A Search for Galactic Black Hole Candidates at MeV Energies

M. McConnell, J. Ryan
University of New Hampshire

W. Collmar, V. Schönfelder, H. Steinle, A. Strong
Max Planck Institut für Extraterrestrische Physik

H. Bloemen, R. van Dijk, W. Hermsen
SRON-Utrecht

K. Bennett, R. Much
ESTEC

Scientific Motivation

- Accreting stellar-mass black hole candidates have been observed at energies above 1 MeV (viz., Cygnus X-1, GRO J0422+32).
- Measurements by COMPTEL (0.75-30 MeV) can :
  - provide important constraints on spectra from e^+/e^- plasmas.
  - search for evidence of pion production.
  - search for nuclear line emissions.
  - search for evidence of non-thermal processes.
- COMPTEL data from the full-sky survey provide the first opportunity for a systematic survey at these energies.

Analysis of COMPTEL Data

- Maximum likelihood imaging gives flux values and associated errors (or upper limits).
- A PSF derived from an E^{-2} spectrum is used for imaging.
- An estimate of the diffuse galactic component ($HI + CO + IC$), is included in the background model.
- For a detection to be claimed, there must be both :
  a) a significant likelihood value at the source location.
  b) a signature in the 3-d dataspace consistent with that of a point source.

Present Analysis

- The analysis was performed in each of the standard COMPTEL energy bands: 0.75-1 MeV, 1-3 MeV, 3-10 MeV and 10-30 MeV.
- Data from mission phases 1-3 are included.
- Results shown below represent time-averaged flux values. For transient sources, this implies a search for *quiescent* emission.
- Some prelimnary results have also been obtained for individual viewing periods.
- Target list is taken largely from White (1994) and Cowley (1992, 1994). The list includes :
  - candidates established from radial velocity measurements.
  - persistent ultra soft / ultra hard sources.
  - transient ultra soft / ultra hard sources.

Target List

Source	XRN	ℓ	b	d(kpc)	Eff Exp[a]
GRO J0422+32	Per 1991	165.9	-11.9	2.4	27.6
LMC X-3		273.6	-32.1	50	20.3
LMC X-1		280.2	-31.5	50	21.7
CAL 87		281.8	-30.7	50	21.7
A0620-003	Mon 1975	210.0	-6.5	0.87	20.2
GRS 1009-45	Vel 1993	275.9	9.4		19.9
GRS 1124-684	Mus 1991	295.0	-7.1	1.4	22.2
GS 1354-645		310.0	-2.8	10	20.3
A1524-617		320.3	-4.4		21.1
4U 1543-475		330.9	5.4	4	27.3
4U 1630-472		336.9	0.3	10	28.5
GX 339-4		338.9	-4.3	10	28.9
GRO J1655-40	Sco 1994	344.9	2.5	3.5	31.5
H 1705-250	Oph 1977	358.6	9.1		34.9
GRO J1719-24	Oph 1993	47.2	30.7		13.5
1E 1740.7-2942		359.1	-0.1	10	36.5
H 1741-322		357.1	-1.6		36.2
4U 1755-338		357.2	-4.9		36.2
GRS 1758-258		4.5	-1.4	10	38.1
GS 1826-238		9.3	-6.0		37.8
EXO 1846-031		29.9	-0.9		35.6
SS433		39.7	-2.2	3	25.8
GRS 1915+105		45.3	-0.9	8.5	24.5
Cyg X-1		71.3	3.1	2.5	28.2
4U 1957+115		51.3	-9.3		25.5
GS 2000+251	Vul 1988	63.4	-3.1	2	25.8
GS 2023+338	Cyg 1989	73.2	-2.2	2	26.6

[a] Effective on-axis exposure (mission phases 1-3), in days.

