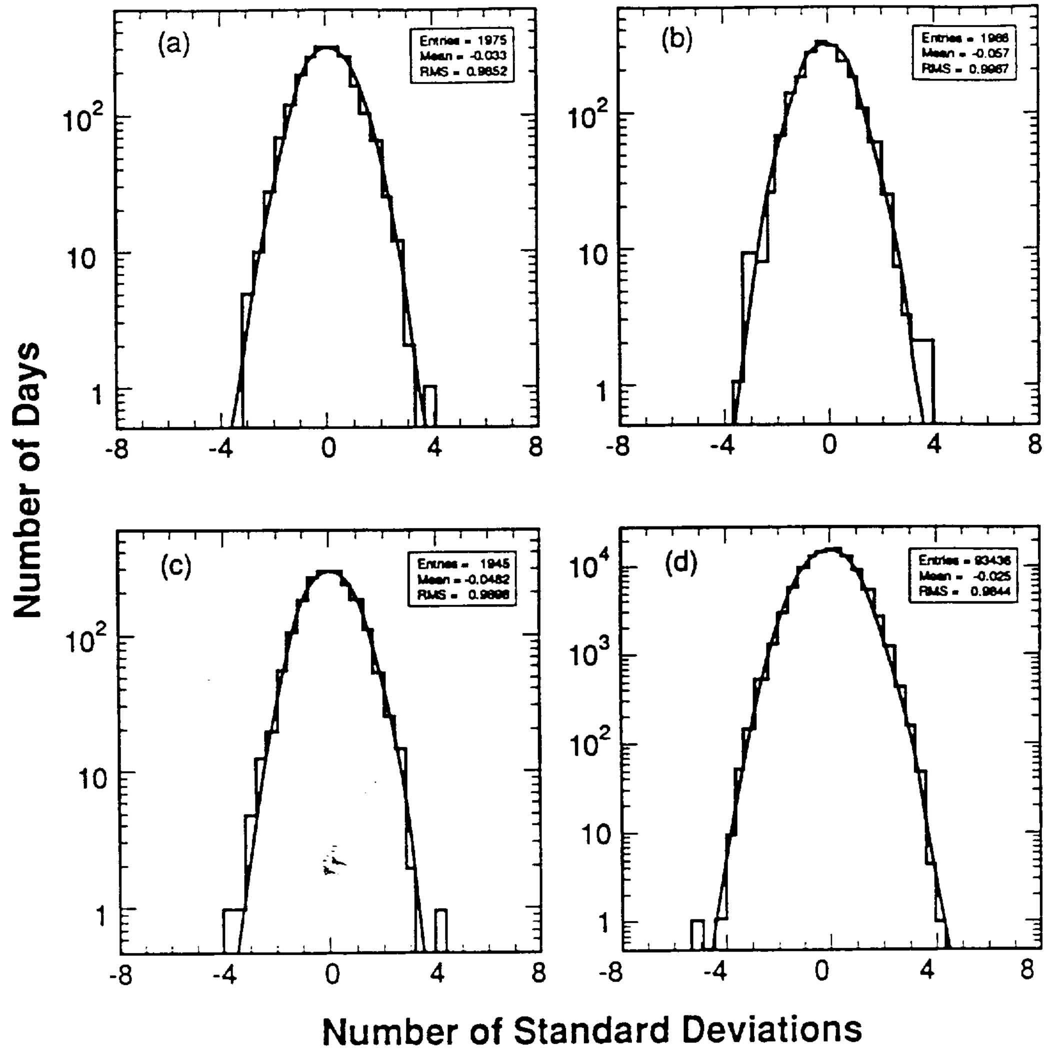

FIG. 3.—Distribution of daily excesses from (*a*) Cyg X-3, (*b*) Her X-1, (*c*) the Crab, and (*d*) the remaining 48 objects. Superposed on each of the four histograms is the best fit to a Gaussian distribution, with the parameters listed in the upper-right corner.

and 1992 April 1, respectively. Note that changing the assumed gamma-ray integral spectral index from -1.7 to -1.0 changes the upper limit for ϕ_γ by less than 10%.

6. DISCUSSION

The data set from the CYGNUS experiment, covering the period from 1986 April 4 through 1992 June 22, has been used to search for emission of UHE gamma rays from astronomical point sources. This paper describes the search for emission with a time scale of 1 day. An earlier paper (Alexandreas et al. 1991a) reported the results of a search for steady emission. These studies constitute part of a systematic search for UHE emission by the CYGNUS experiment. These null results do not preclude the possibility of episodic emission over other time scales, nor of periodic emission over any time scale. Future studies will include searches for these kinds of emission.

The null results reported here and in Alexandreas et al. (1991a) imply that there is now no strong steady UHE point source in the northern sky, nor do any of the objects on our source list strongly emit UHE gamma rays over time scales of 1 day. Our results are not necessarily in direct contradiction to previously reported detections of episodic emission because they are not simultaneous with our observations. In particular, we see no evidence for UHE emission on either the source day preceding or the source day following the reported burst of UHE gamma rays from the Crab on 1989 February 23 (Alexeenko et al. 1992), but the Crab was not overhead in Los Alamos during the time of the burst.

Active galactic nuclei have emerged as a new type of gamma-ray source (Hartman et al. 1992; Michelson et al. 1992) since this analysis was completed. A search of the CYGNUS data for evidence of UHE emission from these objects, especially Markarian 421 which was recently detected at 0.5 TeV (Weekes et al. 1992), is being pursued and will be reported elsewhere.

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REFERENCES

Alexandreas, D. E., et al. 1991a, ApJ, 383, L53
———. 1991b, Nucl. Instr. Meth. A, 311, 350
———. 1991c, Proc. 22d Internat. Cosmic Ray Conf. (Dublin), 4, 504
———. 1991d, Phys. Rev. D, 43, 1735
———. 1992, in preparation
Alexeenko, V. V., et al. 1992, J. Phys. G, 18, L83
Burnett, T. H., et al. 1990, ApJ, 349, L25
Cronin, J. W., et al. 1992, Phys. Rev. D, 45, 4385
Dingus, B. L., et al. 1988, Phys. Rev. Lett., 61, 1906
Forman, W., et al. 1978, ApJS, 38, 357
Gaisser, T. K., et al. 1989, Phys. Rev. Lett., 62, 1425
Hartman, R. C., et al. 1992, ApJ, 385, L1
Helene, O. 1983, Nucl. Instr. Meth., 212, 319
Li, T. P., & Ma, Y. Q. 1983, ApJ, 272, 317
Lloyd-Evans, J., et al. 1983, Nature, 305, 784
Michelson, P. F., et al. 1992, IAU Circ., No. 5470
Nagle, D. E., et al. 1988, Ann. Rev. Nucl. Sci., 38, 609
Protheroe, R. J. 1984, Astron. Express, 1, 33
Samorski, M., & Stamm, W. 1983, ApJ, 268, L17
Stamm, W., & Samorski, M. 1983, in Proc. 18th Internat. Cosmic Ray Conf. (Bangalore), 1, 131
Swanenburg, B. N., et al. 1981, ApJ, 243, L69
Weekes, T. J. 1992, Space Sci. Rev., 59, 315
Weekes, T. J., et al. 1992, IAU Circ., No. 5522