Results for 0.75-1 MeV

Source	n_σ	F (cm^{-2} s^{-1} MeV^{-1}) (ULs are 2σ)	L (ergs s^{-1}) (0.75-1 MeV)
GRO J0422+32	-0.52	$< 1.2 \times 10^{-4}$	$< 2.9 \times 10^{34}$
LMC X-3	0.94	$< 2.8 \times 10^{-4}$	$< 2.9 \times 10^{37}$
LMC X-1	0.22	$< 2.1 \times 10^{-4}$	$< 2.2 \times 10^{37}$
CAL 87	-0.03	$< 1.5 \times 10^{-4}$	$< 1.6 \times 10^{37}$
A0620-00	-0.90	$< 1.4 \times 10^{-4}$	$< 4.4 \times 10^{33}$
GRS 1009-45	0.98	$< 2.7 \times 10^{-4}$	
GRS 1124-684	-1.72	$< 1.2 \times 10^{-4}$	$< 9.8 \times 10^{33}$
GS 1354-645	2.32	$< 3.9 \times 10^{-4}$	$< 1.6 \times 10^{36}$
A1524-617	1.26	$< 2.9 \times 10^{-4}$	
4U 1543-475	0.73	$< 2.4 \times 10^{-4}$	$< 1.6 \times 10^{35}$
4U 1630-472	-1.03	$< 1.3 \times 10^{-4}$	$< 5.4 \times 10^{35}$
GX 339-4	-0.71	$< 1.4 \times 10^{-4}$	$< 5.8 \times 10^{35}$
GRO J1655-40	-0.90	$< 1.5 \times 10^{-4}$	$< 7.6 \times 10^{34}$
H 1705-250	-1.27	$< 1.6 \times 10^{-4}$	
GRO J1719-24	0.04	$< 1.4 \times 10^{-4}$	
1E 1740.7-2942	-2.85	$< 1.6 \times 10^{-4}$	$< 6.6 \times 10^{35}$
H 1741-322	-3.05	$< 1.6 \times 10^{-4}$	
4U 1755-338	-2.60	$< 1.6 \times 10^{-4}$	
GRS 1758-258	-0.30	$< 1.4 \times 10^{-4}$	$< 5.8 \times 10^{35}$
GS 1826-238	0.67	$< 2.7 \times 10^{-4}$	
EXO 1846-031	0.56	$< 2.0 \times 10^{-4}$	
SS433	0.27	$< 1.7 \times 10^{-4}$	$< 6.3 \times 10^{34}$
GRS 1915+105	0.80	$< 2.1 \times 10^{-4}$	$< 6.3 \times 10^{35}$
Cyg X-1	7.88	$6.9(\pm.9) \times 10^{-4}$	$1.8(\pm.2) \times 10^{35}$
4U 1957+115	-0.54	$< 1.1 \times 10^{-4}$	
GS 2000+251	-0.70	$< 1.1 \times 10^{-4}$	$< 1.8 \times 10^{34}$
GS 2023+338	0.83	$< 2.5 \times 10^{-4}$	$< 4.2 \times 10^{34}$

Results for 1-3 MeV

Source	n_σ	F (cm^{-2} s^{-1} MeV^{-1}) (ULs are 2σ)	L (ergs s^{-1}) (1-3 MeV)
GRO J0422+32	0.28	$< 2.3 \times 10^{-5}$	$< 8.8 \times 10^{34}$
LMC X-3	4.27	$4.7(\pm 1.1) \times 10^{-5}$	$7.8(\pm 1.8) \times 10^{37}$
LMC X-1	2.64	$< 5.1 \times 10^{-5}$	$< 8.5 \times 10^{37}$
CAL 87	1.73	$< 4.2 \times 10^{-5}$	$< 7.0 \times 10^{37}$
A0620-00	-1.36	$< 1.9 \times 10^{-5}$	$< 9.6 \times 10^{33}$
GRS 1009-45	0.62	$< 2.8 \times 10^{-5}$	
GRS 1124-684	-0.17	$< 1.7 \times 10^{-5}$	$< 2.2 \times 10^{34}$
GS 1354-645	1.90	$< 3.4 \times 10^{-5}$	$< 2.3 \times 10^{36}$
A1524-617	2.62	$< 4.1 \times 10^{-5}$	
4U 1543-475	0.56	$< 2.1 \times 10^{-5}$	$< 2.2 \times 10^{35}$
4U 1630-472	-3.95	$< 1.7 \times 10^{-5}$	$< 1.1 \times 10^{36}$
GX 339-4	-0.88	$< 1.8 \times 10^{-5}$	$< 1.2 \times 10^{36}$
GRO J1655-40	-4.78	$< 1.9 \times 10^{-5}$	$< 1.5 \times 10^{35}$
H 1705-250	-0.12	$< 2.1 \times 10^{-5}$	
GRO J1719-24	3.15	$3.9(\pm 1.3) \times 10^{-5}$	
1E 1740.7-2942	-2.33	$< 2.1 \times 10^{-5}$	$< 1.4 \times 10^{36}$
H 1741-322	-2.23	$< 2.1 \times 10^{-5}$	
4U 1755-338			
GRS 1758-258	-1.41	$< 1.9 \times 10^{-5}$	$< 1.3 \times 10^{36}$
GS 1826-238	1.78	$< 4.4 \times 10^{-5}$	
EXO 1846-031	-1.71	$< 1.6 \times 10^{-5}$	
SS433	-1.72	$< 1.71.5 \times 10^{-5}$	$< 1.0 \times 10^{35}$
GRS 1915+105	-0.39	$< 1.7 \times 10^{-5}$	$< 8.2 \times 10^{35}$
Cyg X-1	7.53	$7.6(\pm 1.0) \times 10^{-5}$	$3.2(\pm .4) \times 10^{35}$
4U 1957+115	2.98	$< 4.9 \times 10^{-5}$	
GS 2000+251	-0.92	$< 1.7 \times 10^{-5}$	$< 4.5 \times 10^{34}$
GS 2023+338	1.36	$< 3.4 \times 10^{-5}$	$< 9.0 \times 10^{34}$

Results for 3-10 MeV

Source	n_σ	F (cm^{-2} s^{-1} MeV^{-1}) (ULs are 2σ)	L (ergs s^{-1}) (3-10 MeV)
GRO J0422+32	2.45	$< 6.0 \times 10^{-6}$	$< 2.5 \times 10^{35}$
LMC X-3	3.22	$4.7(\pm 1.5) \times 10^{-6}$	$8.6(\pm 2.7) \times 10^{37}$
LMC X-1	4.61	$6.8(\pm 1.5) \times 10^{-6}$	$1.2(\pm 0.3) \times 10^{38}$
CAL 87	4.34	$6.5(\pm 1.5) \times 10^{-6}$	$1.2(\pm 0.3) \times 10^{38}$
A0620-00	0.45	$< 3.4 \times 10^{-6}$	$< 1.9 \times 10^{34}$
GRS 1009-45	1.53	$< 5.2 \times 10^{-6}$	
GRS 1124-684	2.49	$< 6.7 \times 10^{-6}$	$< 9.7 \times 10^{34}$
GS 1354-645	0.43	$< 3.8 \times 10^{-6}$	$< 2.8 \times 10^{36}$
A1524-617	0.49	$< 4.0 \times 10^{-6}$	
4U 1543-475	-2.69	$< 2.4 \times 10^{-6}$	$< 2.8 \times 10^{35}$
4U 1630-472	-2.24	$< 2.5 \times 10^{-6}$	$< 1.8 \times 10^{36}$
GX 339-4	-0.76	$< 2.5 \times 10^{-6}$	$< 1.8 \times 10^{36}$
GRO J1655-40	-4.12	$< 2.4 \times 10^{-6}$	$< 2.2 \times 10^{35}$
H 1705-250	-2.46	$< 2.8 \times 10^{-6}$	
GRO J1719-24	0.09	$< 3.1 \times 10^{-6}$	
1E 1740.7-2942	-0.87	$< 2.8 \times 10^{-6}$	$< 2.1 \times 10^{36}$
H 1741-322	-1.46	$< 2.8 \times 10^{-6}$	
4U 1755-338	-0.82	$< 2.8 \times 10^{-6}$	
GRS 1758-258	-2.22	$< 2.4 \times 10^{-6}$	$< 1.8 \times 10^{36}$
GS 1826-238	1.45	$< 4.8 \times 10^{-6}$	
EXO 1846-031	0.95	$< 4.0 \times 10^{-6}$	
SS433	0.86	$< 4.0 \times 10^{-6}$	$< 2.6 \times 10^{35}$
GRS 1915+105	1.21	$< 4.5 \times 10^{-6}$	$< 2.4 \times 10^{36}$
Cyg X-1	4.80	$6.2(\pm 1.3) \times 10^{-6}$	$2.8(\pm .6) \times 10^{35}$
4U 1957+115	3.63	$5.1(\pm 1.4) \times 10^{-6}$	
GS 2000+251	1.76	$< 5.0 \times 10^{-6}$	$< 1.5 \times 10^{35}$
GS 2023+338	0.84	$< 3.7 \times 10^{-6}$	$< 1.1 \times 10^{35}$

Results for 10-30 MeV

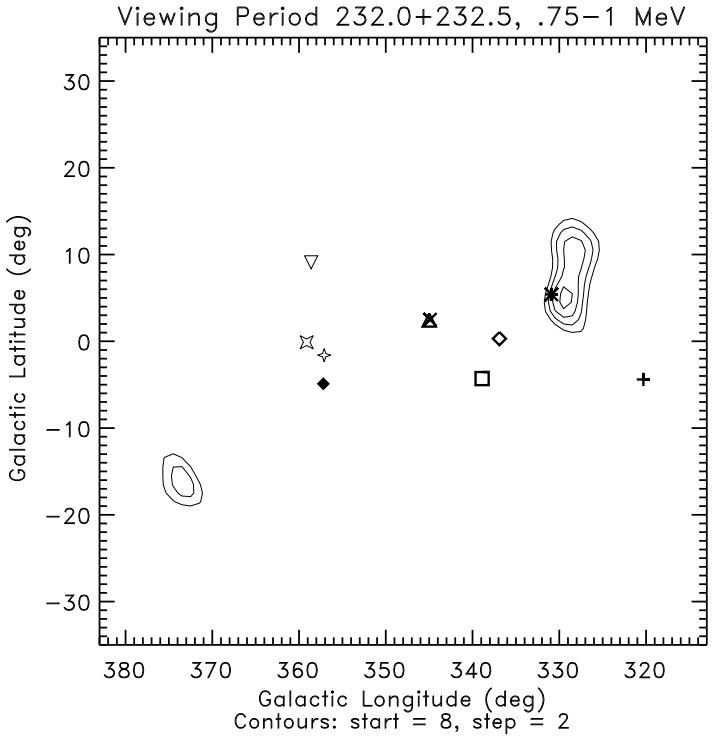
Source	n_σ	F (cm^{-2} s^{-1} MeV^{-1}) (ULs are 2σ)	L (ergs s^{-1}) (10-30 MeV)
GRO J0422+32	-2.74	$< 2.9 \times 10^{-7}$	$< 1.1 \times 10^{35}$
LMC X-3	-0.48	$< 3.0 \times 10^{-7}$	$< 5.0 \times 10^{37}$
LMC X-1	-0.82	$< 3.0 \times 10^{-7}$	$< 5.0 \times 10^{37}$
CAL 87	-0.80	$< 3.1 \times 10^{-7}$	$< 5.1 \times 10^{37}$
A0620-00	0.32	$< 4.9 \times 10^{-7}$	$< 2.5 \times 10^{34}$
GRS 1009-45	0.54	$< 5.3 \times 10^{-7}$	
GRS 1124-684	0.76	$< 6.4 \times 10^{-7}$	$< 8.3 \times 10^{34}$
GS 1354-645	1.83	$< 1.0 \times 10^{-6}$	$< 6.6 \times 10^{36}$
A1524-617	2.99	$< 1.4 \times 10^{-6}$	
4U 1543-475	-1.17	$< 3.7 \times 10^{-7}$	$< 3.9 \times 10^{35}$
4U 1630-472	0.53	$< 6.0 \times 10^{-7}$	$< 4.0 \times 10^{36}$
GX 339-4	-0.11	$< 3.7 \times 10^{-7}$	$< 2.5 \times 10^{36}$
GRO J1655-40	0.73	$< 5.8 \times 10^{-7}$	$< 4.7 \times 10^{35}$
H 1705-250	-0.29	$< 4.3 \times 10^{-7}$	
GRO J1719-24	-1.15	$< 3.9 \times 10^{-7}$	
1E 1740.7-2942	1.31	$< 8.3 \times 10^{-7}$	$< 5.5 \times 10^{36}$
H 1741-322	-1.23	$< 3.6 \times 10^{-7}$	
4U 1755-338	-0.44	$< 3.6 \times 10^{-7}$	
GRS 1758-258	-0.86	$< 3.2 \times 10^{-7}$	$< 2.1 \times 10^{36}$
GS 1826-238	0.92	$< 5.5 \times 10^{-7}$	
EXO 1846-031	0.19	$< 4.4 \times 10^{-7}$	
SS433	-0.12	$< 3.9 \times 10^{-7}$	$< 2.3 \times 10^{35}$
GRS 1915+105	-0.28	$< 3.8 \times 10^{-7}$	$< 1.8 \times 10^{36}$
Cyg X-1	1.19	$< 5.7 \times 10^{-7}$	$< 2.4 \times 10^{35}$
4U 1957+115	0.06	$< 4.3 \times 10^{-7}$	
GS 2000+251	-0.73	$< 3.3 \times 10^{-7}$	$< 8.8 \times 10^{34}$
GS 2023+338	-3.02	$< 2.7 \times 10^{-7}$	$< 7.2 \times 10^{34}$

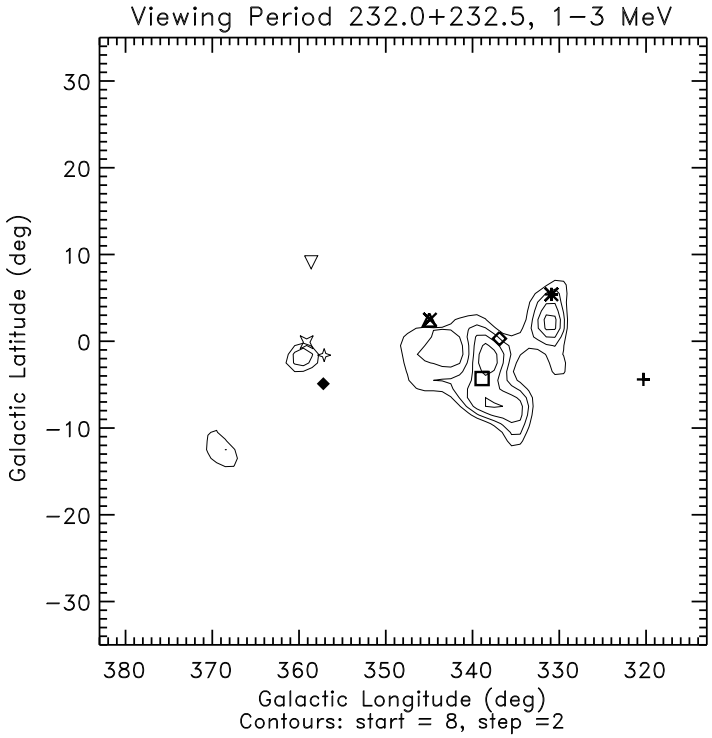
Individual Viewing Periods

- Features in the 3-4σ range have been found in data from a few individual viewing periods. These are still being investigated to determine if they are consistent with point sources.
- The table below shows the list of candidate detections which are under investiagtion.
- One example case is shown in the next panel.

Source	n_σ	Viewing Period	Energy Interval
A1524-617	3.39	12.0	1-3 MeV
4U 1543-475	3.14	232.0+232.5	.75-1 MeV
	3.12	232.0+232.5	1-3 MeV
4U 1630-472	3.69	12.0	3-10 MeV
	3.00	232.0+232.5	1-3 MeV
GX 339-4	3.45	232.0+232.5	1-3 MeV
GRO J1719-24	3.20	16.0	1-3 MeV
1E 1740.7-2942	5.43	16.0	1-3 MeV
	3.16	302.3	1-3 MeV
4U 1755-338	3.29	16.0	1-3 MeV
GS 1826-238	4.34	7.5+13.0	1-3 MeV
	4.30	16.0	1-3 MeV
	4.30	226.0	3-10 MeV
EXO 1846-031	4.36	7.5+13.0	1-3 MeV
	3.18	20.0	3-10 MeV
	3.23	43.0	3-10 MeV
GS 2023+338	3.77	318.0	3-10 MeV

Candidate Detection of 4U 1543-475





Summary of Results

- Cygnus X-1 is clearly detected in the three lowest energy bands (0.75–1, 1–3, 3–10 MeV).
- Several candidate detections have also been found, both in the data summed over all of phases 1–3 and in data from individual viewing periods. These are still under investigation.
- For those cases where upper limits are obtained, the luminosity constraints tend to be well below the Eddington luminosity for a stellar mass black hole.
- Largest uncertainty in the present analysis is the level of galactic diffuse emission.